INTERNATIONAL STANDARD

ISO 22157-1

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Bamboo — Determination of physical and mechanical properties —

Part 1: Requirements

Bambou — Détermination des propriétés physiques et mécaniques —

Partie 1: Exigences

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 22157-1 was prepared by Technical Committee ISO/TC 165, *Timber structures*, in collaboration with INBAR, International Network for Bamboo and Rattan.

ISO 22157 consists of the following parts, under the general title *Bamboo — Determination of physical and mechanical properties*:

— *Part 1: Requirements*

— *Part 2: Laboratory manual*

Introduction

This part of ISO 22157 was originally prepared and submitted by INBAR, the International Network for Bamboo and Rattan, which is an international agency with its head office in Beijing. The aim is to bring bamboo towards the level of an internationally recognized and accepted building and engineering material. INBAR aims to do so in favour of the well-being of lower income groups in developing countries, and in favour of a better environment in bamboo-growing countries.

Discussion about the need of an International Standard started already in 1988, during the International Bamboo Workshop in Cochin, India. Due to lack of funds, the real work started as late as in 1997, when INBAR was launched as an International Agency, and when the Dutch Government provided the required funding.

In 1998, draft texts were written and distributed to a group of specialists inside INBAR who acted as volunteers and spent their time and expertise to propose improvements. Members of this group met for the first time in a meeting on 30-31 October 1998 in San José, Costa Rica. Participants were N.S. Adkoli, K. Ghavami, R. Gnanaharan, H.N.S. Jagadeesh, J.J.A. Janssen, K.S. Pruthi, I.V. Ramanuja Rao, D. Sands, J.O. Siopongco, K. Stochlia and D. Tingley.

During 1999, the results from this meeting were incorporated in the draft texts. In September, these were discussed in a meeting with ISO/TC 165 in Harbin, China. In October 1999, a meeting took place with representatives of the National Standard Institutes of Bangladesh, China, Colombia, Ecuador, Ethiopia, India, Indonesia, Nepal, Philippines, Tanzania, Thailand and Vietnam. This meeting was held at FPRDI in Los Baños, Philippines. The outcome of this meeting was a considerable improvement of the texts, and a general agreement to submit the draft texts to ISO for the formal procedure.

Besides INBAR, CIB (especially committee W 18 B) has also been involved in the preparation. Discussions during meetings of W 18 B (e.g. Singapore 1987 and Kuala Lumpur 1992) have greatly contributed.

Because this part of ISO 22157 is the first Iinternational Standard on bamboo, it does not cancel or replace other documents in whole or in part, besides the draft documents prepared and distributed for internal discussion by INBAR during 1998 and 1999. For similar reasons, significant technical changes from previous editions apply only to these previous draft documents.

Bamboo — Determination of physical and mechanical properties —

Part 1: Requirements

1 Scope

This part of ISO 22157 specifies test methods for evaluating the following characteristic physical and strength properties for bamboo: moisture content, mass per volume, shrinkage, compression, bending, shear and tension.

This part of ISO 22157 covers tests on specimens of bamboo that are conducted to obtain data, which can be used to establish characteristic strength functions and to arrive at the allowable stresses. The data can also be used to establish the relationship between mechanical properties and factors, such as moisture content, mass per volume, growth site, position along the culm, presence of node and internode, etc., for quality-control functions.

2 Terms and definitions

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

2.1
bamboo culm
single shoot of bamboo that is usually hollow, except at nodes which are often swollen

2.2
bamboo clump
cluster of bamboo culms emanating from two or more rhizomes in the same place

2.3
cross-sectional area
area of the section perpendicular to the direction of the principal fibres and vessels

NOTE This is calculated as $(\pi/4) \times [D^2 - (D - 2t)^2]$, in which D and t are the means of the outer diameter and the wall thickness, resulting from measurements on the specimen.

2.4
outer diameter
diameter of a cross-section of a piece of bamboo measured from two opposite points on the outer surface

2.5
moisture content
percentage of water related to oven-dry mass

2.6
wall thickness
thickness of the wall of a piece of bamboo

3 Symbols and abbreviated terms

The following symbols and units apply.

A The cross-sectional area in mm^2, Calculated as $(\pi/4) \times [D^2 - (D - 2t)^2]$, in which D and t are the means of the measurements on the specimen.

D The outer diameter in mm.

δ Deflection or deformation in mm (pronounced “delta”).

E The modulus of elasticity in MPa.

F The load in N.

G The shear modulus in MPa.

I_B The second moment of area in mm^4.

L Full span in bending; length of test piece in compression, shear and tension, in mm.

m Mass in g (kg is also allowed as a unit).

MC Moisture content in %.

π Usually taken as 3,14.

ρ Mass by volume (density) in kg/m^3 (pronounced “rho”).

σ Stress in MPa (pronounce “sigma”).

t Wall thickness in mm.

τ Shear stress in MPa (pronounced “tau”).

V Volume of test piece in mm^3, calculated as $A \times L$, or as measured.

W Section modulus in mm^3.

$\times$ Symbol for multiplication.

Subscript

ult Ultimate (used for strength at failure)

NOTE 1 MPa = 1 N/mm^2

4 Organization and use of this part of ISO 22157

4.1 Introduction

This part of ISO 22157 is organized to provide clear requirements for standard tests to be carried out to determine the properties of bamboo as a building or engineering material. The manual for laboratory staff, ISO/TR 22157-2, is complementary to this part.

NOTE This allows for a more formal content of this part of ISO 22157, and a practical and informal guide (a “how to do it”) in the manual.

4.2 General procedures

4.2.1 Measurement and weight

Prior to each test, the dimensions of each specimen shall be measured correct to

— 10 mm for the length of the culm,

— 1 mm for the length or height of a specimen, parallel to the axis of the culm,

— 1 mm for the diameter of the culm; in each cross-section, the diameter shall be taken twice, in directions perpendicular to each other, and

— 0,1 mm for the wall thickness; in each cross-section, the wall thickness shall be taken four times, in the same places as the diameter has been taken (twice).

The specimen shall be weighed correct to

— 10 g for a culm,

— 1 g for a specimen of more than 100 g, and

— 0,1 g for a specimen of less than 100 g.

4.2.2 Temperature and humidity

To avoid significant changes in strength properties, all test specimens shall be tested within the temperature range of 27 °C ± 2 °C, and the relative air humidity range of 70 ± 5 %.

NOTE This allows for a comparison of test results, and reproducible tests.

However, if tests are meant for local use of the results in the region itself, or if the laboratory is unable to follow the conditions specified above, ambient temperature and relative humidity can be used. The exact values of the temperature and relative humidity of the air shall be recorded, and mentioned in the test report.

4.2.3 Rate of loading

The rate of loading of the testing machine shall not vary by more than ± 20 % from the specified speed for a given test. The load shall be applied continuously without interruption at the required speed throughout the test. The rate of traverse of the movable head of the testing machine shall mean the free running or no-load speed of the head in the mechanical-drive type of machine, and the loaded head speed for testing machines of the hydraulic loading type.

4.2.4 Calibration

All apparatus and testing equipment used in obtaining data shall be calibrated at sufficiently frequent intervals to ensure accuracy.

5 Sampling and storage of specimens

5.1 Sampling

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 scientific research: from localities determined by the purpose of the research, and mentioned in the design-report of the tests;

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

5.2 Selection

Bamboo culms shall be selected from various clumps in the standing condition, by a qualified person who can identify the species and understand the various implications involved in conversion and testing. Whenever necessary and convenient, the testing authority shall inspect the locality before felling.

For scientific research, the culms selected for testing shall be sound and free from any defects, and shall be representative of average dominant bamboo culms of the locality. For commercial tests, they must fairly represent the total population that is to be used for construction purposes, even if the entire population has its drawbacks. Broken, damaged and discoloured bamboos shall be discarded.

The required number of culms shall be randomly selected from different clumps, blocks and compartments. For commercial tests, they shall be of the same mature age group.

Immediately after selection, the bamboo may be marked “T” in the standing condition, at breast height, and the testing authority shall be informed of the locality, so that further special instructions, if any, may be considered.

5.3 Felling, marking and conversion

Before felling, one ring shall be marked at a height of one metre from the ground with white or black paint, and the following data shall be 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 culms;

— details about the marks on the culms;

— number of nodes between ground level and the ring of paint;

— date of felling and of despatch;

— signature.

Also before felling, each culm shall be marked at a distance of about 0,25 m above the ring of paint; if digits 6 or 9 are used, these shall be underlined.

The culms shall be felled according to good local practice, but the ring of paint shall be kept on the culm. In the horizontal position the culm shall be divided into parts to be used for tests or to be thrown away. The parts to be used shall be marked with a ring at the lower end, and the mark of the culm shall be repeated on each part. Also, a mark regarding the position in the culm shall be added, indicating “bottom”, “middle” or “top”, each being 1/3 of the usable part of the culm. The height of these parts in the culm shall be recorded, in metres, from the level where the culm has been felled. Only then shall the culm be divided into parts.

5.4 Despatch

Material should be despatched as early as possible, preferably within two weeks after felling. In case it is not possible to send the material immediately, the material shall be stored in a shady place, protected from rain, and free of contact with the soil. If a risk of cracking exists, the ends can be covered with coal tar, paraffin wax or varnish, or any other appropriate cover.

If the tests are meant for commercial purposes, specimens shall be tested in air-dry conditions. In the case of scientific research, tests might be done on green specimens, in which case the specimens shall be despatched immediately. As bamboo is highly susceptible to attack by destroying agents in many countries, it may need prophylactic treatment to keep it intact during despatch, transit and storage.

All the details of a particular consignment shall be rechecked and signed and dated by the dispatcher. The details shall be sent along with the documents of the consignments.

5.5 Receipt and storage of the bamboo culms

On receipt of the material by the testing authority, the particulars of identification of the various culms shall be checked, and a proper record shall be kept.

The bamboo culms shall be stored for as short a duration as possible, in such a way that no deterioration shall take place.

5.6 Marking and conversion into test specimens

Specimens shall be cut for the various tests, and suitable markings (e.g. 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, as far as possible, changes due to storage and weather conditions, which might affect the comparison of results.

The number of specimens in each test shall not be less than twelve.

5.7 Test report

The test report shall include the following information:

a) the name and address of the laboratory, the date, and the name of the responsible researcher;

b) a reference to this part of ISO 22157, and to applicable national standards;

c) details of the test specimens, as mentioned in 5.3;

d) temperature and air humidity in the laboratory;

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

f) the test results, including the values of moisture content and the mass per volume, the actual dimensions, moduli and/or strength values, mode of failure, and any other information which may influence the use of the test results (e.g. position along the culm);

g) details about the statistical treatment of the test results, including the methods used and the results obtained; the accuracy of a mean value shall be half the standard deviation, and the accuracy of a standard deviation shall be half its own standard deviation;

h) data about the adjustment to a 12 % moisture content, if applicable.

6 Moisture content

6.1 Scope

This clause specifies a method for determining the moisture content of bamboo for physical and mechanical tests.

6.2 Principle

Determination, by weighing, of the loss in mass of the test piece on drying to constant mass. Calculation of the loss in mass as a percentage of the mass of the test piece after drying.

6.3 Apparatus

6.3.1 Balance, with an accuracy of 0,01 g.

6.3.2 Equipment capable of drying bamboo to an absolutely dry condition, e.g. an electric oven.

6.3.3 Equipment to ensure the retention of moisture in the test pieces, e.g. flasks with ground-glass necks, and stoppers.

6.4 Preparation of test pieces

Test pieces for determination of moisture content shall be prepared immediately after each mechanical test. The number of test pieces shall be equal to the number of test pieces for the physical or mechanical test. The form shall be like a prism, approximately 25 mm wide, 25 mm high and as thick as the wall thickness. The test pieces shall be taken near to the place of failure, and stored under conditions which ensure that the moisture content remains unchanged.

6.5 Procedure

The test pieces shall be weighed to an accuracy of 0,01 g, and then dried in an oven at a temperature of 103 ± 2 °C.

After 24 h, the mass shall be recorded at regular intervals of not less than 2 h. Great care shall be taken to prevent any change in moisture content between removal from the oven and subsequent determinations of the mass.

The drying shall be considered to be complete when the difference between the successive determinations of the mass does not exceed 0,01 g.

6.6 Calculation and expression of results

The moisture content MC of each test piece shall be calculated as the loss in mass, expressed as a percentage of the oven-dry mass, using the following formula:

$$\mathrm{MC} = \frac{m - m_{\mathrm{o}}}{m_{\mathrm{o}}} \times 100$$

where

m is the mass of the test piece before drying;

m_{o} is the mass of the test piece after drying;

each with an accuracy of 0,01 g.

The MC shall be calculated to an accuracy of one-tenth of a percent. This MC shall be taken as representative of the MC of the tested specimen as a whole. The arithmetic mean of the results obtained from the individual test pieces shall be reported as the mean value for the moisture content of the test pieces.

6.7 Test report

The results shall be mentioned in the test report (5.7).

7 Mass by volume

7.1 Scope

This clause specifies a method for determining the mass by volume (density) of bamboo for physical and mechanical tests. For accurate comparison between reported values, the basic mass by volume ρ is the most appropriate one, for the determination of which oven-dry mass and green volume will be used because these will not change, irrespective of weather conditions. If the mass by volume is to be reported at the moisture content of the test sample, the mass is taken as the oven-dry mass and only the volume is taken at the MC of the sample. The symbol is ρ_0.

7.2 Principle

Determination of the mass of the test piece by weighing, and of its volume by measurement of its dimensions or by another method. Calculation of the mass of a unit volume of the bamboo.

7.3 Apparatus

7.3.1 measuring instrument, capable of determining the dimensions of the test pieces to an accuracy of 0,1 mm.

7.3.2 balance, capable of weighing to an accuracy of 0,01 g.

7.3.3 equipment, for the determination of the moisture content in accordance with 6.3.

7.4 Preparation of test pieces

Test pieces shall be prepared as specified in 6.4. For the determination of the mass per volume, it is also permitted to prepare the test piece from a full cross-section of a culm, provided that the volume can be measured easily.

7.5 Procedure

Measure the dimensions of the test pieces to the nearest 0,1 mm, and calculate the volume, or determine the volume by a suitable method (e.g. immersion) to an accuracy of 10 mm^3. Do this in the green condition or at the MC during the mechanical test, as required. In the last case, determine the MC as in Clause 6.

Dry the test pieces to constant mass (see 6.5), but do this gradually to minimize their deformation and splitting.

Carry out the weighing operations immediately after drying.

Determine the mass of the test pieces to an accuracy of 0,01 g.

7.6 Calculation and expression of results

The oven-dry mass by volume of each test piece is given by the following formula:

$$\rho = (m / V) \times 10^6$$

where

ρ is the mass by volume, in kg/m^3;

m is the mass, in g, of the test piece, oven-dry;

V is the green volume of the test piece, in mm^3.

Express the result to the nearest kg/m^3.

The mass per volume ρ_0 of each test piece in the same condition as during the test, is given by the same formula with m oven-dry and V in the condition during the test.

Calculate, to an accuracy of 10 kg/m^3, the arithmetic mean of the results obtained for the individual test pieces, and report this as the average value for the mass per volume of the test pieces.

7.7 Test report

The test report shall be in accordance with 5.7.

8 Shrinkage

8.1 Scope

This clause specifies a method to determine the shrinkage of full bamboo culms.

8.2 Principle

The determination of the shrinkage of an internode section of a bamboo culm, by measuring the outer diameter, wall thickness and height, before and after drying.

8.3 Apparatus

8.3.1 **micrometer** for measurement, as in 4.2.1.

8.3.2 **equipment capable of drying bamboo to an absolutely dry condition**, e.g. an electric oven.

8.4 Preparation of test specimens

Specimens shall be prepared from full bamboo culms, internode sections, with a height of 100 mm. In the case of tests on compression, shear and tension, they shall be taken as near to these test pieces as possible; in the case of bending tests, they shall be taken as near to the place of failure as possible. In every case, they shall be free from any initial cracks. If shrinkage tests are done independent from any other test, specimens shall be taken from the lowest section of the culm.

8.5 Procedure

8.5.1 Shrinkage shall be observed in the outer diameter D, in the wall thickness t and also in the length L of the specimen.

8.5.2 Suitable markings shall be done on the specimen, to facilitate making observations every time at the same place. On each specimen, 4 diameters, 4 wall thicknesses (two at each end) and 2 lengths shall be measured. The specimen shall be allowed to dry slowly under gradually decreasing humidity and increasing temperature. Masses and dimensions shall be recorded regularly, until the dimensions are constant or one complete weather cycle is over.

8.5.3 The specimens shall finally be put into an oven at a temperature of about 103 ± 2 °C, so that the specimens shall become completely dry (as in 6.5), after which the dimensions shall be taken for the last time.

8.6 Calculation and expression of results

Shrinkage from initial condition to dry condition, expressed as a percentage correct to one place of decimal, shall be calculated by the following formula:

$$\frac{I - F}{I} \times 100$$

where

I is the initial reading;

F is the final reading;

each of these being the average value for diameter, wall thickness or length, with an accuracy as in 4.2.1.

8.7 Test report

The test report shall be in accordance with 5.7; it shall contain the initial and the final dimensions and MC, a description of defects developed in the specimen during shrinkage, and the results from the calculation.

9 Compression

9.1 Scope

This clause specifies a method for compression parallel-to-the-axis tests on specimens from bamboo culms.

9.2 Principle

The determination of

— the ultimate compressive stress of specimens from culms, and

— the nominal modulus of elasticity.

9.3 Apparatus

The tests shall be carried out on a suitable testing machine. At least one platen of the testing machine shall be equipped with a hemispherical bearing to obtain uniform distribution of load over the ends of the specimen, as in Figure 1. In between both the steel platens of the machine and both the ends of the specimen, an intermediate layer shall be applied to reduce friction to a minimum.

EXAMPLE See Figure 2, which shows a combination of wedges of thin steel plate, Teflon and wax.

9.4 Preparation of test specimens

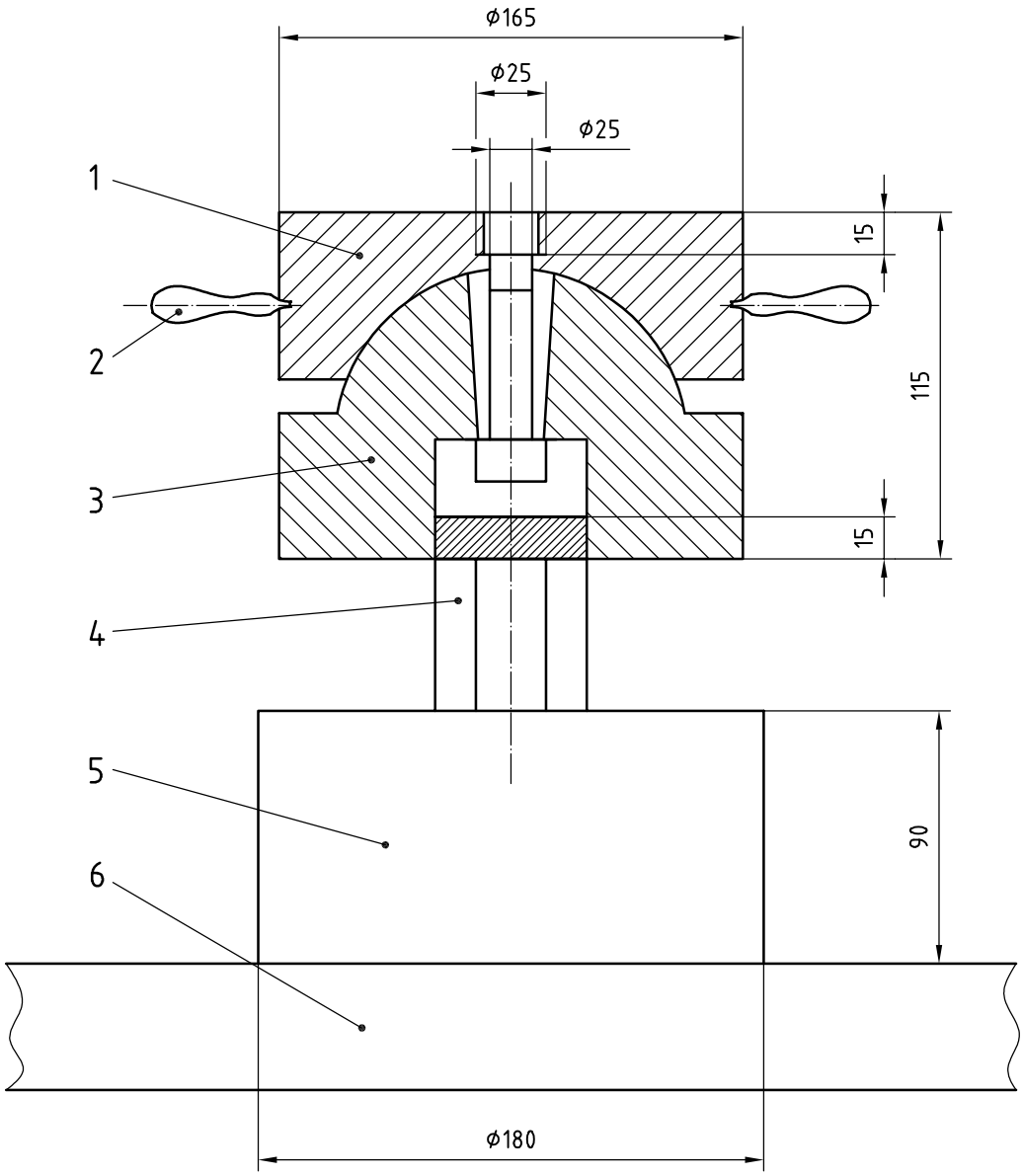
9.4.1 Specimens shall be taken from the bottom part, middle part and top part of each culm. These specimens shall be marked with the letters B, M and T respectively.

9.4.2 Compression tests parallel to the axis shall be made on specimens without any node, and the length of the specimen shall be taken equal to the outer diameter; however if this is 20 mm or less, the height shall be twice the outer diameter. These limitations are valid in the case of testing for commercial purposes; in the case of scientific research tests one is free to determine otherwise.

9.4.3 The end planes of the specimen shall be perfectly at right angles to the length of the specimen; the end planes shall be flat, with a maximum deviation of 0,2 mm.

9.4.4 To determine the modulus of elasticity E, strain gauges shall be applied, with a minimum of two per specimen, each one of them at the opposite side of the specimen.

Dimensions in millimetres



Key

1 spherical block
2 handle
3 top bearing block
4 specimen
5 bottom bearing block
6 machine

Figure 1 — Compression machine

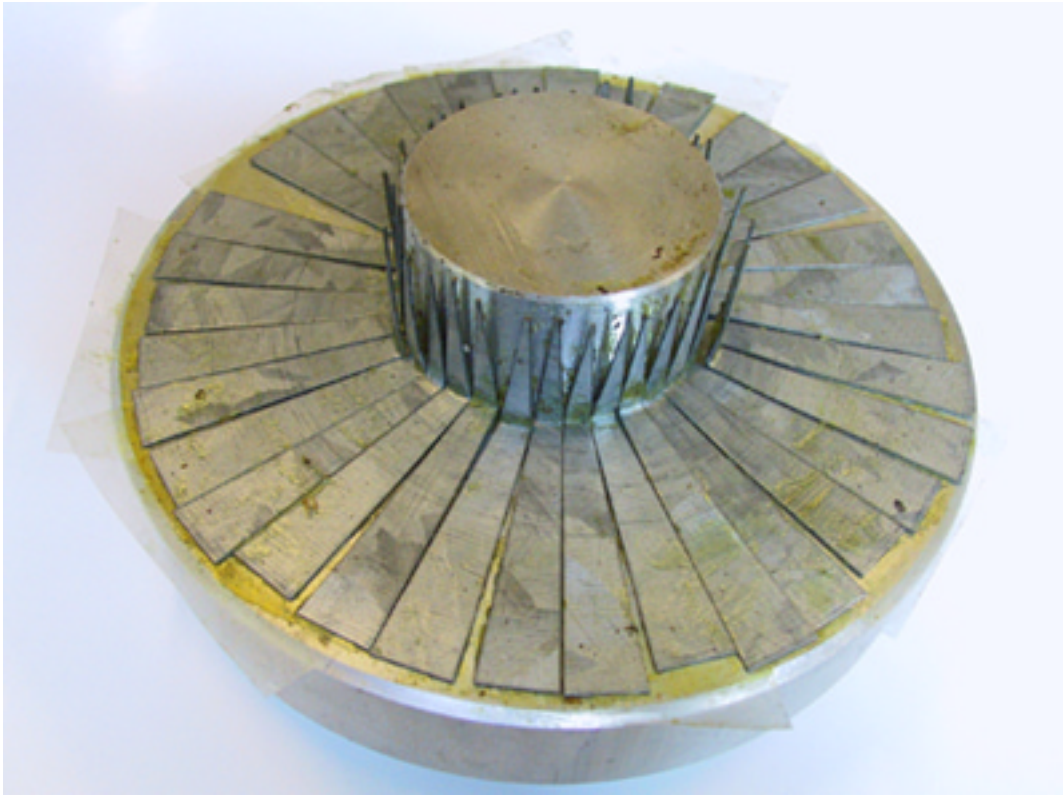


Figure 2 — Intermediate layer

9.5 Procedure

9.5.1 The specimen shall be placed so that the centre of the movable head is vertically above the centre of the cross-section of the specimen, and a small load of not more than 1 kN is initially applied to set the specimen.

9.5.2 The load shall be applied continuously during the test to cause the movable head of the testing machine to travel at a constant rate of 0,01 mm/s.

9.5.3 If applicable, the strain gauges shall be read a sufficient number of times to be able to plot a sufficiently accurate load-deformation diagram form which E is to be determined.

9.5.4 The final reading of the maximum load, at which the specimen fails, shall be recorded.

9.6 Calculation and expression of results

9.6.1 The maximum compressive stress shall be determined by the following formula:

$$\sigma_{\text{ult}} = \frac{F_{\text{ult}}}{A}$$

where

σ_{ult} is the ultimate compressive stress, in MPa (or N/mm^2), rounded off to the nearest 0,5 MPa,

F_{ult} is the maximum load at which the specimen fails, in N,

A is the cross-sectional area (2.3), in mm^2.

9.6.2 The modulus of elasticity E shall be calculated from the mean of the readings of the strain gauges, as a linear relationship between stress and strain between 20 % and 80 % of F_{ult}.

9.6.3 The mean ultimate stress of the tested specimens shall be calculated to the nearest 0,5 MPa as the arithmetic mean of the test results of the individual test specimens.

9.7 Test report

The test report shall be in accordance with 5.7; the MC and the mass per volume shall be determined according to Clauses 6 and 7, respectively.

10 Bending

10.1 Scope

This clause specifies a method for bending tests on bamboo culms.

10.2 Principle

The determination of

— the bending capacity of culms using a four-point bending test, as described in 10.5,

— the curve of load versus vertical deflection, and

— the nominal modulus of elasticity of the culm.

10.3 Apparatus

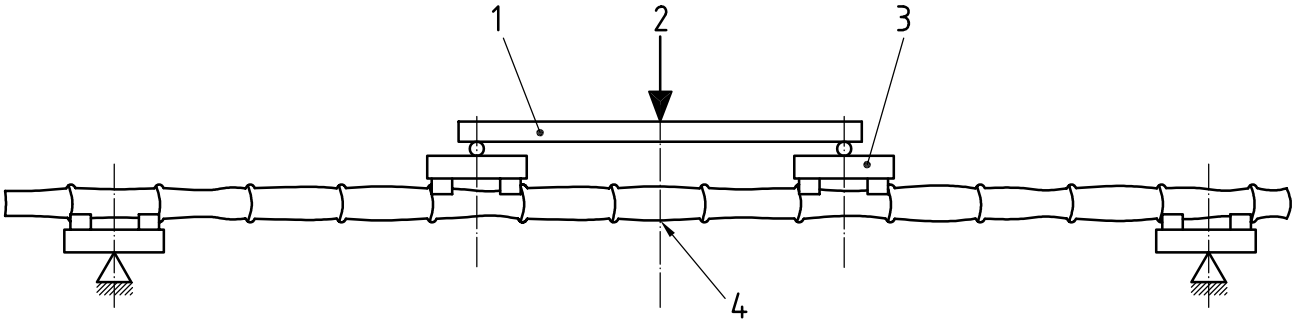
10.3.1 testing machine, capable of measuring load to the nearest 1 %, and the deflection to the nearest mm.

10.3.2 device capable of bending the culm, by applying a load midway between the centres of the device supports. The test shall be a four-point bending test. The load shall be divided into two halves by means of an appropriate beam. To avoid crushing the culm, the halve loads and the reaction forces at the supports shall be applied to the nodes by means of appropriate devices. At the supports, the bamboo culm shall be allowed to rotate freely. See Figure 3.

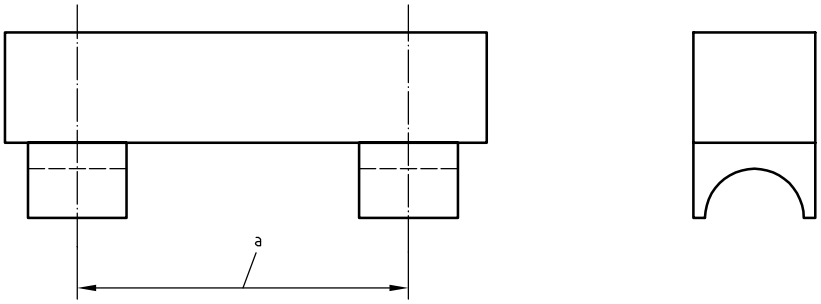
10.4 Preparation of test culms

Test culms shall be without visually apparent defects. In order to obtain a failure in bending, the free span shall be at least $30 \times D$, in which D is the outer diameter as in 4.2.1.

The full length of the culm shall be at least this free length plus, at each end, a half internode-length.



a) Scheme



b) Detail of saddle

Key

1 beam
2 load
3 saddle made of wood
4 position of deformation measurement

a Variable according to the distance of nodes.

Figure 3 — Scheme of bending test

10.5 Procedure

10.5.1 Determine the mean value of the outer diameter D and wall thickness t as in 4.2.1. Calculate the second moment of area:

$$I_B = \pi / 64 \times \left[D^4 - (D - 2t)^4 \right]$$

NOTE This value of I_B is used to predict behaviour during the test.

10.5.2 Put the culm in its place in the bending machine, resting on two devices at the two supports, allowing the culm to find its own position. Next put the two devices and the beam (which divides the load) on top of the culm, and allow the culm again to find its position, and align the culm, the four devices, the load and the supports visually in one vertical plane.

10.5.3 The loading of the culm shall be carried out uniformly at constant speed. The speed of testing (preferably at a constant rate of movement of the loading head of the machine, otherwise at a constant rate of loading) shall be 0,5 mm/s. The maximum load shall be determined with an accuracy as in 10.3.1. Observe the cracks and describe the form of the failure. Plot a load-deflection diagram.

10.5.4 After the test, determine the outer diameter D and the wall thickness t again, as close to the points of load as possible. The average of the diameters and wall thicknesses shall be used to calculate the second moment of area I_B, with the formula in 10.5.1.

10.5.5 Determine the moisture content in accordance with the text in Clause 6 with a sample from near the point of failure.

10.6 Calculation and expression of results

10.6.1 The ultimate strength, σ_{ult}, in MPa (or N/mm^2), in static bending with the moisture content at the time of the test is given by the formula:

$$\sigma_{ult} = F \times L \times \frac{D/2}{6} \times I_B$$

where

F is the applied maximum load, in N (the total load applied at the two points of load);

L is the free span, in mm (or clear span);

D is the outer diameter, in mm, as in 10.5.4;

I_B is the second moment of area, in mm^4, as in 10.5.4.

Express the result to an accuracy of 1 MPa (or N/mm^2).

10.6.2 The modulus of elasticity (Young's modulus) is given by the slope of a linear part of the load-deformation diagram.

The modulus of elasticity E, in MPa, is calculated using the formula:

$$E = 23 \times F \times L^3 / 1\,296 \times \delta \times I_B$$

where

F, L and I_B are as in 10.6.1;

δ is the deflection mid-span, in mm.

Plot a load-deflection diagram.

10.6.3 If enough data (about the relationship between mechanical properties and moisture content) are available, the ultimate strength in static bending shall be adjusted to a 12 % moisture content, to an accuracy of 1 MPa.

10.6.4 The mean ultimate strength of the sample and its standard deviation shall be calculated to an accuracy of 1 MPa from the results of the individual culms of the sample.

10.7 Test report

The test report shall be in accordance with 5.7.

This report shall also include

— the test results as calculated in 10.6,

— dimensions of the culms, and the free span,

— the load-deflection diagrams, and

— the values for σ_{ult} and E for each culm.

The MC and the mass per volume shall be determined according to Clauses 6 and 7.

11 Shear

11.1 Scope

This clause specifies a method for shear tests on specimens from bamboo culms, parallel to the fibres.

11.2 Principle

The determination of the ultimate shear strength of specimens from culms.

11.3 Apparatus

The tests shall be carried out in a compression machine like that in Clause 9, without the intermediate layers described in 9.3. Instead of these, the specimen shall be supported at the lower end over two quarters, opposite one another; and loaded at the upper end over the two quarters which are not supported; see Figure 4. This way to support and to load the specimen results in four shear areas.

11.4 Preparation of test specimens

11.4.1 Specimens shall be taken from the bottom part, middle part and top part of each culm. These specimens shall be marked with the letters B, M and T, respectively.

11.4.2 Shear tests parallel to fibre shall be made on specimens, 50 % with a node and 50 % without, and the length of the specimen shall be taken as equal to the diameter. These limitations are valid in the case of testing for commercial purposes; in the case of scientific research, one is free to determine otherwise.

11.4.3 The end planes of the specimen shall be at right angles to the length of the specimen; the end planes shall be flat.

11.4.4 The wall thickness t and the height L of the specimen shall be taken at all four shear areas.

11.5 Procedure

11.5.1 The specimen shall be placed so that the centre of the movable head is vertically above the centre of the cross-section of the specimen. The specimen shall also be centred with regard to the supporting and loading quarters. A small load of not more than 1 kN is initially applied to set the specimen.

11.5.2 The load shall be applied continuously during the test to cause the movable head of the testing machine to travel at a constant rate of 0,01 mm/s.

11.5.3 The final reading of the maximum load, at which the specimen fails, and the number of areas that fail, shall be recorded.

Dimensions in millimetres

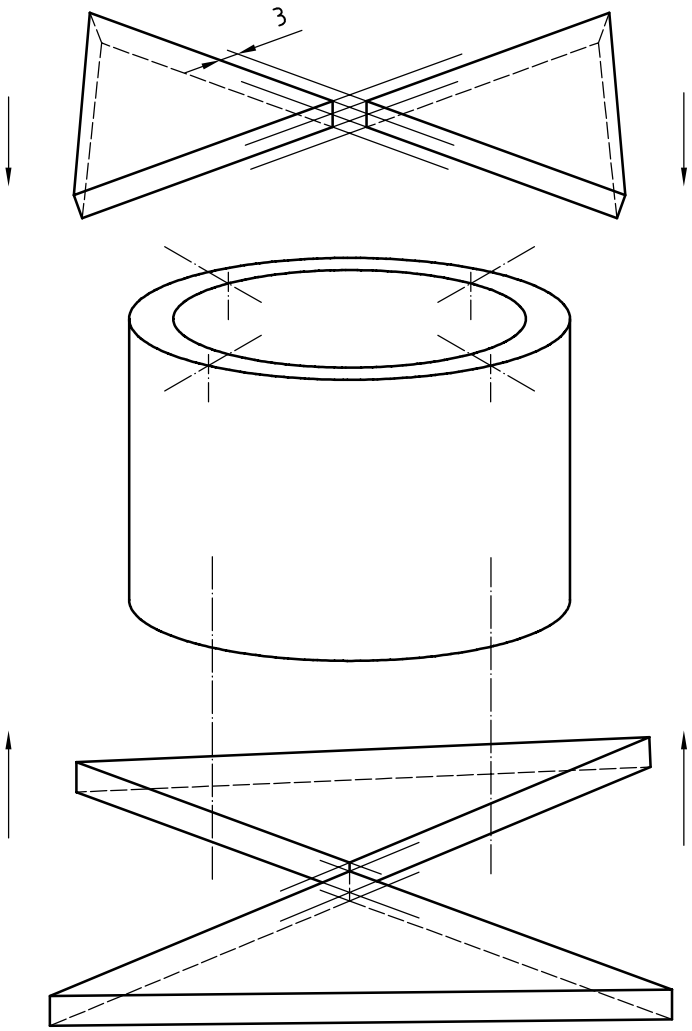


Figure 4 — Shear test

11.6 Calculation and expression of results

The ultimate shear strength shall be calculated using the following formula:

$$\tau_{\text{ult}} = \frac{F_{\text{ult}}}{\sum(t \times L)}$$

where

τ_{ult} is the ultimate shear strength, in MPa, rounded off to the nearest 0,1 MPa,

F_{ult} is the maximum load at which the specimen fails, in N,

$\sum(t \times L)$ is the sum of the four products of t and L.

11.7 Test report

The test report shall be in accordance with 5.7; the MC and the mass per volume shall be determined according to Clauses 6 and 7.

12 Tension

12.1 Scope

This clause specifies a method for tension parallel-to-the-fibres tests on strips made from bamboo culms.

12.2 Principle

The determination of the ultimate tensile strength parallel to the fibre by application of a gradually increasing load to a test piece.

12.3 Apparatus

12.3.1 The grips of the tension machine shall ensure that the load is applied along the longitudinal axis of the test piece, and shall prevent longitudinal twisting of the test piece. The grips shall press the test piece perpendicular to the fibres and in a radial direction.

12.3.2 The load shall be applied continuously throughout the test at a rate of motion of the movable crosshead of 0,01 mm/s. The load shall be measured to 1 %.

12.3.3 The cross-sectional dimensions of the gauge portion of the test piece shall be measured to an accuracy of 0,1 mm.

12.4 Preparation of test specimens

12.4.1 Specimens shall be taken from the bottom part, middle part and top part of each culm. These specimens shall be marked with the letters B, M and T.

12.4.2 Tension tests parallel to fibre shall be made on specimens with one node, which shall be in the gauge section. This limitation is valid in the case of testing for commercial purposes; in the case of scientific research, one is free to determine otherwise.

12.4.3 The general direction of the fibres shall be parallel to the longitudinal axis of the gauge portion of the test piece. The gauge portion shall have a rectangular cross-section, with dimensions of the wall thickness or less in the radial direction, and of 10 mm to 20 mm in the tangential direction. The gauge length shall be from 50 mm to 100 mm.

12.4.4 The ends of the test pieces shall be so shaped as to ensure that the failure occurs within the gauge portion, and to minimize stress concentration in the transition area. It is permitted to use test pieces with laminated ends.

12.4.5 To determine the modulus of elasticity E, strain gauges shall be applied, two per test piece, each one of them at the opposite side of the test piece.

12.5 Procedure

12.5.1 Measure the cross-sectional dimensions of the gauge portion of the test piece to an accuracy of 0,1 mm, at three places in the gauge portion, and calculate the mean value.

12.5.2 Clamp the ends of the test piece between the grips of the testing machine, at a safe distance from the gauge portion. Load the test piece at a constant rate. Read the maximum load. Discard results obtained on test pieces which fail outside the gauge portion. After the test, determine the MC.

12.5.3 If applicable, the strain gauges shall be read a sufficient number of times to be able to plot an accurate load-deformation diagram from which E is to be calculated.

12.6 Calculation and expression of results

12.6.1 The ultimate tensile strength shall be determined by the following formula:

$$\sigma_{ult} = \frac{F_{ult}}{A}$$

where

σ_{ult} is the ultimate tensile strength, in MPa, rounded off to the nearest whole MPa;

F_{ult} is the maximum load at which the piece fails, in N;

A is the mean cross-sectional area of the gauge portion, in mm^2.

12.6.2 The modulus of elasticity E shall be calculated from the mean of the readings of the strain gauges, as a linear relationship between stress and strain between 20 % and 80 % of F_{ult}.

12.7 Test report

The test report shall be in accordance with 5.7; the MC and the mass per volume shall be determined from the gauge portion, and in accordance with Clauses 6 and 7.

Bibliography

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[8] INDIAN STANDARD I.S. 6874, 1973, *Method of tests for round bamboos*[2)]

1) Figure 2 is taken from this thesis.

2) Figure 1 is based on this Standard.

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