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Bamboo structures — Glued laminated bamboo — Product specifications

Structures en bambou — Bambou lamellé-collé — Spécifications du produit

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document 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).

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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.

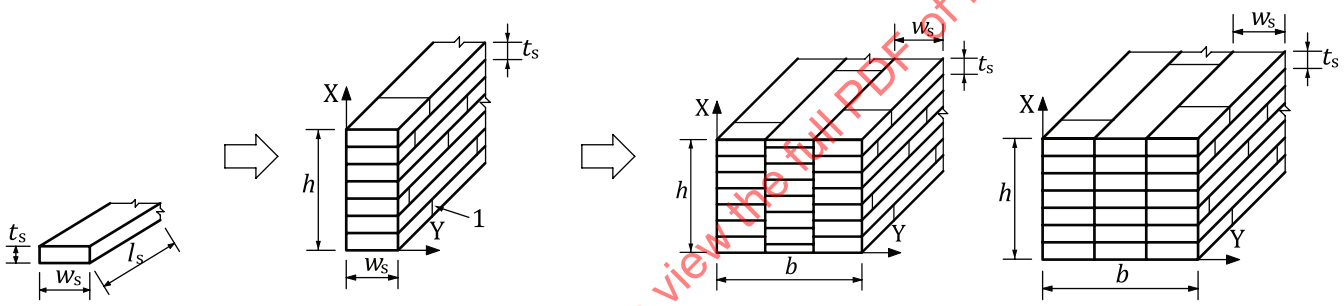
Introduction

Glued laminated bamboo is produced by bonding together bamboo strips with their fibres parallel to each other. A member with a rectangular or non-rectangular solid cross-section can be produced through this manufacturing process.

The purpose of the requirements in this document is to provide minimum product specifications to achieve adequate in-service performance of glued laminated bamboo building structures.

Figure 1 shows the typical manufacturing steps of glued laminated bamboo. Figure 1 a) shows a single bamboo strip (also known as 'lamina') with rectangular cross section ($w_s \times t_s \times l_s$ as shown in Figure 1 a) which is typically lengthened by adding bamboo strips using non-structural joints (see 6.1). Figure 1 b) shows a multiple layered glued laminated bamboo "board" (having width w_s and height h) component that results from bonding together bamboo strips. The boards are subsequently assembled into glued laminated bamboo components (having width b and height h) as shown in Figure 1 c) and Figures 1 d). The layup shown in Figure 1 c) is the commonly used glued laminated bamboo arrangement. Other arrangements permitted by this document are shown in Figures 1 d).

When producing multiple-board glued laminated bamboo, care shall be taken that the extension joints in adjacent boards are staggered by at least the greater of $10w_s$ and $2h$ (see Figure 2).



a) Single bamboo strip, the basic component of glued laminated bamboo

b) Several bamboo strips are vertically pressed

c) Several bamboo strips are pressed both vertically and laterally to form a solid glued laminated bamboo

d) Other way to form a solid glued laminated bamboo

Key

1 extension joint

Figure 1 — Key manufacturing process for the products covered by this document

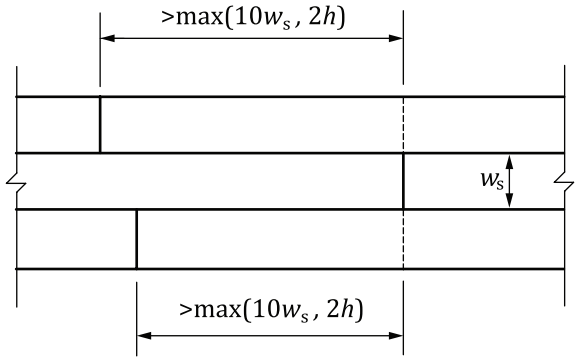


Figure 2 — Requirement for the staggering of extension joints in adjacent boards in the longitudinal direction

Bamboo structures — Glued laminated bamboo — Product specifications

1 Scope

This document specifies requirements for the components of glued laminated bamboo members intended for structural use.

Although currently most glued laminated bamboo is made from *Phyllostachys edulis* (Moso), this document also applies to other bamboo species (e.g. *Guadua angustifolia*, *Dendrocalamus asper*) if the performance required by this document can be shown to have been achieved.

The basic requirements apply to structural members of all service classes; however, special precautions are necessary for service class 3, for example, the use of weather resistant adhesives (see 5.2).

Annex C contains informative references for formaldehyde emission.

The requirements will need to be supplemented to take into consideration any relevant special conditions as well as material and/or functional requirements.

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 12579, *Timber structures — Glued laminated timber — Method of test for shear strength of glue lines*

ISO 12580, *Timber structures — Glued laminated timber — Methods of test for glue-line delamination*

ISO 20152-1, *Timber structures — Bond performance of adhesives — Part 1: Basic requirements*

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

ISO 23478, *Bamboo structures — Engineered bamboo products — Test methods for determination of physical and mechanical properties*

3 Terms and definitions

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

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

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

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

3.1
bamboo failure percentage
at the plane of shear failure, the ratio of failed bamboo material to the total failure surface expressed as a percentage

3.2
total delamination
sum of delamination lengths of all glue lines around the perimeter of a test piece

3.3
lamination
piece or pieces of bamboo, with or without extension joints forming part of a glued laminated bamboo product

3.4
service class
group designation characterized by the moisture content of the members corresponding to the temperature and relative humidity of the surrounding air

3.4.1
service class 1
characterised by an equilibrium moisture content in the glued laminated bamboo not exceeding 12 %

Note 1 to entry: Service class 1 is representative of indoor air-conditioned or heated environments in which relative humidity is maintained below 65 %.

3.4.2
service class 2
characterised by an equilibrium moisture content in the glued laminated bamboo not exceeding 20 %

Note 1 to entry: Service class 2 is representative of indoor unheated or uncooled environments in most locations except those with relative humidity regularly or for prolonged periods exceeding 85 %.

3.4.3
service class 3
characterised by ambient or climatic conditions leading to moisture contents in glued laminated bamboo higher than *service class 2* (3.4.2), such as when a member is fully exposed to the weather

3.5
characteristic value
value of a material or product property having a prescribed probability of non-exceedance in a hypothetical unlimited test series

Note 1 to entry: The value is expressed in terms of a specified fractile of the assumed statistical distribution of the property expressed with a specified confidence.

3.6
density
characteristic mean density obtained at 75 % confidence limit determined at conditions of equilibrium moisture content of 12 %

3.7
modulus of elasticity
characteristic mean modulus at a 75 % confidence limit obtained from the results of tests using test specimens at an equilibrium moisture content resulting from a temperature of 20 °C and an equilibrium moisture content of 12 %

3.8
strength
modulus of rupture
ultimate strength of beam element tested in flexure determined by first occurrence of tensile rupture or compression failure of extreme fibres

Note 1 to entry: Expressed as a characteristic 5^{th}-percentile value at a 75 % confidence limit.

3.9
moisture content
portion of material weight consisting of water expressed as percentage of oven-dry weight

4 Symbols

w_s	width for the cross-section of the bamboo strip
t_s	thickness for the cross-section of the bamboo strip
l_s	length of the bamboo strip
f_v	shear strength, newtons per square millimetre
A	area, in square millimetres
b	width of cross section, in millimetres
G	shear modulus, in newtons per square millimetre
h	depth of section, in millimetres
ρ	density, in grams per cubic centimetre
$f_{m,k}$	characteristic value of bending strength
$f_{c,k}$	characteristic value of compressive strength parallel to grain, newtons per square millimetre
$f_{t,k}$	characteristic value of tensile strength parallel to grain, newtons per square millimetre
$f_{v,k}$	characteristic value of shear strength parallel to grain, newtons per square millimetre
$f_{c,90,k}$	characteristic value of shear strength perpendicular to grain, newtons per square millimetre
E	modulus of elasticity, newtons per square millimetre

5 Component requirements

5.1 Bamboo strip requirements

5.1.1 Appearance

Bamboo culms shall be selected to permit the fabrication of straight bamboo splits. The length of bamboo splits shall be adequate to make bamboo strips at least 2 000 ± 3 mm in length and at least 16 ± 0,1 mm in width.

The material used for glued laminated bamboo shall be free from physical damage, decay, and insect attack.

There may be variations from element to element, but the total impression of the glued laminated bamboo shall show a homogeneous character.

NOTE Since bamboo is a natural material, colour variations can occur naturally or due to exposure to light over time.

Any part of the material, such as the bamboo outer layer (outer skin) or the bamboo inner layer (inner skin) that hinders preservation, bonding, and finishing shall be removed entirely.

Splinters, cracks, and gaps within a single strip are not permitted.

5.1.2 Maturity

Bamboo shall be used and harvested at species-specific optimal maturity.

NOTE for most suitable species, optimal maturity is in the range of (4 to 7) years.

5.1.3 Density

The dry density of the bamboo strip shall be greater than 0,50 g/cm^3.

5.2 Adhesives

Adhesives shall meet the requirements of ISO 20152-1. Adhesives containing formaldehyde require special consideration as described in Annex C.

NOTE Additional requirements for adhesives can be specified by national standards or governing codes.

The adhesive shall enable joints such that the strength, durability and integrity of the bond is maintained throughout the intended lifetime of the structure.

The adhesive shall be chosen considering the conditions during fabrication and in-service including climate, moisture conditions, exposure to elevated temperature, the bamboo species, the preservative used (if any), and the production method.

6 Performance requirements

6.1 Extension joints in laminations

Extension joints to increase the length of bamboo strips can be used. These end extension joints shall not be considered mechanical joints (i.e., they do not transmit force). These joints are only meant to facilitate the manufacture of longer glued laminated bamboo elements. Extension joints shall not align across adjacent strips or adjacent layers of laminated boards. Joints in adjacent strips of a single board (Figure 3) shall be staggered a distance of at least the greater of $10w_s$ and 200 mm in the lengthwise direction of the strip (Figure 3).

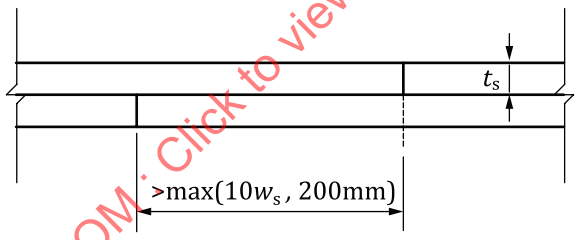


Figure 3 — requirement for the staggering of non-structural extension joints in adjacent strips in the longitudinal direction

6.1.1 Moisture content of bamboo strips

The mean moisture content of a single bamboo strip shall be less than 15 %. The difference of the mean moisture contents of the bamboo strips to be extended shall be less than 2 %.

6.1.2 Extension joints geometry

Examples of extension joints that are currently used in glued laminated bamboo are shown in Annex D.

6.1.3 Extension joint surface and adhesive application

At the time of arrangement, the extension joint shall not be damaged, the extension joint surface shall be clean.

The adhesive shall meet requirements in 5.2 and shall be used in accordance with the instructions of the adhesive manufacturer.

The adhesive shall be applied fully and evenly on the extension joint surface.

6.2 Glue line integrity and strength

The bonding operations shall result in a reliable and durable bond between laminations.

6.2.1 Glue line integrity between layers

The glue line integrity shall be based on testing of the glue line in a full cross-sectional specimen, cut from the manufactured glued laminated bamboo member.

The specimens shall be representative of the manufacturing process and any pre-gluing chemical treatment of the laminations. For all service classes, bond strength shall be determined using block shear tests in accordance with 6.2.2 and delamination tests shall be performed as specified in 6.2.3.

6.2.2 Block shear tests in accordance with ISO 12579 shall be performed. The following minimum shear strength parallel to fibre and bamboo failure percentages shall be met.

The average glue line shear strength shall be no less than the shear strength parallel to fibre of the unbonded bamboo of the same species.

The average shear strength of each glue line shall be at least 8 N/mm^2; individual test values no lower than 7 N/mm^2 are permitted if the bamboo failure percentage is 100 %, see Table 1, individual values.

The average bamboo failure percentage for all glue lines in a cross-section and any individual value shall exceed the minimum bamboo failure percentages stated in Table 1.

Table 1 — Minimum bamboo failure percentages relating to the shear strength parallel to grain f_v

	Average			Individual values		
Shear strength parallel to grain f_v[a], in N/mm^2	8	10	$f_v \geq 12$	$7 \leq f_v \leq 8$	8	$f_v \geq 12$
Minimum bamboo failure percentage, in %	90	75	50	100	75	25
[a] Linear interpolation may be used.						

6.2.3 Delamination test in accordance with ISO 12580 shall be performed based on service class. Total delamination shall not exceed the values given in Table 2.

For structures of service class 3, delamination tests shall be made according to methods A, B, or a combination of D and E of ISO 12580.

For structures of service class 2, delamination tests shall be performed according to methods A, B, C, or a combination of D and E of ISO 12580.

For all delamination test methods, the maximum delamination percentage of any single glue line shall not exceed 10 %.

Table 2 — Total permitted delamination percentage obtained from ISO 12580 testing

Service class	ISO 12580 method	Total delamination percentage after cycle 1	Total delamination percentage after cycle 2
2 or 3	A	5 %	10 %
2 or 3	B	5 %	10 %
3	D and E[a]		5 %
2	C	5 %	—
2	D and E[a]	5 %	—
[a] It is necessary that methods D and E be used together.			

6.3 Property requirements

Qualification tests shall be undertaken to calculate and declare characteristic values for bending strength, modulus of elasticity, compression strength, shear strength, and tension strength, or whenever a new process or change involving a new adhesive, end joint, lamination thickness or similar is applied.

Routine tests shall verify the ongoing achievement of the properties established by the qualification tests.

Eight (8) grades are classified according to the bending strength. The characteristic value of strength and modulus of elasticity for all grades of glued laminated bamboo products are shown in Table 3. Shear performance tests conducted in accordance with Annex A shall be performed and tests for other relevant properties shall be conducted in accordance with ISO 23478. The sample shall be representative of the manufacture. The test pieces shall be prepared or selected in such a manner that they are representative of the production run. Tests shall be conducted at the equilibrium moisture content between 6 % and 15 %.

Table 3 — Characteristic value of strength and modulus of elasticity for all grades of glued laminated bamboo (N/mm^2)

Grade	Characteristic value of strength					Modulus of elasticity E
	Bending strength $f_{m,k}$	Compressive strength parallel to grain $f_{c,k}$	Tensile strength parallel to grain $f_{t,k}$	Shear strength parallel to grain $f_{v,k}$	Compressive strength perpendicular to grain $f_{c,90,k}$	
B_L40	40	28	36	6	10	6 000
B_L50	50	35	45	6	10	6 200
B_L60	60	42	54	7	12	6 600
B_L70	70	49	63	8	13	7 200
B_L80	80	56	72	8	15	7 600
B_L90	90	63	81	9	16	8 200
B_L100	100	70	90	10	17	9 200
B_L110	110	77	100	10	18	10 000

7 Manufacturing requirements

7.1 General

The manufacturer shall produce reliable glued laminated bamboo. Necessary production conditions are given in Annex B.

7.2 Adhesives

The adhesives shall comply with the requirements of 5.2.

7.3 Bamboo

The bamboo species, moisture content, and lamination dimensions shall be suitable for glued laminated bamboo production. At the time of fabrication of the glued laminated bamboo member fabrication, the equilibrium moisture content for bamboo strips shall be between 6 % and 15 %.

8 Factory production internal quality control

8.1 General

To ensure that the glued laminated bamboo produced conforms to this document, the manufacturer shall establish and maintain documented internal factory production quality control.

The effectiveness of the production control shall be assessed in accordance with 8.2.

NOTE Additional requirements for quality control may be specified by national standards or governing codes, such as EN 14080:2013, 6.3.

8.2 Glue line integrity

8.2.1 The glue lines shall be tested in a full cross-sectional specimen, which is to be cut from a cured glued laminated bamboo member produced during each working shift.

8.2.2 The results of the testing for glue line integrity shall be documented as described in 6.2.

8.2.3 For products that are required to be certified in accordance with national standards or governing codes, these sampling requirements should be approved by the product certification body.

8.3 Gluing record

A gluing record shall be kept containing the following:

a) the date and identification of production;

b) the species;

c) the dimensions of the member;

d) the moisture content of the bamboo prior to gluing;

e) the time at the start of adhesive application;

f) the time after adhesive application before start of clamping;

g) the time at start and end of the clamping process;

h) the clamping pressure;

i) the type of adhesive;

j) the adhesive spread (g/m^2);

k) the temperature of the air in bamboo storage, gluing and clamping area.

The gluing record shall be signed off by the nominated responsible member of staff.

Annex A
(normative)

Shear performance test

A.1 Test setup

The following test method and specimen should be chosen for the shear performance as shown in Figure A.1. A different setup is needed for each specimen size.

A.2 Size of specimens

For glued laminated bamboo, shear tests shall be conducted on a 50 mm by 50 mm by 63 mm specimen notched in accordance with Figure A.1 b) to produce shear failure on the 50 mm by 50 mm surface.

For individual bamboo strips, shear tests shall be conducted on a 25 mm by t_s by 35 mm specimen notched in accordance with Figure A.1 c) to produce shear failure on the 25 mm by t_s surface.

Tolerance for all specimen dimensions shall be ±0,5 mm.

A.3 Procedure

Measure the dimension of the shearing surface, accurate to 0,5 mm.

Apply the specimen to the L shape supporting bracket.

Adjust screws 4 and 5, make sure the top surface and surface I are fully pressed against the U shaped jig.

Apply the loading steel plate on surface II of the specimen, and adjust screw 8, make sure the loading steel plate touches to the U shaped jig.

Apply the assembled specimen on the test machine, and align the centre of the loading steel plate with the centre of the movable cross loading head.

A.4 Speed of testing

The load shall be applied continuously throughout the test at a rate of 0,6 mm/min.

A.5 Moisture content

Tests shall be conducted at an equilibrium moisture content between 6 % and 15 %.

A.6 Shear strength

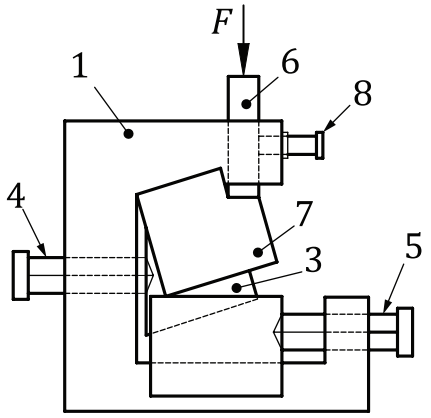
The shear strength f_v shall be calculated from Formula (A.1):

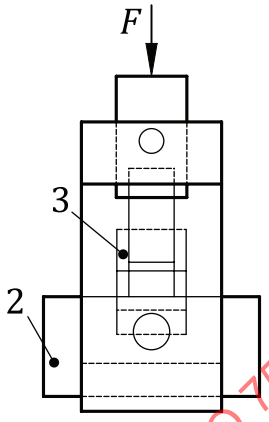
$$f_v = \frac{F_u}{A_s} \tag{A.1}$$

where:

F_u is the ultimate loading value (in N),

A_s is the shear area of the test specimen (in mm^2); for Figure A.1 b), the shear area is 2 500 mm^2.

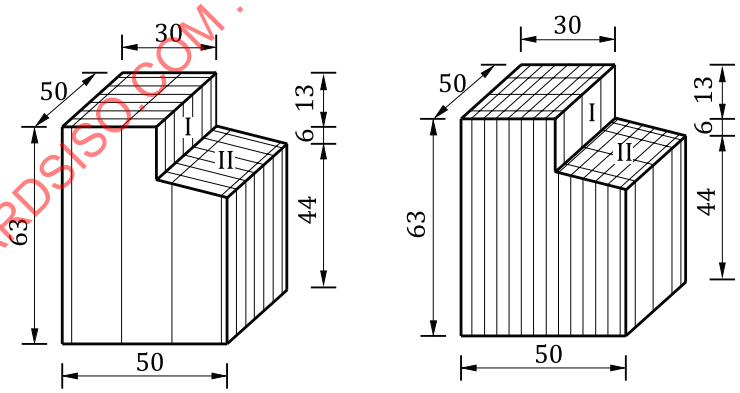




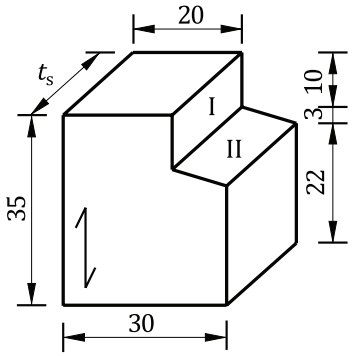
Key

1	U shaped jig
2	bearer supporting bracket
3	bearer supporting bracket with L shape
4, 5 and 8	screw
6	steel plate for loading
7	test specimen

a) Test setup



b) Test specimen for glued laminated bamboo (unit: mm)



c) Test specimen for the bamboo strip (unit: mm)

Figure A.1 — Test setup and specimen for shear performance

Annex B
(informative)

Personnel, facilities, manufacture, and quality control

B.1 Personnel

The staff should have the necessary skills for the production of glued laminated bamboo.

B.2 Facilities

B.2.1 Premises

B.2.1.1 The premises should be suitable for all phases of production, taking into consideration the requirements given in this document. The manufacturer may conduct relevant testing off-site to ensure the quality of glued laminated bamboo products. Special consideration should be given to a) the size of the members and b) air temperature.

B.2.1.2 If the temperature and relative humidity of the air are critical to gluing, then the appropriate temperature and relative humidity need to be maintained throughout the gluing and curing cycle.

B.2.1.3 Drying and storage facilities of sufficient capacity should be available to enable the required moisture content and temperature to be achieved.

B.2.1.4 Where pre-dried bamboo is used, storage facilities should be available to maintain the required moisture content of the bamboo.

B.2.1.5 Unless resin and hardener are pumped directly from storage tanks and mixed automatically during application, there should be a separate room for the preparation of the adhesive (mixing resin and hardener).

There should be suitable resin and hardener storage facilities and an area for cleaning the adhesive equipment. For single-component adhesives, these references to resin and hardener are not applicable.

The resin and hardener storage should be arranged so that the “first in, first out” principle is maintained.

B.2.2 Equipment

Equipment and personnel should be available

a) to continuously monitor the temperature of the air in storage, production and curing areas,

b) to measure the moisture content of the bamboo and check the calibration of moisture meters,

c) for visual grading where these operations are carried out by the producer,

d) to measure lamination thickness,

e) to provide surfaces that fulfill the requirements of the thickness tolerances and surface quality (usually a lamination planer),

f) for weighing and mixing resin and hardener in the required proportions,

g) for the uniform application of the required quantity of adhesive,

h) to obtain the required glue line pressure and temperature during the curing of the adhesive, and

i) to test the integrity of the glue lines.

B.3 Manufacture

B.3.1 Laminations

B.3.1.1 The individual laminations should be end-jointed to the final length before planning if resurfacing of the laminations is required prior to face bonding.

B.3.1.2 At assembly, the equilibrium moisture content in every bamboo strip of non-treated bamboo should be in the range of 6 % to 15 %.

B.3.1.3 At the time of bonding, the surfaces of the bamboo strips should be clean.

B.3.1.4 As for the lamination dimensions, the width should be greater than 20 mm and the length should be greater than 1 000 mm with the tolerances of 0,5 mm for width and 1 mm for length.

B.3.2 Bonding

B.3.2.1 The adhesive shall be spread uniformly at a rate recommended by the adhesive manufacturer.

B.3.3 Clamping

B.3.3.1 The clamping arrangement should ensure uniform pressure over the glue line.

B.3.3.2 The pressure should be those recommended by the adhesive manufacturer.

B.3.3.3 Sufficient pressure should be maintained during clamping.

Tightening-up should be carried out as necessary and, in all cases, immediately after clamping.

B.3.4 Curing and conditioning

B.3.4.1 The adhesive manufacturer's instructions should be followed.

The temperature during curing should be within the temperature range prescribed by the adhesive manufacturer.

B.3.4.2 If it is necessary to raise the temperature during clamping, the time from initial clamping to the start of the temperature raising should not exceed 8 h.

B.3.4.3 Glued laminated bamboo should not be loaded, other than by incidental loading that may be induced during handling or exposed to temperatures below 15 °C until the adhesive has cured completely.

These recommendations should be followed for at least 72 h after the end of clamping for phenolic-based adhesives and 24 h for amino plastic adhesives. For other adhesive types, applicable handling recommendations should be established.

B.4 Organization of factory production control

B.4.1 Responsibility and authority

The responsibility, authority, and the interrelation of all personnel who manage, perform, and verify work affecting quality should be defined, particularly for personnel who need the organizational freedom and authority to

a) initiate action to prevent the occurrence of non-conformity of glued laminated bamboo, and

b) identify and record any quality problems with glued laminated bamboo.

B.4.2 Delegated by the manufacturer

At every factory unit, the manufacturer should appoint a person with appropriate authority, knowledge, and experience in the production of glued laminated bamboo to be responsible for conducting and supervising factory production control procedures and ensuring that the requirements given in this document are implemented and maintained.

B.4.3 Inspection by the manufacturer

The production control system adopted to satisfy the requirements of this document should be reviewed at appropriate intervals by the manufacturer's management to ensure its continuing suitability and effectiveness. Records of such reviews shall be maintained.

B.5 Documentation of the quality control system

B.5.1 The manufacturer's documentation, procedures and instructions should be relevant to the production and process control of the glued laminated bamboo and should be adequately described in a work's manual, covering:

a) quality aims and the organizational structure, responsibilities and authority of management with regard to the conformity of the glued laminated bamboo;

b) procedures for specifying and verifying the quality of the bamboo and the adhesive;

c) manufacturing, production control, and other techniques, processes and systematic actions to be used; and

d) inspections and tests that will be carried out before, during and after manufacture, and the frequency with which they are to be carried out.

NOTE The documentation of the gluing record and the glue line tests are typically recorded and kept separately.

B.5.2 All documentation shall be registered so that raw materials and production conditions for each glued laminated bamboo member are traceable, at least to the production week and year.

B.5.3 All documentation shall be kept for a period in keeping with national statutory requirements.

B.6 Species

Any species may be used where it can be demonstrated that it meets the requirements of this document.