Table A.13 — Characteristics of bulkheads

Item	Unit	Formula[a]
Solid plywood bulkheads	mm	$t_b = 7{,}0\ D_b$[a]
Sandwich bulkhead with identical plywood skins	mm²	$t_{io} \times t_c \geq \frac{t_b^2}{6}$ strength criterion and
	mm³	$t_{io} \times \frac{t_c^2}{2} \geq \frac{t_b^3}{12}$ stiffness criterion
Sandwich bulkhead with identical FRP skins	mm²	$t_{io} \times t_c \geq \frac{t_b^2}{6} \cdot \left(\frac{25}{\sigma_d}\right)$ strength criterion and
	mm³	$t_{io} \times \frac{t_c^2}{2} \geq \frac{t_b^3}{6} \cdot \left(\frac{4\,000}{E_{io}}\right)$ stiffness criterion

Metal bulkheads shall be calculated as watertight bulkheads.

[a] D_b is the depth of the bulkhead from bottom of canoe body to actual side/deck connection (m).

t_{io} and t_s are respectively the inner and outer skins and core thickness (mm).

The minimum design shear stress of the core shall be as required in Table 17 and Table A.7.

A.14 Structural support for sailing craft ballast keel

A.14.1 General

The requirements on floors, girders, keelsons, etc. supporting loads connected to sailing craft ballast keel (heeling, vertical or longitudinal grounding or docking) are given in ISO 12215-9.

A.14.2 Reminder of requirements of ISO 12215-9

Annex D of ISO 12215-9:2012 requires that, unless specifically engineered and documented, the thickness and/or structural arrangement of the bottom shell or keel skeg plating in an area located longitudinally and transversally within 0,2 T_{MAX} from the ballast keel junction with the hull, shall be such that the design pressure of the plating is 1,8 times the bottom pressure defined in this document, including the factor k_{SLS}. This may be obtained by extra thickness or closer spacing of stiffeners. See Table A.14.

Table A.14 — Excerpt of Table D.2 of ISO 12215-9:2012

An "established practice" equivalent to 1,8 times the pressure, is to have a hull thickness of $t_{\mathrm{H\,min}} = 0{,}06 b_s^{0{,}95} A_R \left(1 - 0{,}25 A_R\right) \frac{m_{\mathrm{LDC}}^{0{,}175}}{\sigma_{\mathrm{D}}^{0{,}5}}$ with — A_R = panel aspect ratio (not less than 1,0 nor greater than 2,0). — Design stress $\sigma_d = 0{,}5\ \sigma_{uf}$ (FRP and wood), $\sigma_d = 0{,}9\ \sigma_{Yield}$ (metals). — b_s = in mm, is the distance between adjacent stiffeners, floor or girder webs, whichever is the shorter distance (mm) not to be taken less than 350 + 5 L_{WL} (FRP) or 250 + 5 L_{WL} (other materials).
NOTE The hull thickness t_{Hmin} correspond to the requirements of ISO 12215-5 around the keel area idem for the values of σ_d above which differ from the design stress σ_d in this part of ISO 12215.

Annex B
(normative)

Mechanical properties and design stress of metals

Unless otherwise specifically documented, the mechanical properties and design stress of metal plating and metal stiffeners shall be taken from Table B.1 and Table B.2, respectively. For aluminium alloys, data are derived from EN 14195-1.

Table B.1 — Mechanical properties and design stress of metal plating

Design stress for plating											
Mild steel σ_d=min(0,6 σ_u; 0,9 σ_y) and τ_d =0,58 σ_d			Temper	σ_u	σ_{uw}	σ_y	σ_{yw}	σ_d/σ_u	σ_d/σ_y	σ_d	τ_d [a]
E24 / A				400	400	235	235	0,6	0,9	212	123
E32 - AH 32				470	470	315	315	0,6	0,9	282	164
E36 - AH 36				490	490	355	355	0,6	0,9	294	171
Aluminium alloys (non-heat treatable) σ_d=min(0,6 σ_{uw}; 0,9 σ_{yw}) and τ_d =0,58 σ_d											
EN reference	Product and thickness	Composition	Temper	σ_u	σ_{uw}	σ_y	σ_{yw}	σ_d/σ_u	σ_d/σ_y	σ_d [b]	τ_d [a]
EN AW-5052	Sheet, strip, plate $3 < t < 50$	Al,Mg 2,5	H32	210	170	160	65	0,6	0,9	59	34
EN AW-5052	Sheet, strip, plate $3 < t < 50$	Al,Mg 2,5	H34	235	170	180	65	0,6	0,9	59	34
EN AW-5754	Sheet, strip, plate $3 < t < 50$	Al,Mg 3	0/H111	225	190		80	0,6	0,9	72	42
EN AW-5754	Sheet, strip, plate $3 < t < 50$	Al,Mg 3	H24	240	190	190	80	0,6	0,9	72	42
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	0/H111	215	215	85	85	0,6	0,9	77	44
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	H24	240	215	200	85	0,6	0,9	77	44
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	0/H111	240	240	100	100	0,6	0,9	90	52
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	H34	275	240	185	100	0,6	0,9	90	52
EN AW-5083	Sheet, strip, plate $t < 6$	Al,Mg 4,5 Mn 0,7	0/H111	275	270	125	125	0,6	0,9	113	65
EN AW-5083	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,7	H32	305	270	215	125	0,6	0,9	113	65
AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	0/H111	330	300	160	160	0,6	0,9	144	84

[a] This value is not explicitly required in this part of ISO 12215; it is taken as 0,58 σ_d for ductile materials.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min (0,6σ_{uw} or 0,9σ_{yw}) unwelded.

NOTE σ_u and σ_y are tensile stresses.

The value of E modulus of metal is required in some formulas (e.g. Tables A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel: E= 210 000 N/mm^2 Aluminium alloys E: = 70 000 N/mm^2.

Table B.1 *(continued)*

AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	H34	370	300	270	160	0,6	0,9	144	84
EN AW-5383	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,9	0/H111	290	290	145	145	0,6	0,9	131	76
EN AW-5383	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,9	H34	305	290	220	145	0,6	0,9	131	76

[a] This value is not explicitly required in this part of ISO 12215; it is taken as 0,58 σ_d for ductile materials.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min ($0,6\sigma_{uw}$ or $0,9\sigma_{yw}$) unwelded.

NOTE σ_u and σ_y are tensile stresses.

The value of E modulus of metal is required in some formulas (e.g. Tables A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel: E= 210 000 N/mm^2 Aluminium alloys E: = 70 000 N/mm^2.

Table B.2 — Mechanical properties and design stress of metal stiffeners

Design stress for stiffeners										
Mild steel $\sigma_d = 0,8\ \sigma_y$ and $\tau_d = 0,58\ \sigma_d$				σ_u	σ_{uw}	σ_y	σ_{yw}	σ_d/σ_y	σ_d	τ_d
E24 / A				400	400	235	235	0,8	188	109
E32 - AH 32				470	470	315	315	0,8	252	146
E36 - AH 36				490	490	355	355	0,8	284	165
Aluminium alloys (non-heat treatable) $\sigma_d = 0,7\ \sigma_{yw}$										
EN reference	**Product and thickness**	**Composition**	**Temper**	σ_u [a]	σ_{uw} [a]	σ_y	σ_{yw}	σ_d/σ_{yw}	σ_d [b]	τ_d
EN AW-5052	Sheet, strip, plate $3 < t < 50$	Al,Mg 2,5	H32	210	170	160	65	0,7	46	26
EN AW-5052	Sheet, strip, plate $3 < t < 50$	Al,Mg 2,5	H34	235	170	180	65	0,7	46	26
EN AW-5754	Sheet, strip, plate $3 < t < 50$	Al,Mg 3	0/H111	225	190	80	80	0,7	56	32
EN AW-5754	Sheet, strip, plate $3 < t < 50$	Al,Mg 3	H24	240	190	190	80	0,7	56	32
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	0/H111	215	215	85	85	0,7	60	35
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	H24	240	215	200	85	0,7	60	35
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	0/H111	240	240	100	100	0,7	70	41
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	H34	275	240	185	100	0,7	70	41
EN AW-5083	Sheet, strip, plate $t < 6$	Al,Mg 4,5 Mn 0,7	0/H111	275	275	125	125	0,7	88	51
EN AW-5083	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,7	H32	305	275	215	125	0,7	88	51

[a] The ultimate values are given for information only as the design stress is based on yield strength in welded conditions.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min ($0,6\sigma_{uw}$ or $0,9\sigma_{yw}$) unwelded a.

NOTE σ_u and σ_y are tensile stresses.

The value of *E* modulus of metal is required in some formulas (e.g. Table A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel E = 210 000 N/mm^2 Aluminium alloys E = 70 000 N/mm^2.

Table B.2 *(continued)*

AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	0/H111	330	300	160	160	0,7	112	65
AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	H32	370	300	270	160	0,7	112	65
EN AW-5383	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,9	0/H111	290	290	145	145	0,7	102	59
EN AW-5383	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,9	H32	305	290	220	145	0,7	102	59
Aluminium alloys (heat treatable) $\sigma_d = 0,7\ \sigma_{yw}$ and $\tau_d = 0,58\ \sigma_d$										
EN AW-6060	Profiles, bars, Tubes $3 < t < 25$	Al,Mg Si	T5,T6	190	95	150	65	0,7	46	26
EN AW-6061	Profiles, bars, Tubes $3 < t < 25$	Al,Mg1, Si Cu	T5,T6	260	165	240	115	0,7	81	47
EN AW-6061	Closed profiles	Al,Mg1, Si Cu	T5,T6	245	165	205	115	0,7	81	47
EN AW-6063	Profiles, bars, Tubes $3 < t < 25$	Al,Mg 0,7 Si	T5	150	100	110	65	0,7	46	26
EN AW-6063	Profiles, bars, Tubes $3 < t < 52$	Al,Mg 0,7 Si	T6	205	100	170	65	0,7	46	26
EN AW-6005A	Profiles, bars, Tubes $3 < t < 51$	Al,Si,Mg (A)	T5,T6	260	165	215	115	0,7	81	47
EN AW-6005A	Closed profiles $3 < t < 50$	Al,Si,Mg (A)	T5,T6	250	165	215	115	0,7	81	47
EN AW-6082	Profiles, bars, Tubes $3 < t < 25$	Al,Si 1,Mg,Mn	T5,T6	310	170	260	115	0,7	81	47
EN AW-6082	Closed profiles	Al,Si 1,Mg,Mn	T5,T6	290	170	240	115	0,7	81	47
EN AW-6106	Profiles, bars, Tubes $3 < t < 25$	Al,Mg,Si,Mn	T6	240	240	195	195	0,7	81	47

[a] The ultimate values are given for information only as the design stress is based on yield strength in welded conditions.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min ($0,6\sigma_{uw}$ or $0,9\sigma_{yw}$) unwelded a.

NOTE σ_u and σ_y are tensile stresses.

The value of E modulus of metal is required in some formulas (e.g. Table A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel E = 210 000 N/mm^2 Aluminium alloys E = 70 000 N/mm^2.

Annex C
(normative)

FRP laminates properties and calculations

C.1 Status of this Annex

This Annex shall be used for the analysis methods 1 to 3 of Table 2. For the analysis method 5 (FEM), other documented values may be used but it should be checked that their values do not differ from the ones in this Annex by a large margin.

C.2 Determination of the mechanical properties

C.2.1 Tests and test standards

Mechanical properties to be used as input in determining the bending moment, stiffness and shear capabilities of FRP laminates and stiffeners may be derived either by testing of representative samples using the appropriate ISO or ASTM test standards or by calculation or by a combination of the two.

Table C.1 — Examples of test standard references and specific tests

1-Examples of test standards
Tensile properties: ISO 527-4, ISO 527-5
Flexural properties: ISO 178
Compressive properties: ISO 14126
Inplane shear properties: ISO 14129
Interlaminar shear stress: ISO 14130
Through-thickness « flatwise » tensile properties: ASTM D7291
2-General application of the above standards
Where an International Standard does not exist, a national standard may be used instead. The number of samples to be tested shall be as laid down in international or national standards but shall not be less than five samples for any given property.
When determining the flexural strength, the gel coat side of the specimen shall be stressed in tension.
Unless specifically stated in the test standard, the mechanical properties used in the calculations shall be corrected from test values as follows: — for strength 90 % of the mean ultimate strength or the mean value minus two standard deviations whichever is the lesser; — for elastic modulus, the mean value.

Table C.1 *(continued)*

3-Alternative method for testing compression strength of UDs
It is often difficult to apply ISO 14126, particularly for carbon-based UD
An alternative method based on four-point bending tests can be used to measure compressive stress of unidirectional composites (glass, carbon fibres).
Comparing to « pure » compressive tests (ISO 14126), the advantages of four-point bending tests are the followings: — sample geometry (no end tabs, tolerances); — common tooling's; — adapted for thick laminates; — possibility to measure ultimate compressive stress of unidirectional layers inside real scantlings.
In order to prevent early damages under load points, bi-axial layers (0/90 or +−45) on sample facings and load tabs can be used.
Sample failures are validated when the failure occur at the upper face between the 2 load points.
From ply thickness measurements, an ultimate compressive strength in the UD is then calculated using the recorded force at failure.
These tests may be conducted using the specifications of ASTM D6272 standard.

As a minimum, the fibre mass fraction (ψ) shall be measured by weighing a resin-consolidated panel of known fibre mass, see Example 1. Resin ignition tests may also be used. The panels used for this purpose shall be representative of the as built quality. Where it is not practical to take suitably sized panels from the actual or previous craft, special care must be taken to ensure that laboratory made samples are representative.

Table C.2 gives the relations between the mass fraction ψ, the volume fraction ϕ, the ratio t/w and laminate density ρ.

NOTE 1 The above requirements aim at taking the appropriate steps to ensure that the mechanical capability (not simply mechanical properties, but also taking geometry into account) and properties of the as-built laminate are equal or superior to those at the design stage.

C.2.2 Topics on tests and calculation

Many CLT software consider a linear behaviour $\sigma = E \times \varepsilon$, which is not true in reality: when testing a laminate, one can see that, after an initial linear behaviour, the stress/strain plot gets curved. This is due to micro cracks or damages occurring after the failure of some, non-critical, plies.

It is practically difficult to measure ε_u real, and when the initial elastic modulus, E initial, and $\sigma_{u\ \text{test}}$ are measured, one shall take E calculation = E initial and $\varepsilon_{\text{calc}} = \dfrac{\sigma_{\text{test}}}{E_{\text{initial}}}$, see Figure C.1.

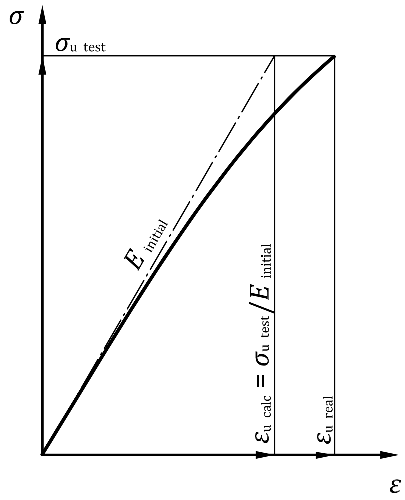

Figure C.1 — Determination of ε_u

Table C.2 — Values of t/w, composite density ρ_c according to fibre content by volume ϕ or mass ψ

$\psi = \dfrac{\phi \times \rho_f}{\phi \times \rho_f + (1-\phi) \times \rho_m}$	$\phi = \dfrac{\psi}{\psi + (1-\psi) \times \dfrac{\rho_f}{\rho_m}}$	$\dfrac{t}{w} = \dfrac{1}{\phi \times \rho_f}$
$\rho_c = \rho_f \times \phi + \rho_m \times (1-\phi)$ or $\rho_c = \dfrac{\rho_f \times \rho_m}{\rho_f + \psi(\rho_m - \rho_f)}$		$t = \dfrac{w}{\rho_f \times \rho_m}\left(\dfrac{\rho_f}{\psi} + \rho_m - \rho_f\right)$
t	Thickness of the laminate	mm
w	Dry mass of fibre	kg/m2
ϕ	Fibre content by volume in the laminate (dry fibre volume/laminate volume)[a]	1
ψ	Fibre content by mass in the laminate (dry fibre mass/laminate mass).	1
ρ_f, ρ_m	Density, respectively of fibre and matrix, may be taken from Table C.2 or from manufacturer's information	kg/m3
[a] For guidance purposes see also Table C.7.		

C.2.3 Use of flexural strain and strength

The values of flexural stresses as tested with ISO 178 or equivalent give significantly high stresses compared with tensile/compression. Reference [25] quotes $\sigma_{uf} = k_G \times \sigma_{ut} /(1 + \sigma_{ut}/\sigma_{uc})$ for GRP with k_G ranging from 2,5 to 3 according to the type of laminates, similar values for Carbon and Aramid. This high values of σ_{uf} induced that ISO 12215-5:2008 required single skin laminates using σ_f that were always thinner than the ones required by the ply by ply analysis of Annex H, using σ_t.or σ_c. However as the -thinner- laminates designed with σ_f did not prove to be underbuilt in practice, this revision document allows the use of $\pm\sigma_f$ instead of σ_t/ σ_c for the ply by ply analysis of single skin laminates in Annex H. The reason is that these laminates are likely to operate in the large deflection regime, particularly under high slam pressures. As the scantling formulas are based on the more conservative small deflection theory, the use of in plane ultimate strains may be a case of "double penalty". Sandwich panels, being stiffer are more likely to be operating within the small deflection regime and hence the use of inplane strains is appropriate. CLT theory method usually only apply σ_t/σ_c. Tables C.6 and C.9/C.10 detail the values of ε_{uf}.

C.2.4 Mechanical properties for the simplified method

The "simplified" method described in 11.2 and Table A.5 only considers Glass Reinforced Plastics (not Carbon composites). Unless derived from tests, according to C.2, the mechanical properties shall be derived from Tables C.6 to C.10. These tables do not give the values for one "thick" layer of a mixing of the plies given in Table C.6, like, for example, Mat/Roving. Clause C.4 and Table C.11 give some examples on such calculations.

C.2.5 Elastic constants using 'CLT' method (classical laminate theory)

In the 'CLT' method, the elastic constants are derived from manufacturers' fibre and resin properties for a known fibre volume content using well-established and empirically modified rule of mixtures formulas. It is not necessary to provide these formulas within the document since they are documented in the "Law of mixtures" and Classical Lamination theory (CLT). As for single skin, the flexural stress is used, it is recommended to replace the design strains ε_{ut} or ε_{uc} by $\pm\varepsilon_{uf}$ otherwise the scantlings could be conservative compared to the simplified or enhanced method.

NOTE For guidance, the Bureau Veritas or DNV-GL publications listed in the bibliography were among the source references used in developing Tables C.5 and C.6. Elastic constants of woven roving, double-bias (+45/−45), etc. may be obtained separately from the [A] submatrix by combining unidirectional plies at the appropriate orientation (a symmetrical layup being recommended to eliminate in-plane/out of plane coupling).

C.2.6 Elastic constants using 'SRM' method (simplified regression method)

For the builders or designers not wishing to use the CLT method, the simpler Simplified Regression Method (SRM) is proposed, both methods work similarly for cross plies, but treat angle plies differently, see details in C.2.5. Table C.4 shows physical and mechanical properties used in the CLT method, and Table C.5 gives the main mechanical properties of UD and of several "typical" plies/multiplies.

Table C.3 sums up the "flow chart" of the procedure to follow in either SRM/Ply stack analysis or CLT.

Table C.3 — Procedure to obtain mechanical properties and allowable bending moment and shear forces for single skin or sandwich plating

<table>
<tr><th colspan="2">STAGE 1-PLY ELASTIC CONSTANTS AND BREAKING STRAINS</th></tr>
<tr><td colspan="2">Obtained from;
Test data or Simplified regression formulas (Tables C.4 to C.8 tabulated in Tables C.9 & C.10) or Other verified formulae (Tables C.2 & C.5)</td></tr>
<tr><th colspan="2">STAGE 2-MODIFY PROPERTIES TO REFLECT BOAT BUILDING CHARACTERISTICS k_{BB} (Table 16)</th></tr>
<tr><td colspan="2">Obtained from;
Same formulas as above but modified following tests and details and by k_{BB} in Table 16</td></tr>
<tr><th colspan="2">STAGE 3-OBTAIN LAST PLY FAILURE BENDING MOMENT AND SHEAR FORCES</th></tr>
<tr><td colspan="2">For single skin laminates use σ_d = 0,5 ± σ_{uf} × k_{BB}
For sandwich laminates, depending on stress sense use σ_d = σ_{ut} or σ_{uc} or wrinkling × k_{BB}
Obtain flexural stiffness for deflection checks</td></tr>
<tr><th>OPTION 1
Annex H: Simplified laminate stack method</th><th>OPTION 2
CLT (Classical Lamination Theory)[a]</th></tr>
<tr><td>Multiply the previous design stress by k_{AM} = 0,95 for FRP according to Table 16 (Enhanced method)
Caution: the strains and stresses are along fibre</td><td>Multiply the previous design stress by k_{AM} = 1 for FRP according to Table 16 (developed method)
Caution; CLT software may not always check wrinkling, then a manual check is needed
For DBx and Qx input as angled WR combination and transformed into 1-2 system for assessment
Failures are based on any of the generally recognized failure envelope formulas.</td></tr>
</table>

Table C.3 *(continued)*

STAGE 4-OBTAIN ACTUAL vs REQUIRED LAST PLY FAILURE BENDING MOMENT AND SHEAR FORCES
Use Annex H or CLT software to find last ply failure stress (see NOTE), calculate design stress per Table 17 and find the compliance factor CF=σ design/ σ actual that shall be ≥1
[a] For sandwich check whether CLT software can obtain shear force internally (need to have transverse shear stiffness with 4 × 4 matrix) otherwise use method in Annex H for sandwich.
NOTE The last ply failure is usually the first ply failure, but this is not always the case, particularly when one mix stiff (carbon) and non stiff plies (GRP), or when using UD plies at 90° from mains stress direction. For example in a ply with 90 % UD in the sense of maximal stress and 10 % UD perpendicular to it, the transverse ply fails first but 90 % of the strength remains.

C.2.7 Final mechanical properties

This Annex proposes several methods to define the mechanical properties of the laminate, but their final values depend significantly on the “as built” quality of the material achieved by the boatbuilder. Therefore, the final "design" mechanical properties used for calculation of composites in Table 17 needs to be adjusted by the factors k_{BB} and k_{AM} defined in Table 16.

Tables C.4 to C.10 may be implemented for other fibres or matrices.

Table C.4 — Physical and mechanical properties of fibres and matrices

			Reinforcement fibres			Matrices
			E Glass	Aramid	Carbon HS	Polyester/epoxy
Specific gravity ρ (ρ_f or ρ_m)		t/m^3	2,56	1,44	1,78	1,2
Elastic modulus E (E_{f1} , E_{f2} or E_m)	E_{f1}// Fibres	N/mm^2	73 000	124 000	235 000	3 300
	E_{f2}⊥ Fibres	N/mm^2	73 000	6 900	20 000	3 300
Shear modulus G (G_f or G_m)		N/mm^2	30 000	2 800	50 000	1 222
Poisson's ratio ν (ν_f or ν_m)		1	0,22	0,36	0,27	0,32

NOTE The standard formulas in the CLT method are either exact linear (major modulus and Poisson’s ratio) or very nearly quadratic (minor modulus and shear modulus). The CLT method requires input data which may not be readily available from manufacturers, such as transverse modulus of fibre and resin Poisson’s ratio. Furthermore, there is no fixed relationship between for example modulus of polyester versus that of epoxy which holds for all commercially available resin. Consequently, the source references above together with predictions from formulas used either using Reference [24] or by the National Physical Laboratory (UK) (which include empirical correction factors) have been used for generic fibres and resin as defined in Table C.4.

Table C.5 — Formulas for UD and laminates of Tables C.6 and C.7

1-Theoretical formulas for UD			
$E_{UD1} = 0{,}975 \times \left[E_{f1} \times \phi + E_m \times (1-\phi) \right]$		$E_{UD2} = E_m \dfrac{1+\zeta \times \eta_E \times \phi}{1-\eta_E \times \phi}$ with $\zeta = 1$ and $\eta_E = \dfrac{E_{f2}/E_m - 1}{E_{f2}/E_m + \zeta}$	
$G_{UD12} = G_m \dfrac{1+\zeta \times \eta_G \times \phi}{1-\eta_G \times \phi}$ with $\zeta = 1$ and $\eta_G = \dfrac{G_f/G_m - 1}{G_f/G_m + \zeta}$		$\nu_{UD} = \nu_f \times \phi + \nu_m \times (1-\phi)$ Poisson's ratio	
$\tau_{UIL} = 22{,}5 - \dfrac{33\phi}{\phi + 0{,}89}$ interlaminar shear stress		$\nu_{UD\,21} = \nu_{UD\,12} \dfrac{E_{UD2}}{E_{UD1}}$	
The above formulas are derived from Halpin-Tsai formulas, where ϕ is the fibre content in volume, and other variables defined in Table C.4			
2-Formulas for other laminates: CSM; biaxial 0/90 (BD+); double bias ±45 (DB×), and quadriaxial (Q×)			
Except for *E* glass chopped strand mat, the formulas apply to any "building" FRP fibre (Glass, carbon, Aramid, etc.)			
Material	Young's modulus	Shear modulus	Major Poisson's ratio
E Glass Chopped strand mat	$E_{CSM} = 3/8\ E_{UD1} + 5/8\ E_{UD2}$	$G_{CSM} = 1/8\ E_{UD1} + 1/4\ E_{UD2}$	$\nu_{CSM} = E_{CSM}/2\ G_{CSM} - 1$
BD+ 0/90 Biaxial or woven roving	$E_{BD+} = 0{,}5\ (E_{UD1} + E_{UD2})$	$G_{BD+} = G_{UD12}$	$\nu_{BD+} = \nu_{UD12} \dfrac{E_{UD2}}{E_{BD+}}$
DB× ±45° Double bias	$E_{DBx} = \dfrac{4E_{BD+}}{\dfrac{E_{BD+}}{G_{BD+}} + 2(1-\nu_{BD+})}$	$G_{DBx} = \dfrac{E_{BD+}}{2(1+\nu_{BD+})}$	$\nu_{DBx} = \dfrac{E_{DBx}}{4E_{BD+}} \left[\dfrac{E_{BD+}}{G_{BD+}} - 2(1-\nu_{BD+}) \right]$
Q× Quadriaxial 0/45/90/−45°	$E_{QX} = 0{,}5[A_{11} - A_{12}^2/A_{11}]$	$G_{QX} = 0{,}5\ (G_{BD+} + G_{DBx})$	$\nu_{QX} = A_{12}/A_{11}$
with $A_{11} = \dfrac{E_{BD+}}{1-\nu_{BD+}^2} + \dfrac{E_{DBx}}{1-\nu_{DBx}^2}$ and $A_{12} = \dfrac{\nu_{BD+} \times E_{BD+}}{1-\nu_{BD+}^2} + \dfrac{\nu_{DBx} \times E_{DBx}}{1-\nu_{DBx}^2}$			

C.2.8 Breaking strains — Both methods CLT or SRM

The breaking strains, to be used in Table C.8 are given in Table C.6.

Table C.6 — Breaking strains in %

Breaking strains[a] (ultimate strength/initial *E* modulus) in %			
Type of fibre & resin		E Glass & polyester	HS Carbon & epoxy
$\varepsilon_{ufi} = k_G\, \varepsilon_{uti}/(1 + \varepsilon_{uti}/\varepsilon_{uci})$ with i = 1 or 2 and k_G[b]= 2,50 or 2,94, see columns 3 and 4.		k_G = 2,50	k_G = 2,94
Unidirectional quoted "UD"	ε_{ut1}	1,90	1,00
	ε_{ut2}	0,50	0,50
	ε_{uc1}	1,40	0,70
	ε_{uc2}	1,40	1,90
	ε_{uf1}[b]	2,02	1,21
	ε_{uf2}[c]	0,92	1,16
	γ_{u12}	1,70	1,50
CSM Chopped strand mat	ε_{ut}	1,35	Not applicable
	ε_{uc}	1,70	
	ε_{uf}[b]	1,88	
	γ_{u12}	2,00	
WR/bidirectional 0/90° quoted" BD+"	ε_{ut}	1,55	1,00
	ε_{uc}	1,40	0,70
	ε_{uf}[b]	1,84	1,21
	γ_u	1,70	1,40
Double bias ±45 quoted "DB×"°	ε_{ut}	1,06	0,77
	ε_{uc}	1,02	0,75
	ε_{uf}[b]	1,30	1,12
	γ_u	1,80	1,02
Quadriaxial 0/45/90/_45 quoted "Q×"°	ε_{ut}	1,30	0,92
	ε_{ut}	1,20	0,74
	ε_{uf}[b]	1,56	1,21
	γ_u	1,70	1,02

[a] Design strain (%) = 0,5 × breaking strain. Design stress= 0,5 × Associated modulus × breaking strain/100 Associated modulus means use E_{UD2} with ε_{UC2} to obtain compressive strength perpendicular to fibres for a unidirectional, G_{BX} with γ_U to obtain the shear strength for a biaxial, etc.

[b] The experimental factor k_G is proposed by Green in Reference [25] to correlate flexural strain with tensile and compressive strains in the fibre direction for UD and generally in composites.

[c] The value in b above has been applied to transverse strains on UD, but this is pending validation, σ_{uf2} being anyway << σ_{uf1}.

NOTE Table C.6 is based on published values in two classification rules, ISO 12215-5:2008 and data supplied by industry.

NOTE Tables C.6, C.7, C.9 and C.10 are only computed for *E* glass/polyester and *HS* Carbon/epoxy. Other building fibres (Other type of glass or carbon, Aramid, etc) or resins may be used provided documented values are used.

C.2.9 Practical use of CLT & SRM methods

C.2.9.1 Preliminary

When using the CLT method, panel coordinate system strains (ε_x, ε_y and γ_{xy}) are transformed into individual ply coordinate system strains (ε_1, ε_2 and γ_{12}) and hence a double-bias cloth is transformed into a WR/BD+ and the above strains may be used.