EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 14272

December 2011

ICS 79.060.10

Supersedes ENV 14272:2002

English Version

Plywood - Calculation method for some mechanical properties

Contreplaqué - Méthode de calcul pour certaines caractéristiques mécaniques

Sperrholz - Rechenverfahren für einige mechanische Eigenschaften

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 14272:2011: E

Contents

Page

Foreword

This document (EN 14272:2011) has been prepared by Technical Committee CEN/TC 112 "Wood-based panels", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2012, and conflicting national standards shall be withdrawn at the latest by June 2012.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes ENV 14272:2002.

Annex A and Annex B are normative.

Compared to ENV 14272:2002, the following modifications have been made:

a) calculation applies to panels of any composition, symmetrical or not;

b) values resulting for the panels can be used for calculation as characteristics values as required by EN 1995-1-1;

c) new Annex A (normative) provides the derivation for the veneer values (basic values);

d) new Annex B (normative) provides practical spreadsheets to derive the properties;

e) new Annex C (informative) gives an example of bending strength.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This European Standard specifies, for plywood panels of any composition, symmetrical or not, a calculation method to derive some mechanical properties (strength and stiffness in bending, tension, compression, panel and planar shear) as well as density from the wood compounding the layers.

NOTE Usually, the lay-up of the panels is symmetrical but, very often, the surface appearance of the face and the surface appearance of the back face differ, hence a difference between the mechanical properties of the respective veneers. Therefore, in this case, the composition is not mechanically symmetrical and a symmetry independent calculation method is needed.

Provided that structural characteristic values are taken for the layers, the resulting values for the panels can be used as characteristic values as required by EN 1995-1-1.

Conversely, Annex A defines the procedures to derive the veneer properties, in bending, tension and compression, either from testing panels according to EN 789 and EN 1058 or from timber testing according to EN 408 or from imposed values defined in EN 338.

Annex B provides practical spreadsheets, which are applications of the equations in the main part of this standard.

Annex C provide an example for the calculation of bending strength, in accordance with Annex B.

2 Normative references

The following referenced documents are indispensable for the application 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.

EN 325, *Wood-based panels — Determination of dimensions of test pieces*

EN 338:2009, *Structural timber — Strength classes*

EN 384, *Structural timber — Determination of characteristic values of mechanical properties and density*

EN 408, *Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties*

EN 789, *Timber structures — Test methods — Determination of mechanical properties of wood based panels*

EN 1058*, Wood-based panels — Determination of characteristic 5-percentile values and characteristic mean values*

EN 12369-2, *Wood-based panels — Characteristic values for structural design — Part 2 Plywood*

EN 14358, *Timber structures — Calculation of characteristic 5-percentile values and acceptance criteria for a sample*

3 Principle

Using the mechanical properties of the wood species, which compound the layers (in this standard referred to as veneer or basic values), it consists in deriving, by calculation, the mechanical properties of a panel.

For bending, tension and compression, each layer property value, along and across the length of the panel, is weighted by a geometrical factor related to its weight in the panel cross section.

In this standard, where a value for a given property of the veneers is derived with a specified test method (including exploitation of the results), the models in this standard will provide a panel value for that property as if derived with the specified test method.

EXAMPLE For instance, if, in a panel composition, a specified percentile of a bending property of veneers is determined with EN 789 and EN 1058, the calculated value of the bending property of the panel will be its specified percentile as if determined by using EN 789 and EN 1058.

4 Terms and definitions

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

4.1
characteristic strength
population fifth percentile value relating to a temperature of 20 °C and a relative humidity of 65 %

4.2
characteristic stiffness
either the population fifth percentile or the mean value relating to a temperature of 20 °C and a relative humidity of 65 %

4.3
characteristic density
population fifth percentile value with mass and volume corresponding to equilibrium at a temperature of 20 °C and a relative humidity of 65 % either of the wood species or of the panels, single species or mixed species

NOTE The density values found from calculation refer to the minimum acceptable density of veneers used in the lay-up of plywood. In the case of single species plywood these values are taken as the characteristic values for the plywood. In the case of mixed species plywood the characteristic value of density of the panel is calculated from the characteristic densities of the individual veneers according to the proportion of each species

4.4
veneer value or basic value
characteristic value of a property to be used for each layer in the equations of the calculation method

NOTE Characteristic values of the wood species, along and across the grain, are fifth percentile values for strength but either mean values or fifth percentile values for stiffness (modulus of elasticity).

4.5
reference panel value
value of a given mechanical property of a panel composition

NOTE It is to be used to derive the veneer value (or basic value) of the property.

5 Symbols

5.1 Main symbols

A area ($b \cdot t_{nom}$), in square millimetres

f strength, in Newtons per square millimetre

E modulus of elasticity, in Newton per square millimetre

Fs shear forces in a bending panel, in Newtons

G modulus of rigidity, in Newtons per square millimetre

b width of panel (equal to 1 in the equations), in millimetres

t, thickness of layers, in millimetres

T thickness of panels, in millimetres

W section modulus, equal to $\left(b.t_{\text{nom}}^{2} / 6\right)$, in cubic millimetres

I second moment of area, equal to $\left(b.t_{\text{nom}}^{3} / 12\right)$, in millimetres to the fourth power

ρ density, in kilograms per cubic metre

k_{a} modification factor, appearance class grade

z distance of the axis of a layer to the neutral axis of the panel, in millimetres

Z distance of the neutral axis from either face of the panel, in millimetres

Ecc eccentricity factor, no dimension

$\Delta L/L$ relative elongation of the layers (bending, tension and compression)

P property

V strength or modulus, in Newton per square millimetre

Rw in the set of layers, the weaker ratio of strength upon modulus for the properties of the wood species involved in the composition of a panel

Up stiffness of the panel

s standard deviation

5.2 Subscripts

m bending

t tension

c compression

v panel shear

r planar shear

w applies to the lower ratio strength/modulus (f/E) of a property of a layer in a multi-species panel

nom, mean nominal value and mean value respectively

n number of layers of the panel (from top face to bottom face)

i rank of layers from top face

ax stands for neutral axis in bending

ρ density

0 parallel to length of the plywood (direction of the grain of the face layers)

90 perpendicular to the length

05 5 percentile characteristic value

6 Calculation method

6.1 General

The mechanical properties of plywood, in bending, tension, compression panel shear and planar shear can be derived by calculation.

The calculation method described in this standard can be applied to plywood panels of any composition, symmetrical or not.

For the classification according to appearance classes of plywood, see EN 635-2 and EN 635-3.

6.2 Properties relevant to the calculation methods

For calculation of characteristic values of mechanical properties for different plywood compositions, the values of the properties of the veneers compounding the layers shall be derived in accordance with Annex A.

The relevant properties are as listed in Table 1.

6.3 Wood species

For calculating the characteristic values of panel mechanical properties, test values shall be used where available for each wood species in the plywood panel composition; where not, imposed values from EN 338 shall be used.

NOTE EN 338 values, related to the density of the wood species, are quite conservative and therefore should be used as a last resort option.

6.4 Factors for plywood composition

The characterization of plywood composition is shown in Table 2.

For the purposes of calculation, if two or more plies are glued together in the same grain direction, they can be considered as one single layer provided that they belong to the same wood species; otherwise they shall be considered as independent layers.

The calculations are based on the following equations:

$V_i = E_i$ (Modulus of elasticity of the i^{th} layer in Table 2) (1)

or

$V_i = f_i$ (Strength of the i^{th} layer in Table 2) (2)

Table 1 — Property values for the calculation method

Property
Characteristic strength values, N/mm^2
$f_{m, 05}$: Bending
$f_{t, 05}$: Tension
$f_{c, 05}$: Compression
$f_{v, 05}$: Panel shear
$f_{r, 05}$: Planar shear
Mean values for stiffness properties, N/mm^2
E_m: Bending
E_t: Tension
E_c: Compression
G_v: Panel shear
Characteristic values for stiffness properties, N/mm^2
$E_{m, 05}$: Bending
$E_{t, 05}$: Tension
$E_{c, 05}$: Compression
$G_{v, 05}$: Panel shear
$\rho_{, 05}$: Density values, kg/m^3

Table 2 — Plywood composition factors

Layer rank	Wood Species	t_i (mm)	V_i (N/mm²)	k_{ai}	**Grain direction**
1					==========
2					IIIIIIIIIIIIIIIIIIII
3					==========
------------	----------------	----------------	----------------	----------------	--------------------------------------
i -1					==========
i					IIIIIIIIIIIIIIIIIIII
i+1					==========
------------	----------------	----------------	----------------	----------------	--------------------------------------
n -2					==========
n -1					IIIIIIIIIIIIIIIIIIII
n					==========

t_i : layer thickness

V_i : mechanical property of the i^{th} layer

k_a : appearance factor

====== : grain along the length

IIIIIIIIIIIIIII : grain across the length

7 Characteristic values for strength and stiffness in bending, tension and compression

7.1 General

The properties of the panels are derived from those of their layers as if the panels were homogenous. The equations are based on strength of materials.

7.2 Bending

7.2.1 General

The general equation to be used for the derivation of the second moment of area of a cross section is based on the area A_i of the elementary rectangles compounding the cross section of the panel:

$$I = \sum_{i=1}^{i=n} A_i \times z_i^2 + \sum_{i=1}^{i=n} \frac{A_i \times t_i^2}{12} \quad (3)$$

NOTE This equation can be applied to any composition, symmetrical or not.

If calculation is based on a unit of width, Equation (3) becomes:

$$I = \sum_{i=1}^{i=n} t_i \times z_i^2 + \sum_{i=1}^{i=n} \frac{t_i^3}{12} \quad (4)$$

7.2.2 Modulus of elasticity

The stiffness of the panel (as if homogenised) is equal to the sum of the stiffness of the compounding layers as defined by the following equation:

$$Ep_m \times I = Ep_m \times \frac{T^3}{12} = \sum_{i=1}^{i=n} V_{mi} \times t_i \times z_i^2 + \sum_{i=1}^{i=n} \frac{V_{mi} \times t_i^3}{12} \quad (5)$$

$$Ep_m = \frac{12 \times \sum_{i=1}^{i=n} V_{mi} \times t_i \times z_i^2 + \sum_{i=1}^{i=n} V_{mi} \times t_i^3}{\left(\sum_{i=1}^{i=n} t_i \right)^3} \quad (6)$$

Width is assumed to be equal to 1 unit.

Cross layers properties can be taken into account where the values are derived from timber.

E_{mi} shall be input as 0 wherever the cross layers are not taken into account in the determination of the basic values as defined in Annex A.

Annex B provide practical spreadsheets to carry out this calculation (see Tables B.1 and B.2).

7.2.3 Strength

The capacity of the panel (as if homogenised) is equal to the sum of the capacities of the compounding layers as defined by the following equations:

$$fp_m \times \frac{I}{T/2} = fp_m \times \frac{T^3}{12} \times \frac{2}{T} = \frac{\sum_{i=1}^{i=n} V_{mi} \times t_i \times z_i^2 + \sum_{i=1}^{i=n} \frac{V_{mi} \times t_i^3}{12}}{Z} \quad (7)$$

$$fp_m = \frac{12 \times \sum_{i=1}^{i=n} V_{mi} \times t_i \times z_i^2 + \sum_{i=1}^{i=n} V_{mi} \times t_i^3}{\left(\sum_{i=1}^{i=n} t_i\right)^3} \times \frac{\sum_{i=1}^{i=n} t_i}{2 \times Z} \quad (8)$$

It can be simplified as:

$$fp_m = \frac{12 \times \sum_{i=1}^{i=n} V_{mi} \times t_i \times z_i^2 + \sum_{i=1}^{i=n} V_{mi} \times t_i^3}{2 \times Z \times \left(\sum_{i=1}^{i=n} t_i\right)^2} \quad (9)$$

Width is assumed to be equal to 1 unit.

NOTE 1 However, Equation (8) should be preferred because it allows the use of the same procedure of calculation as Equation (6), the difference between Equations (6) and (8) lying in the factor of eccentricity of the neutral axis $Ecc = T/2Z$ to be applied on the result yielded by Equation (5).

$$Ecc = T/2Z = \frac{\sum_{i=1}^{i=n} t_i}{2 \times Z} \quad (10)$$

Z is the distance (or eccentricity) of the neutral axis to either face or back face. Where composition is not symmetrical, the bigger value shall be picked so as to be on the safe side; it is expressed as:

$$Z = \max\left\{Z_{ax}; \left(\sum_{i=1}^{i=n} t_i - Z_{ax}\right)\right\} \quad (11)$$

NOTE 2 For symmetrical composition Z = T/2 and the calculation can be made using Equation (6) where Ep_m value is substituted by fm_p value.

For safety in the determination of the ultimate limit state, cross layers properties shall not be taken into account.

Annex B provide practical spreadsheets to carry out this calculation (see Tables B.1 to B.4).

7.3 Tension and compression

7.3.1 Stiffness and capacity of the layers in the cross section

The stiffness or capacity of the panel is given by:

$$Up = \sum_{i=1}^{i=n} t_i \times V_i \tag{12}$$

7.3.2 Stiffness and capacity of the panel

$$Up = Vp_{t,c} \times T = Vp_{t,c} \times \sum_{i=1}^{i=n} t_i \tag{13}$$

7.3.3 Property of the panel (as if homogenized)

With Equations (12) and (13):

$$Vp_{t,c} = \frac{Up}{T} = \frac{\sum_{i=1}^{i=n} t_i \times V_{it,c}}{\sum_{i=1}^{i=n} t_i} \tag{14}$$

Width is assumed to be equal to 1 unit; V_i is entered as 0 where cross layers are not taken into account in the derivation of the basic values.

Cross layers properties can be taken into account for stiffness under the same conditions as for bending (see 7.2.2).

Annex B provides a practical spreadsheet to carry out this calculation (see Tables B.5 to B.10).

7.4 Property values for layers

7.4.1 General

These values are derived according to the methods specified in Annex A.

A modification factor k_a related to surface appearance of the face veneers shall be applied to the characteristic value of modulus of elasticity and of strength in accordance with Table 3.

Table 3 — Modification factor k_a for the properties of the veneers

Appearance class	E	I	II	III	IV
k_a	1,0	1,0	1.0	0,85	0,75

Where the inner layers are not appearance graded, class 4 (k_a = 0,75) shall be assumed.

NOTE This table is relevant where the basic values are derived from panels made of veneers with an appearance grade E, I or II. Where these values are derived from panels with faces with appearance class III, k_a, if faces are classified IV, is derived according to:

$$k_a = \frac{k_{a,layer}}{k_{a,basic}} = 0.88 \tag{15}$$

where

k_a,*basic* is k_a of the veneers of the sample of panels for the derivation of the basic values;

k_a,*layer* is k_a of the veneer of the layer of the panel to be calculated.

7.4.2 Modulus of elasticity (E_m, E_t, E_c)

For bending as well as for tension and compression, the basic value of the modulus of elasticity of the veneer of the plies of each layer is input, weighted with the appearance class, together with the thickness of the layer.

$$V_i = k_{ai} \times E_i \qquad (16)$$

If the purpose is to derive a mean value or a 5th percentile for the panel, then the mean modulus or the 5th modulus respectively is input.

7.4.3 Resistance

7.4.3.1 General

For strength properties, the veneer value of a specified layer depends on:

— the corresponding property of its wood species;

— its stress level.

7.4.3.2 Common procedure to bending, tension and compression

Firstly, the 5th percentile value of the strength of the wood species of each layer is picked (in accordance with Annex A).

Secondly, the stress level in the layer shall be derived prior to enter the stress value; though similar in principle, the procedure for tension-compression and bending differ slightly.

Thirdly, in case of mixed species panels or of mixed grade single species panels, as the weaker layer(s) may fail before reaching the maximum load, the procedure of calculation shall be resumed.

Once the first calculation is over, the weaker layer(s) and the corresponding panel strength is recorded in the relevant direction of grain, another calculation shall be carried out with the input, for them, of close to 0 values for strength and modulus of elasticity (but the input shall be such that the value of the ratio f_{mi}/E_{mi} shall not be the lower in the composition).

NOTE 1 For instance, an equal value of 1/1000 N/mm² can be input for E_{mi} and f_{mi}. Indeed, for the weaker layer(s), zero values cannot be input in the equations (or the spreadsheets of Annex B) because the calculation of the ratio f_{mi}/E_{mi} of the layer(s) cannot be determined.

This result of the calculation is then recorded. This procedure shall be repeated as long as the result of strength is greater than the one obtained previously. As soon as the strength value is less than the previous one, the higher value in the set of results provided by the repetition of the procedure shall be accepted as the panel strength.

NOTE 2 The repetition of the procedure is justified by the fact that EN 789 aims at determining the maximum force as the failure force.

7.4.3.3 Tension and compression strength (f_t, f_c)

The strength V_i of the i^{th} layer is given by:

$$V_i = k_{ai} \times Rw_{tc} \times E_{tci} \tag{17}$$

Where

$$Rw_{tc} = \min_{1 \to n} \left\{ \frac{f_{tci}}{E_{tci}} \right. \tag{18}$$

Rw_{tc} is the minimum value taken by this ratio within the whole set of layers compounding the panel in the direction under consideration.

NOTE The layer (pair of layers where composition is symmetrical) made of the wood species with the lowest capacity in elongation in the set of layers is the first to fail. This corresponds to the lower $\Delta L / L$ (Rw_{tc}) of the wood species involved in the panel composition: in the other layers, it determines a stress level less than the failure level.

According to species, f_m/E_m is in a range [2.5/1000 (red balau) - 10/1000 (kotibé)].

7.4.3.4 Bending strength (f_m)

First, the following ratio of the weaker layer in the composition is determined with Equation (19)

$$Rw_b = Min_{1 \to n} \left\{ \frac{f_{mi}}{z_i \times E_{mi}} \right. \tag{19}$$

Rw_b is the minimum value taken by this ratio within the whole set of layers in the direction under consideration.

When this weaker layer fails and if it is not the face layer (or closer to the face in crosswise bending), it entails a certain stress level in the reference face layer. It is given by Equation (20)

$$S_1 = \frac{E_{m1} \times z_1 \times Rw_b}{f_{m1}} \tag{20}$$

Then the stress value V_i of the i^{th} layer is in proportion to the stress level of the first layer and takes the following value:

$$V_i = S_1 \times k_{ai} \times f_{mi} \tag{21}$$

8 Shear properties

8.1 Panel shear

8.1.1 Panel shear rigidity (G_v)

Panel shear rigidity G_v (as in EN 789) is an average value of shear rigidities of all the individual layers in the panel and shall be calculated with equation:

$$G_v = \frac{\sum_{i=1}^{i=n} k_{ai} \times G_{vi} \times t_i}{\sum_{i=1}^{i=n} t_i} \tag{22}$$

8.1.2 Panel shear strength (f_v)

The strength f_v for panel shear shall be derived with the equation:

$$f_v = G_v \times Rw_v \quad (23)$$

where Rw_v:

$$Rw_v = Min_{1 \to n}\left(\frac{f_{vi}}{G_{vi}}\right) \quad (24)$$

Table B.11 provides a calculation template.

8.2 Planar shear

8.2.1 General

The planar shear properties are derived by using equations derived from those in EN 789 which defines a test method where a constant stress level is applied across the thickness of the panel.

NOTE In most of the practical conditions, such as bending, the stress level is not constant. Therefore, the designer can determine the distribution of the stress level across the thickness of the panel and compare it to the capacity of each layer.

8.2.2 Planar shear rigidity (G_r)

8.2.2.1 General

Two options are possible: the available figures for stiffness apply to the homogenized panel (as derived from the current EN 789 calculation equations) or to the veneers across the shear direction.

8.2.2.2 Homogenized shear fitness

Planar shear stiffness is determined by all the layers in each direction of the shear forces. It shall be calculated with:

$$G_r = \frac{\sum_{i=1}^{i=n} t_i}{\sum_{i=1}^{i=n} \frac{t_i}{k_{ai} \times G_{ri}}} \quad (25)$$

8.2.2.3 Veneer shear stiffness

Equation (25) applies but the thickness of the layers whose grain is parallel to the shear forces direction is not relevant. Therefore, the t_i values of the layers across the shear forces direction are only input in Equation (25).

NOTE Mechanically, mixing length and cross layers to derive a homogenized is rather approximate. Indeed, the layers whose grain is parallel to the shear forces are much stiffer than those across (they are even assumed as being infinitely stiff if compared to the layers whose grain is perpendicular to the shear force). However, EN 789 does not take this fact into account and gives only a homogenized shear planar modulus. Annex A provides details to derive the cross veneer stiffness modulus.

8.2.3 Planar shear strength (f_r)

As the same force is applied to all layers through the thickness, the failure of the panel will occur in the layer with the weaker strength in the composition.

$$f_r = Min_{1 \to n}\left(k_{ai} \times f_{ri}\right) \tag{26}$$

Only the layers, whose grain is perpendicular to the shear forces, are relevant.

Tables B.12 to B.14 provide calculation templates.

NOTE In most applications, the planar shear strain is not constant. For instance, in bending, it is distributed according to a curve whose maximum is located at the neutral axis. Therefore, for any kind of loading, the designer can determine the actual shear strain within the panel across its thickness; then, in relation to each layer position z_i with regard to the neutral axis of the panel, the designer can check its strain value with the planar shear strength of the wood species of that layer.

For information purposes, the planar shear strain in a bending panel is related to the shear forces Fs and is given by:

$$f_{ri} = \frac{6 \times Fs}{\sum_{i=1}^{i=n} t_i} \times \left[\frac{1}{4} - \left(\frac{z_i}{\sum_{i=1}^{i=n} t_i}\right)^2\right] \tag{27}$$

f_{ri}, taking into account its face appearance class (see Table 2), shall not exceed the planar shear strength of the wood species of that layer. With such a distribution, a panel whose weaker layers are close to the neutral axis may fail a certain load but pass if those layers are close to the faces.

In practice, short span (in relation to panel thickness) allows for high shear forces F_s, hence higher planar shear strains.

9 Ratio of strength upon modulus

This ratio is needed to derive the strength of the panel for all properties addressed by EN 789. Two options are available to derive this ratio: either the equations defined in this part of the standard or an experimental derivation as defined in Annex A.

The first option is the ratio of the 5th percentile value of the strength upon the mean value of the modulus of elasticity (as in this part); the second option is the 5th percentile value of this ratio as defined in Annex A.

10 Density

The characteristics density of the panel ($P_{p,05}$) is calculated as follows:

$$\rho_{p,05} = \frac{\sum_{i=1}^{i=n} \rho_{i,05} \times t_i}{\sum_{i=1}^{i=n} t_i} \tag{28}$$

The characteristic density of each wood species, of the i^{th} layer in the panel is derived from its mean value in accordance with:

$$\rho_{i,05} = 1.92 + 0.829 \times \rho_{i,mean} \quad (29)$$

NOTE 5th percentile derived from correlation of 5th percentile density with mean density in Table 1 in EN 338:2009.

11 Conversion from strength and modulus of elasticity to capacity and stiffness

Conversion from strength to capacity, or from modulus of elasticity to stiffness, can be calculated using Table 4.

Table 4 — Conversion from strength and modulus of elasticity to capacity and stiffness

Property	Strength		Capacity[a]	
Bending	f_m	MPa or N/mm^2	$f_m\ W\ /\ b$	N
Tension	f_t	MPa or N/mm^2	$f_t\ A\ /\ b$	N/mm
Compression	f_c	MPa or N/mm^2	$f_c\ A\ /\ b$	N/mm
	Modulus of Elasticity		Stiffness[a]	
Bending	E_m	MPa or N/mm^2	$E_m\ I\ /\ b$	kNmm
Tension	E_t	MPa or N/mm^2	$E_t\ A\ /\ b$	kN/mm
Compression	E_c	MPa or N/mm^2	$E_c\ A\ /\ b$	kN/mm
[a] The capacity and stiffness values are per unit panel width b.				

Annex A
(normative)

Derivation for the veneer values (or basic values)

A.1 Scope

The calculation method is based on the fact that plywood is an engineered product and therefore can be manufactured in different compositions which may involve several wood species.

If a wood species used in plywood panels, has no well-established properties values (strength and modulus of elasticity both for the mean and the characteristic value), this annex gives suitable methods to determine the property values to be applied to those species where used in plywood.

A.2 Principle

A.2.1 Option 1: Using plywood test results

The veneer values of properties to be used for the layers of a given species are derived from the corresponding properties obtained by testing plywood panels symmetrically made of that single species. Properties along and possibly across the length of the panels are taken to derive the value of the property of the veneers:

— along their grain (length direction);

— across it only for the modulus of bending, tension and compression where both directions are tested.

A.2.2 Option 2: Using solid timber properties

Two sub-options are available:

— to test solid timber in accordance with EN 408 and EN 384;

— to use imposed values fully defined in EN 338.

In both cases, the modulus of bending, tension and compression across the length can be taken into account by referring to EN 338 values.

NOTE These two options are penalizing, especially the EN 338 one.

A.3 Procedure for derivation of properties from testing plywood

A.3.1 General

Each of the plywood panels to be tested to provide the basic values of a given wood species shall be made entirely made of this wood species.

The other following conditions apply:

— the minimum number of layers is 5;

— the minimum number of lay-ups is 3;

— the layer thickness of the panels in the batch shall cover the contemplated range in production.

NOTE However, results can be applied to panels whose layers are thinner than those of the initial type testing.

All the layers of the sample of panels shall either belong to the same appearance grade (recommended option) or the appearance class of each layer shall be provided by the manufacturer.

A single layer thickness is recommended for the sample of panels in the tested lay-ups; if a single layer thickness is intended for testing, the thicker one in the production should be tested. If several layer thicknesses are contemplated, each panel should be made with a single thickness; if not, the thickness of each layer shall be recorded.

A.3.2 Sampling

For the initial type testing, at least 32 panels are sampled in accordance with EN 1058 and EN 789.

A.3.3 Test pieces

A.3.3.1 Cutting

Two options are allowed:

— cutting test pieces only along the length of the panels;

— cutting test pieces along and across the length of the panels.

In both cases, the 32 test pieces corresponding to each direction to be tested shall be cut according to the cutting plans defined in EN 789.

A.3.3.2 Conditioning

The test pieces are conditioned in climate (20 ± 2) °C, (65 ± 5) % relative humidity as defined in EN 789.

A.3.4 Testing

A.3.4.1 Semi-size values

A.3.4.1.1 General

The procedure specified in EN 789 for modulus and strength applies to bending, tension and compression and shear (panel and planar).

For shear modulus, the testing as well as the exploitation of the results according to EN 789 provides a homogenised value but not a veneer value.

A.3.4.1.2 Planar shear modulus of elasticity

EN 789 derives a homogenized G_r value for this property, suitable to all panels but plywood. Indeed, the stiffness of the layers parallel to shear direction is not of the same order as the stiffness of the layers across and their slip (u in the equation hereunder) can be neglected compared to that of the layers across. Therefore, the true modulus of elasticity of the veneers across the direction of the shear forces is given by the equation derived from the one in EN 789:

$$G_{rv} = \frac{(F_2 - F_1) \times \sum_{i=1}^{i=n} t_{i\_/\_}}{(u_2 - u_1) \times l \times b} \tag{A.1}$$

where

$t_{i\_/\_}$ is the thickness of the i^{th} layer, whose grain is across the shear force direction (instead of the thickness of any layer, whatever its grain direction with regard to shear forces), in millimetres;

G_{rv} is the modulus of elasticity for planar shear of the veneers (instead of the homogenized planar shear as implied in EN 789), in Newtons per square millimetre.

NOTE Compared to homogenized G_r, veneer G_{rv} is increased by the ratio of the total thickness upon the cumulated thickness of the layers across the shear force direction.

A.3.4.2 Small test pieces values

The procedure defined in EN 310 can be applied to the determination of the modulus of elasticity and the strength.

NOTE This procedure can be useful to determine internal control values wherever only short production runs are available. It cannot claim relevance to load-bearing applications.

A.3.4.3 Density

It is measured on at least one test piece cut from each panel of the sample.

A.3.4.4 Thickness

The thickness of each panel is measured in accordance with EN 325.

The thickness of the layers is either provided by the manufacturer or measured with a suitable device.

NOTE Optical meters accurate to 1/10 mm are suitable.

A.3.5 Exploitation of the results

A.3.5.1 General

The purpose of the calculation method is to get veneer characteristic values, 5^{th} percentile or mean values (according to the property), for the wood species involved in the testing.

The characteristic values of the relevant property of the layers are obtained from a reference value of the panel, along its tested direction.

The thickness of each layer and its surface appearance are recorded.

Then, according to the sampling, the reference values of each test piece are processed to yield a veneer value specific to the wood species along and, if relevant, across the length of the panel.

A.3.5.2 Procedure for deriving a veneer value for a wood species

A.3.5.2.1 General

The procedure applies first to each test piece and then, the whole sample shall be processed taking into account the tested directions.

A.3.5.2.2 Test pieces along and across the length

A.3.5.2.2.1 Bending, tension and compression

For each panel, the along the length and the across the length property results are summed up and recorded. This is the reference method.

NOTE Since the panels are made with a single species, the sum yields value of the wood species compounding the panel; this sampling along and across the length simplifies the calculation procedure.

A.3.5.2.2.2 Shear properties

Each test piece property result is recorded.

A.3.5.2.3 Test pieces along the length only

The procedure consists in applying the reverse procedure of the main part of the standard; Annex B shall be used.

The thickness and the surface appearance class modification of Table 2 of the main part of this standard are put into the relevant cells (in columns t_i and k_{ai} respectively) for each layer along the length of the panel. In the across direction, the V_i values are equal to 0.

Then, for each layer a value is assumed for the veneer value (or basic value) of the property to be determined is entered into the property cells (V_i in the spreadsheets of Annex B).

The calculation is then started; it yields a panel value for that property.

Lastly, this panel value is compared to the test value of the property of the panel (the reference for it).

If the value derived for the panel is equal to the panel test value, the assumed value of the veneers becomes the veneer of basic value of that panel. If not, the previous procedure is repeated until the derived value for the panel is equal to its reference value.

This is repeated for each test piece of the sample.

NOTE This procedure could also apply where the two directions of the panel are tested and, if so, the along and across length results should be averaged; it is more complicated than the reference additive method.

A.3.5.2.4 Procedure for a sample of panels

Once the veneer values of the sample of test pieces are obtained, the following statistical procedure shall be applied.

Since EN 14358 assumes a log-normal distribution, the characteristic properties (5th percentile values) and the mean values are defined in *a)* and *b)* respectively.

a) Characteristic properties

The following equations shall be used:

$$f_{p,k} = \exp\left(\overline{y} - k_s \times s_F\right) \quad \text{(A.2)}$$

where $\overline{y}$:

$$\bar{y} = \frac{\sum_{i=1}^{i=n} LN\left(V_{\mathrm{p},i}\right)}{n} \tag{A.3}$$

And s_F :

$$s_F = \sqrt{\frac{\sum_{i=1}^{i=n} \left[LN\left(V_{p,i}\right) - \bar{y}\right]^2}{n-1}} \tag{A.4}$$

with: $S_F \geq 0{,}05$

and lastly k_s, in relation to the sample size n and in accordance with Table A.1:

Table A.1 — Factor k_s values

n	3	5	10	12	15	20	32	40	50
k_s	3,15	2,46	2,10	2,06	1,99	1,93	1,86	1,83	1,81
In case of intermediate values for n, k_s shall be interpolated linearly, (the value for 12 test specimens is already an interpolated value).									

V_i is either strength or modulus of elasticity (where buckling may be involved) of each panel (either the summation of the corresponding property along and across the length of each panel or the property derived by reverse calculation using the table in Annex B)

NOTE The table values are in compliance with EN 14358 for test results.

b) Mean values

The mean value for the modulus V_{mean} is given by:

$$V_{\mathrm{mean}} = \exp\left[\frac{\sum_{i=1}^{i=n} LN\left(V_{\mathrm{i}}\right)}{n}\right] \tag{A.5}$$

where

V_{i} is the modulus of the i^{th} test panel;

V is the modulus of elasticity E or G.

A.3.5.3 Calculation of the ration strength/modulus

The derivation of any strength property of a panel involves the ratio strength upon modulus. Where the individual panel values are not available, this ratio Rw is defined, in the main part of this standard, as the 5th percentile strength f05 upon the 50th percentile modulus value M50.

$$Rw = \frac{f_{05}}{M_{50}} \tag{A.6}$$

Where the individual panel values are available the following procedure shall apply:

For each panel *i*, the ratio $R_{i,d} = \frac{f_i}{M_i}$ is calculated.

Lastly, the 5th percentile value of R_i is calculated so as to get Rw:

$$Rw = \overline{R} - 1.73 \times s_R \tag{A.7}$$

where

$\overline{R}$ is the mean of the ratio strength upon modulus *f/M;*

s_R is the standard deviation between the 32 $R_{i.}$

A.3.5.4 Cross layers properties

The modulus of elasticity of cross layers (with regard to the loading direction), in bending, tension and compression can be taken into account only if it is derived:

— either from timber (either by testing in accordance with EN 408 or by picking imposed value in EN 338);

or

— from panels only if the sample comprises test pieces along and across the length.

Cross layers properties shall be derived from EN 338 which provides the following information:

— For softwoods species:

$$E_{90,m,t,c} = \frac{E_{0,m}}{30} \tag{A.8}$$

— For hardwood species:

$$E_{90,m,t,c} = \frac{E_{0,m}}{15} \tag{A.9}$$

NOTE Where panel testing is used, properties across the length are already integrated into the results along the length.

A.3.5.5 Calculation of the characteristic density of the veneers

It is calculated according to:

$$\rho_{v,05} = \overline{\rho_v} - 1.73 \times s_\rho \tag{A.10}$$

where

$\overline{\rho_v}$ is the average density of the sample of 32 single species panels;

$s\rho$ is the standard deviation of the sample;

$\rho_{v,05}$ is the characteristic density.

NOTE The common unit in this equation is the kg/m^3.

A.4 Derivation of estimated values for veneers

A.4.1 General

Where data is not available, estimated values for timber properties may be used. The panel properties derived from this basis will have the same level of uncertainty as the values estimated for the veneers.

To derive estimated values for veneers along the grain, the following options are open: either by testing or by using imposed values; values across the grain are imposed values.

NOTE Such values may be somewhat conservative and hence, penalising plywood panels, especially the imposed values for timber.

A.4.2 Values obtained by testing

Solid timber values along the grain are derived directly in accordance with:

- EN 408 with regard to testing;
- EN 384 for sampling and derivation of the characteristic value in relation to the number of samples;
- EN 14358 for the derivation of the characteristic value within a sample.

A.4.3 Imposed values

They are derived from EN 338 in relation to density:

- classes C14 to C50 for softwoods and hardwoods with a mean density less than 640 kg/m^3 and;
- classes D30 to D70 for hardwoods with a mean density of 640 kg/m^3 and more;
- as it does not provide any figure for planar shear stiffness, these values shall be provided by EN 12369-2.

NOTE In this Annex, hardwood species with a density less than 640 kg/m^3 are assimilated to softwood species.

A.5 Report

Its content consists of:

- the composition of the panel, including the wood species, the layer thickness and the surface appearance class of the veneers, including the inner ones;
- the process used to get the veneers in the panels (peeling or slicing);
- the individual test results in accordance with EN 789 or, if, relevant (bending), quality control values;
- the panel values (as the average of the two test directions);

— the characteristic values for each property, in accordance with this Annex;

— the ratio of strength/modulus R_w;

— the 5th percentile density.

Annex B
(normative)

Practical spreadsheets to derive the properties

B.1 General

The purpose of these spreadsheets is to provide a template in order to carry out all the operations necessary to get, from a property of the layers compounding a panel, the value of that property for that panel.

This annex provides, for panels, a calculation method based on spreadsheets composed with columns and lines intersecting in cells.

The principle is based on this: since plywood is a stack of layers, each with defined property values, the first part of the spreadsheet consists in providing the data, about lay-up and properties, in the first columns of the spreadsheet; the other part contains the operations leading to the determination of the property.

The first line contains a letter naming the corresponding column.

The second line contains the definitions of the cells below. The definition of the cells is about the features of the panels and its layers (the first ones) and about the operations to be carried out in each of them (the others).

The following features of the panel are entered into the cells:

— rank of the layers;

— thickness of the layers;

— the modification factor related to surface appearance class of the layers;

— the value of the property (either directly or after some processing for strength properties).

NOTE The wood species can be added.

All the cells of the other columns define the intermediate operations for the calculation of the panel property. For instance in column "A" of Table B.1 defines the following operation: from each line, from 1 to n (number of layers), take the t, V & ka values and multiply them and put the result into the cell (one for each layer). For each column, the same procedure applies.

The bottom lines summarize the results of the relevant columns and deliver the results for the panel property.

The tables below cover the properties in the 0° direction as well as the 90° direction.

B.2 Bending

B.2.1 General

Table B.1 provides a spreadsheet to derive the modulus and the strength of the panel (as if homogenized) in accordance with Equation (7) in the main part of this standard.

B.2.2 Main tables

Modulus values of the layers are input directly into the cells of column “V” but for strength, prior to their input, an additional table is needed to derive the strength resulting from the stress level.

A table is proposed for each of the two panel directions.

Table B.1 — Panel bending modulus and strength parallel to its length

Layers		t	V	K	A	T	X	B	Z	C	J	I
		t_i	V_{mi}	k_{ai}	$A_i = t_i . V_{mi} . k_{ai}$	$T_i = t_{i-1} + T_{i-1}$	$X_i = T_i + t_i/2$	$B_i = A_i . X_i$	$z_i = \lvert Z_{ax} - X_i \rvert$	$C_i = z_i^2$	$J_i = A_i . C_i$	$I_i = t_i^2 . A_i / 12$
N°	Grain	mm	N/mm²	-	N	mm	mm	Nxmm	mm	mm²	N/mm²	N/mm²
1	===					0						
2	IIIIIII											
-----	----	-----	----------			------------	------------	------------ -	----------	----------	----------	------------
i -1	===											
i	IIIIIII											
i+1	===											
-----	----	-----	----------			------------	------------	------------ -	----------	----------	----------	------------
n -1	IIIIII											
n	===											

$T = \sum_{i=1}^{i=n} t_i =$					
$\sum_{i=1}^{i=n} A_i =$		$\sum_{i=1}^{i=n} B_i =$		$Jc = \sum_{i=1}^{i=n} J_i =$	
$Z_{ax} = \frac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$		mm	$Ic = \sum_{i=1}^{i=n} I_i =$		
$\sum (E \times I) = Jc + Ic =$					
$Pp_m = 12 \times \frac{Jc + Ic}{T^3} =$		N/mm²			
For f_m where non symmetrical	$Z = \max\{Z_{ax} ; T - Z_{ax}\}$	$Ecc = \frac{T}{2 \times Z}$	$fp_m = Ecc \times Pp_m$		

Table B.2 — Panel bending modulus and strength perpendicular to its length

Layers		t	V	K	A	T	X	B	Z	C	J	I
		t_i	V_{mi}	k_{ai}	$A_i = t_i . V_{mi} . k_{ai}$	$T_i = t_{i-1} + T_{i-1}$	$X_i = T_i + t_i/2$	$B_i = A_i . X_i$	$z_i = \lvert Z_{ax} - X_i \rvert$	$C_i = z_i^2$	$J_i = A_i . C_i$	$I_i = t_i^2 . A_i / 12$
N°	Grain	mm	N/mm²	-	N	mm	mm	Nxmm	mm	mm²	N/mm²	N/mm²
1	IIIIIII					0						
2	===											
-----	----	-----	----------			------------	------------	------------ -	----------	----------	----------	------------
i -1	IIIIIII											
i	===											
i+1	IIIIIII											
-----	----	-----	----------			------------	------------	------------ -	----------	----------	----------	------------
n -1	===											
n	IIIIIII											

$T = \sum_{i=1}^{i=n} t_i =$					
$\sum_{i=1}^{i=n} A_i =$		$\sum_{i=1}^{i=n} B_i =$		$Jc = \sum_{i=1}^{i=n} J_i =$	
$Z_{ax} = \frac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$		mm		$Ic = \sum_{i=1}^{i=n} I_i =$	
$\sum (E \times I) = Jc + Ic =$					
$Pp_m = 12 \times \frac{Jc + Ic}{T^3} =$		N/mm²			
For f_m where non symmetrical	$Z = \max\{Z_{ax}; T - Z_{ax}\}$	$Ecc = \frac{T}{2 \times Z}$	$fp_m = Ecc \times Pp_m$		

In Tables B.1 and B.2 and in accordance with Annex A, the bending modulus of the layers marked "**IIIIIII**" may be input in the relevant cells of column "V"; if not, a 0 value shall be input.

For strength, a 0 value shall be always input.

B.2.3 Tables for strength values

A table is provided for each panel direction. Being related to the thickness of the layers, the content of the cells of the "t", "T" and "X" columns is identical to that of the corresponding columns in Tables B.1 and B.2; however, the content of the cells of columns "B" and "Z" differ because of the modification of the position of the neutral axis related to the difference between nominal strength and stress level.

Table B.3 — Layer bending strength parallel to panel length

Layers		t	F	E	A	T	X	B	Z	R	V
		t_i	f_i	E_i	$A_i = k_{ai}.\ t_i.\ f_{mi}$	$T_i = t_{i-1} + T_{i-1}$	$X_i = T_i + t_i/2$	$B_i = A_i\ .\ X_i$	$z_i = Z_{ax} - X_i$	$r_i = \dfrac{f_i}{z_i \times E_i}$	$V_i = Sl \times f_{mi}$
N°	Grain	mm	N/mm²		N	mm	mm	Nxmm	mm	mm^{-1}	N/mm²
1	========					0					
2	IIIIIIIIIIIIIII		0								0
-----	-------------	-------	----	----	--------	-----------	-----------	----------	----------	----------	-----------
i -1	========										
i	IIIIIIIIIIIIIII		0								0
i+1	========										
-----	-------------	-------	----	----	--------	----------	----------	----------	----------	----------	-----------
n -1	IIIIIIIIIIIIIII		0								0
n	========										
$T = \sum_{i=1}^{i=n} t_i =$			Stress level Sl $Sl = \dfrac{E_{m1} \times z_1 \times Rw_m}{f_{m1}} =$					Minimum [R_1 to R_n] = Rw_m =			
$\sum_{i=1}^{i=n} A_i =$							$\sum_{i=1}^{i=n} B_i =$		$Z_{ax} = \dfrac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$		

Table B.4 — Layer bending strength for layers perpendicular to panel length

Layers		t	F	E	A	T	X	B	Z	R	V
		t_i	f_i	E_i	$A_i = k_{ai}. t_i. f_{mi}$	$T_i = t_{i-1} + T_{i-1}$	$X_i = T_i + t_i/2$	$B_i = A_i . X_i$	$z_i = Z_{ax} - X_i$	$r_i = \frac{f_i}{z_i \times E_i}$	$V_i = Sl \times f_{mi}$
N°	**Grain**	mm	N/mm²		N	mm	mm	Nxmm	mm	mm^{-1}	N/mm²
1	**IIIIIII**		0			0					0
2	**===**										
-----	-------------	-------	----	----	--------	----------	----------	----------	----------	----------	-----------
i -1	**IIIIIII**		0								0
i	**===**										
i+1	**IIIIIII**		0								0
-----	-------------	-------	----	----	--------	----------	----------	----------	----------	----------	-----------
n -1	**===**										
n	**IIIIIII**		0								0
$T = \sum_{i=1}^{i=n} t_i =$			Stress level Sl $Sl = \frac{E_{m1} \times z_1 \times Rw_m}{f_{m1}} =$					Minimum [R_1 to R_n] = $Rw_m =$			
$\sum_{i=1}^{i=n} A_i =$							$\sum_{i=1}^{i=n} B_i =$		$Z_{ax} = \frac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$		

ka_i shall be picked, in accordance with face appearance class, in Table 3 of the main part of this standard.

The values in the cells of column "V" are ready for transfer into those of column "V" in Tables B.1 and B.2 respectively to get the strength of the panel.

B.3 Tension and compression

Tables B.5 to B.8 provide suitable spreadsheets to derive the modulus and the strength of the panel (as if homogenized) in accordance with Equation (14) in the main part of this standard.

Table B.5 — Panel modulus in tension and compression with loading direction parallel to face grain

Layers		t	K	V	A
		t_i	k_{ai}	Vi	$A_i = t_i.. k_{ai}.V_i$
N°	**Grain**	mm	-	N/mm²	N
1	**===**				
2	**IIIIII**				
-------------	-------------	-------------	-------------	-------------	-------------
i –1	**===**				
I	**IIIIII**				
i+1	**===**				
-------------	-------------	-------------	-------------	-------------	------------
n –1	**IIIIII**				
n	**===**				
$T = \sum_{i=1}^{i=n} t_i =$					
$A = \sum_{i=1}^{i=n} A_i =$					
$Vp_{t,c} = \frac{A}{T} =$					

Table B.6 — Panel modulus in tension and compression with loading direction perpendicular to face grain

Layers		t	K	V	A
		t_i	k_{ai}	Vi	$A_i = t_i . k_{ai} . V_i$
N°	**Grain**	mm	-	N/mm²	N
1	**IIIIII**				
2	**===**				
---------	---------	-------------	-------------	-------------	-------------
i –1	**IIIIII**				
I	**===**				
i+1	**IIIIII**				
-----------	-----------	-------------	-------------	-------------	------------
n –1	**===**				
n	**IIIIII**				
$T = \sum_{i=1}^{i=n} t_i =$					
$A = \sum_{i=1}^{i=n} A_i =$					
$Vp_{t,c} = \frac{A}{T} =$					

The cells of column V have to be fed with 5th or 50th percentile values of the modulus of elasticity. If the layers perpendicular to the loading direction are not taken into account, the value in the corresponding cell V_i is equal to 0.

Table B.7 — Panel strength in tension and compression with loading direction parallel to face grain

Layers		**t**	**K**	**V**	**A**
		t_i	k_{ai}	Vi	$A_i = t_i .\, k_{ai} . V_i$
N°	**Grain**	mm	-	N/mm²	N
1	**===**				
2	**IIIIII**			0	
-------------	-------------	-------------	-------------	-------------	-------------
i –1	**===**			0	
I	**IIIIII**				
i+1	**===**				
-------------	-------------	-------------	-------------	-------------	-------------
n –1	**IIIIII**			0	
n	**===**				
$T = \sum_{i=1}^{i=n} t_i =$					
$A = \sum_{i=1}^{i=n} A_i =$					
$Vp_{t,c} = \frac{A}{T} =$					

Table B.8 — Panel strength in tension and compression with loading direction perpendicular to face grain

Layers		t	K	V	A
		t_i	k_{ai}	Vi	$A_i = t_i . k_{ai} . V_i$
N°	**Grain**	mm	-	N/mm²	N
1	**IIIIII**				
2	**===**				
---------	---------	-------------	-------------	-------------	-------------
i –1	**IIIIII**			0	0
I	**===**				
i+1	**IIIIII**			0	0
-----------	-----------	-------------	-------------	-------------	------------
n –1	**===**				
n	**IIIIII**			0	0
$T = \sum_{i=1}^{i=n} t_i =$					
$A = \sum_{i=1}^{i=n} A_i =$					
$Vp_{t,c} = \frac{A}{T} =$					

Cells of column V have to be fed with the 5th percentile values which have to be processed in accordance with 7.4.3.3 The layers perpendicular to loading direction are not taken into account; the value in the corresponding Vi cell is equal to 0.

Since strength in tension and compression differ, Tables B.7 and B.8 have to be calculated for both properties

NOTE Strength: Tables B.9 and B.10 can be used to derive the strength in tension and compression to be input in column V of Tables B.7 and B.8 respectively.

.

Table B.9 — Layer strength for tension and compression with loading direction parallel to face grain

Layers		E	F	R	V
		E_i	f_i	$R_i = f_i/E_i$	$Vi = E_i.Rw_{tc}$
N°	Grain	N/mm²	N/mm²	-	N/mm²
1	===				
2	IIIIIII		0		0
-----------	-----	-----------	-----------	-----------	-----------
i-1	===				
i	IIIIII		0		0
i+1	===				
-----------	-----	-----------	-----------	-----------	-----------
n-1	IIIIII		0		0
n	===				
Rw_{tc} = Minimum [R_{tc1} to R_{tcn}] =					

The V_i values are ready for transfer into column V in Table B.5 to get the strength of the panel.

NOTE Table B.9 can be merged into Table B.5.

Table B.10 — Layer strength for tension and compression with loading direction perpendicular to face grain

Layers		E	F	R	V
		E_i	f_i	$R_i = f_i/E_i$	$Vi = E_i.Rw_{tc}$
N°	Grain	N/mm²	N/mm²	-	N/mm²
1	IIIIIII		0		0
2	===				
-----------	-----	-----------	-----------	-----------	-----------
i-1	IIIIII		0		0
i	===				
i+1	IIIIII				
-----------	-----	-----------	-----------	-----------	-----------
n-1	===				
n	IIIIII		0		0
Rw_{tc} = Minimum [R_{tc1} to R_{tcn}] =					

The V_i values are ready for transfer into column V in Table B.5 to get the strength of the panel.

NOTE Table B.10 can be merged into Table B.5.

B.4 Panel shear

The modulus G_v and the strength f_v of the panel can be derived using Table B.11.

Table B.11 — Panel shear modulus and strength for both shear-loading directions

<table>
<tr><th rowspan="2">N°</th><th rowspan="2">Grain</th><th>T</th><th>K</th><th>G</th><th>F</th><th>R</th><th>N</th></tr>
<tr><th>t_i</th><th>k_{ai}</th><th>G_{ri}</th><th>f_{ri}</th><th>$R_i = f_{ri}/G_{ri}$</th><th>$N_i = t_i.k_{ai}.G_{vi}$</th></tr>
<tr><td>1</td><td>======</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>||||||||||||||</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td></tr>
<tr><td>i</td><td>======</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>i+1</td><td>||||||||||||||</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td></tr>
<tr><td>n-1</td><td>||||||||||||||</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>n</td><td>======</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">$T = \sum_{i=1}^{i=n} t_i =$</td><td></td><td colspan="3">Minimum [R_1 to R_n] = Rw =</td><td></td><td></td></tr>
<tr><td>$G_v = \frac{N}{T} =$</td><td></td><td colspan="2">$G_r = G_v \times Rw =$</td><td></td><td colspan="2">$N = \sum_{i=1}^{i=n} N_i =$</td><td></td></tr>
</table>

As for the previous tables, the operations are defined for each cell in the second cell of each column.

The grain directions of the second column have to be adapted to the direction of the panel.

B.5 Planar shear

B.5.1 General

The modulus G_r and the strength f_r of the panel can be derived using Tables B.12 and B.13 or B.14.

B.5.2 Available veneer values

Table B.12 — Modulus and strength of panel with shear-loading direction parallel to face grain

<table>
<tr><th rowspan="2">N°</th><th rowspan="2">Grain</th><th>T</th><th>K</th><th>G</th><th>F</th><th>P</th><th>N</th></tr>
<tr><th>t_i</th><th>k_{ai}</th><th>G_{ri}</th><th>f_{ri}</th><th>$P_i = k_{ai}.f_{ri}$</th><th>$N_i = t_i/(k_{ai}.G_{ri})$</th></tr>
<tr><td>1</td><td>======</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0</td></tr>
<tr><td>2</td><td>||||||||||||||</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td></tr>
<tr><td>i</td><td>======</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0</td></tr>
<tr><td>i+1</td><td>||||||||||||||</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td><td>--------</td></tr>
<tr><td>n-1</td><td>||||||||||||||</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>n</td><td>======</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0</td></tr>
<tr><td colspan="2">$T = \sum_{i=1}^{i=n} t_i =$</td><td></td><td colspan="3">Minimum $[P_1 \ to \ P_n] = Pw$</td><td></td><td></td></tr>
<tr><td colspan="7">$N = \sum_{i=1}^{i=n} N_i =$</td><td></td></tr>
<tr><td colspan="3">$G_r = \frac{T}{N} =$</td><td colspan="2"></td><td colspan="2">$fr = Pw =$</td><td></td></tr>
</table>

Table B.13 — Modulus and strength of panel with shear-loading direction perpendicular to face grain

N°	Grain	T	K	G	F	P	N
		t_i	k_{ai}	G_{ri}	f_{ri}	$P_i = k_{ai}.f_{ri}$	$N_i = t_i/(k_{ai}.G_{ri})$
1	IIIIIIIIIIIIII						
2	======	0	-	-	-	-	0
--------	--------	--------	--------	--------	--------	--------	--------
i	IIIIIIIIIIIIII						
i+1	======	0	-	-	-	-	0
--------	--------	--------	--------	--------	--------	--------	--------
n-1	======	0	-	-	-	-	0
n	IIIIIIIIIIIIII						
$T = \sum_{i=1}^{i=n} t_i =$			Minimum [P_1 to P_n] = Pw =				
						$N = \sum_{i=1}^{i=n} N_i =$	
$G_r = \frac{T}{N} =$			$f_r = Pw =$				

In Tables B.12 and B.13, the layers perpendicular to the shear direction are the only ones relevant (because much weaker)

B.5.3 Veneer values not available

Table B.14 — Modulus and strength of panel for both shear directions

N°	Grain	T	K	G	F	P	N
		t_i	k_{ai}	G_{ri}	f_{ri}	$k_{ai}.f_{ri}$	$N_i = t_i/(k_{ai}.G_{ri})$
1	======						
2	IIIIIIIIIIIIII						
--------	--------	--------	--------	--------	--------		
i	======						
i+1	IIIIIIIIIIIIII						
--------	--------	--------	--------	--------	--------		
n-1	IIIIIIIIIIIIII						
n	======						
$T = \sum_{i=1}^{i=n} t_i =$			Minimum [$k_{a1}fr_1$ to $k_{an}.fr_n$] $Pw =$				
						$N = \sum_{i=1}^{i=n} N_i =$	
$G_r = \frac{T}{N} =$				$f_r = Pw =$			

All the cells shall be documented.

As for the previous tables, the operations are defined for each cell in the second cell of each column.

The grain directions of the second column have to be adapted to the direction of the panel.

Annex C
(informative)

Example of bending strength

NOTE As Annex B is fully developed, a single example is proposed as an instruction for use of the spreadsheets of Annex B. The composition of the panel is fictitious.

C.1 Determination of the stress in the layers

Table C.1 — Layer bending strength parallel to panel length

Layers		t	F	E	K	A	T	X	B	Z	R	V
		t_i	f_{mi}	E_{mi}	k_{ai}	$A_i=k_{ai}.t_i.f_{mi}$	$T_i=t_{i-1}+T_{i-1}$	$X_i=T_i+t_i/2$	$B_i=A_i.X_i$	$z_i=\lvert Z_{ax}-X_i\rvert$	$R_i=f_i/(z_i.E_i)$	$V_i = Sl \times f_{mi}$
N°	**Grain**	mm	N/mm²		-	N	mm	mm	Nxmm	mm	mm^{-1}	N/mm²
1	**=====**	2,0	70,0	12 000	1,0	140	0	1,0	140	9,6	$6,10 \times 10^{-4}$	64,2
2	**IIIIIIIIIIII**	3,0					2,0					
3	**=====**	2,0	40,0	10 000	0,85	68	5,0	6,0	408	4,6	$8,76 \times 10^{-4}$	36,7
4	**IIIIIIIIIIII**	2,0					7,0					
5	**=====**	4,0	30,0	8 000	0,75	90	9,0	11,0	990	0,4	$8,66 \times 10^{-4}$	27,5
6	**IIIIIIIIIIII**	2,0					13,0					
7	**=====**	2,0	40,0	10 000	0,85	68	15,0	16,0	1088	5,4	$7,36 \times 10^{-4}$	36,7
8	**IIIIIIIIIII**	3,0					17,0					
9	**=====**	2,0	70,0	12 000	0,85	119	20,0	21,0	2499	10,4	$5,59 \times 10^{-4}$	64,2
$T=\sum_{i=1}^{i=n} t_i =$		22	Stress level *Sl* $Sl = \frac{E_{m1} \times z_1 \times Rw_m}{f_{m1}} =$			0.917			Minimum [R_1 to R_n] = Rw_m =		**$5,59 \times 10^{-4}$**	
					$\sum_{i=1}^{i=n} A_i =$	485		$\sum_{i=1}^{i=n} B_i =$	5125	$Z_{ax} = \frac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$		10,6

Table C.2 — Layer bending strength for layers perpendicular to panel length

Layers		t	F	E	K	A	T	X	B	Z	R	V
		t_i	f_{mi}	E_{mi}	k_{ai}	$A_i=k_{ai}.t_i.f_{mi}$	$T_i=t_{i-1}+T_{i-1}$	$X_i=T_i+t_i/2$	$B_i=A_i\,.\,X_i$	$z_i=\lvert Z_{ax}-X_i\rvert$	$R_i=f_i/(z_i.E_i)$	$V_i = Sl \times f_{mi}$
N°	Grain	mm	N/mm²		-	N	mm	mm	Nxmm	mm	mm^{-1}	N/mm²
1	IIIIIIIIIIII	2,0	0				0					0
2	=====	3,0	60	11 000	1,0	180	2,0	3,5	630	7,1	$7{,}72 \times 10^{-4}$	53,5
3	IIIIIIIIIII	2,0	0									0
4	=====	2,0	40	10 000	0,85	68	7,0	8,0	544	2,6	$1{,}56 \times 10^{-3}$	35,6
5	IIIIIIIIIII	4,0	0									0
6	=====	2,0	40	10 000	0,85	68	13,0	14,0	952	3,4	$1{,}17 \times 10^{-3}$	35,6
7	IIIIIIIIII	2,0	0									0
8	=====	3,0	60	11 000	0,85	153	17,0	18,5	2831	7,9	$6{,}88 \times 10^{-4}$	53,5
9	IIIIIIIIIIII	2,0	0									
$T = \sum_{i=1}^{i=n} t_i =$		22	Stress level Sl $Sl = \frac{E_{m1} \times z_1 \times Rw_m}{f_{m1}} =$			0,891			Minimum [R_1 to R_n] = $Rw_m =$		$6{,}88 \times 10^{-4}$	
				$\sum_{i=1}^{i=n} A_i =$	469		$\sum_{i=1}^{i=n} B_i =$		4 957	$Z_{ax} = \frac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$		10,6

The V values are ready for transfer into column V in Tables B.1 and B.2 respectively to get the strength of the panel.

ka_i is picked in Table 3 in the main part of this standard.

C.2 Determination of the panel strength

Table C.3 — Panel bending strength parallel to its length

Layers		t	V	K	A	T	X	B	Z	C	J	I
		t_i	V_{mi}	k_{ai}	$A_i = t_i . V_{mi} . k_{ai}$	$T_i = t_{i-1} + T_{i-1}$	$X_i = T_i + t_i/2$	$B_i = A_i . X_i$	$z_i = \lvert Z_{ax} - X_i \rvert$	$C_i = z_i^2$	$J_i = A_i . C_i$	$I_i = t_i^2 . A_i/12$
N°	Grain	mm	N/mm²	-	N	mm	mm	Nxmm	mm	mm²	N/mm²	N/mm²
1	=====	2,0	64,2	1,0	128	0	1,0	128,4	9,6	91,5	11 750	43
2	IIIIIIIIIIII	3,0				2,0						
3	=====	2,0	35,7	0,85	62	5,0	6,0	62,4	4,6	20,9	1 301	21
4	IIIIIIIIIIII	2,0				7,0						
5	=====	4,0	27,5	0,75	83	9,0	11,0	82,5	0,4	0,2	15	110
6	IIIIIIIIIIII	2,0				13,0						
7	=====	2,0	36,7	0,85	62	15,0	16,0	62,4	5,4	29,5	1 841	21
8	IIIIIIIIIII	3,0				17,0						
9	=====	2,0	64,2	0,85	109	20,0	21,0	109,1	10,4	108,8	11 878	40
$T = \sum_{i=1}^{i=n} t_i =$		22										

$\sum_{i=1}^{i=n} A_i =$	485		$\sum_{i=1}^{i=n} B_i =$	5 125	$Jc = \sum_{i=1}^{i=n} J_i =$	26 785
$Z_{ax} = \frac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$			10,6	mm	$Ic = \sum_{i=1}^{i=n} I_i =$	231
$\sum (E \times I) = Jc + Ic =$			27 015			
$Pp_m = 12 \times \frac{Jc + Ic}{T^3} =$			**29,3**	N/mm²		
For f_m where non symmetrical	$Z = \max\{Z_{ax} ; T - Z_{ax}\}$		$Ecc = \frac{T}{2 \times Z}$		$fp_m = Ecc \times Pp_{bending}$	

V_i and C_i values come from Table B.3.

Table C.4 — Panel bending strength perpendicular to its length

Layers		t	V	K	A	T	X	B	Z	C	J	I
		t_i	fi/V_{mi}	k_{ai}	$A_i = t_i . V_{mi} . k_{ai}$	$T_i = t_{i-1} + T_{i-1}$	$X_i = T_i + t_i/2$	$B_i = A_i . X_i$	$z_i = \lvert Z_{ax} - X_i \rvert$	$C_i = z_i^2$	$J_i = A_i . C_i$	$I_i = t_i^3 . A_i / 12$
N°	Grain	mm	N/mm²	-	N	mm	mm	Nxmm	mm	mm²	N/mm²	N/mm²
1	IIIIIIIIIIII	2,0				0						
2	=====	3,0	53,5	1,0	160	2,0	3,5	561	7,1	50,0	8 014	120
3	IIIIIIIIIIII	2,0				5,0						
4	=====	2,0	35,6	0,85	61	7,0	8,0	485	2,6	6,6	400	20
5	IIIIIIIIIIII	4,0				9,0						
6	=====	2,0	35,6	0,85	36	13,0	14,0	848	3,4	11,8	714	20
7	IIIIIIIIIIII	2,0				15,0						
8	=====	3,0	53,5	0,85	136	17,0	18,5	2 522	7,9	62,9	8 578	102
9	IIIIIIIIIIII	2,0				20,0						
$T = \sum_{i=1}^{i=n} t_i =$		22										

$\sum_{i=1}^{i=n} A_i =$	418	$\sum_{i=1}^{i=n} B_i =$	4 417	$Jc = \sum_{i=1}^{i=n} J_i =$	17 705
$Z_{ax} = \dfrac{\sum_{i=1}^{i=n} B_i}{\sum_{i=1}^{i=n} A_i} =$	10,6	mm		$Ic = \sum_{i=1}^{i=n} I_i =$	263

$\sum (E \times I) = Jc + Ic$ =	17 968

$Pp_m = 12 \times \dfrac{Jc + Ic}{T^3}$ =	19,5	N/mm²

For f_m where non symmetrical	$Z = \max\{Z_{ax}; T - Z_{ax}\}$	$Ecc = \dfrac{T}{2 \times Z}$	$fp_m = Ecc \times Pp_{bending}$

Bibliography

[1] EN 310, *Wood-based panels — Determination of modulus of elasticity in bending and of bending strength*

[2] EN 635-2, *Plywood — Classification by surface appearance — Part 2: Hardwood*

[3] EN 635-3, *Plywood — Classification by surface appearance — Part 3: Softwood*

[4] EN 1995-1-1, *Eurocode 5 — Design of timber structures — Part 1-1: General — Common rules and rules for buildings*