Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology № 88, 2014: 14-22
(Ann. WULS - SGGW, For. and Wood Technol. 88, 2014)

Bending and Tension Strength Classes in European Standards

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Abstract: The current strength classification system for softwood in Europe is based on bending properties (C classes). To optimize the efficient use of timber, especially for engineered timber products, an additional strength class system based on tension properties (T classes) was defined and will be included in the next revision of EN 338. The strength profiles of both strength classes are compared. Today there are grading methods available which are optimized for both strength class systems.

Keywords: bending, tension, strength class system

INTRODUCTION

Timber for structural use is graded into strength classes. In order to stay versatile and affordable, the European strength class system is based on only three grade determining properties: strength (MOR) ($f_{m,k}$), modulus of elasticity (MOE) parallel to the grain ($E_{0,mean}$) and density (ρ_k). All other structural properties needed for the design of timber structures are derived by empirical formulas from these primary properties [Steiger et.al. 2010]. For safety reasons, the formulas for those derived properties were defined conservatively..

The strength class system for softwood (C classes) given in the current European standard EN 338:2009 is based on edgewise bending properties. Tension strength parallel to grain ($f_{t,0,k}$) is derived from bending strength by the formula $f_{t,0,k} = 0.6\ f_{m,k}$. Strength classes based on tension properties are included in the draft prEN 338:2013 (T classes) and new formulas to derive the other structural properties in the draft prEN 384:2013. This paper aims to clarify the differences between these two approaches and highlight implications for strength grading.

STRENGTH CLASS SYSTEM

Civil engineers need a full strength profile for their calculations. For reasons of simplicity, strength classes are defined by testing only the most important properties and the other properties are derived by empirical formulas.

In Australia and New-Zealand a stress grade is defined in AS/NZS 1748.2:2011 by five properties: bending modulus of elasticity, bending strength, tension strength parallel to grain, compression strength parallel to grain and bending shear strength. During qualification of a grading method, the tension/bending ratio is established to allow to do the ongoing verification according to AS/NZS 4490:2013 on only one of those two strength properties.

In North America WCLIB requires four properties for MSR graded lumber: bending modulus of elasticity, bending strength, tension strength parallel to grain and density (specific gravity). In ASTM D1990:2014 formulas for visually graded timber are given in order to estimate tension strength from bending strength and vice versa in the event that they are not both derived by destructive tests. Those formulas were developed from large datasets of several North American commercial species groups (Table 1).

Table 1. Formulas to derive bending and tension strength (according ASTM D1990:2014)

Based on		**edgewise bending**	**tension**
Strength properties in N/mm²			
Bending	$f_{m,k}$	given	**1.2 $f_{t,0,k}$**
Tension parallel	$f_{t,0,k}$	**0.45 $f_{m,k}$**	given

In WCLIB Technical Report No. 2 (2003) the tension/bending ratio for machine graded timber was published for species groups (Spruce-Pine-Fir, Douglas Fir, Hem-Fir) from the Western United States (min: 0.50, avg: 0.70, max: 1.01). DeVisser and Galligan (2005) found the tension/bending ratio for Pine and Spruce from Central Europe (min: 0.46, avg: 0.64, max: 0.83). The variability of the tension/bending ratio between different data sets was very high. The conclusion was to test both properties at the time of qualification in order to establish higher ratios than in ASTM D1990.

In Europe a strength class is defined in EN 338:2009 by only three primary properties: bending strength, bending modulus of elasticity and density. Currently in both EN 338:2009 Annex A and EN 384 Clause 6.2 formulas are given to calculate the other properties including tension strength by the tension/bending ratio ($f_{t,0,k}/t_{m,k}$) of 0.6. This approach is considered conservative and therefore not the most efficient for products where the tension strength is more important than the edgewise bending strength. Over the last decade, additional strength classes were defined based on tension properties to optimize the use of timber for several engineered wood products (glued-laminated-timber, cross-laminated-timber, flanges for I-joists, wood trusses): L classes, LS classes, LD classes were published in EN 14081-4:2009 and T classes in EN 14080:2013. Because a full strength profile with all necessary properties is not currently available, the use of those strength classes is currently limited to applications "where tensile strength controls the design" (EN 14081-4:2009) and boards and planks for glued-laminated-timber (EN 14080:2013). Table 5 compares the grade determining properties for the different strength class systems. For the C classes the tension strength values are given.

CEN/TC124 recognized the need to standardize strength classes based on tension properties and provide full strength profiles. In the draft prEN 338:2013 an additional table was added with grade determining properties identical to the T classes in EN 14080:2013. The class names in the current draft was called CT classes (as an alternative to C classes) to be able to add in a second step of DT classes for hardwoods (as an alternative to D classes). It is expected that those new classes will be renamed back to T classes to avoid confusion in practice.
More important than the name are the formulas to calculate a full strength profile. In draft prEN 384:2013 the proposal given in Table 2 was published. Compression strength perpendicular to grain and mean density are derived from characteristic density and are equal for both systems. Different formulas are given for values derived either from bending or tension strength.
For compression strength parallel to grain the formula for tension is derived from the existing formula for bending by inserting $f_{t,0,k} = f_{m,k} / 0.6$:

$$f_{c,0,k} = 4.2\, {f_{m,k}}^{0.5} = 4.2\left(\frac{f_{t,0,k}}{0.6}\right)^{0.5} = 4.2\left(\frac{1}{0.6}\right)^{0.5} {f_{t,0,k}}^{0.5} = 5.42\, {f_{t,0,k}}^{0.5} \sim 5.5\, {f_{t,0,k}}^{0.5}$$

Shear strength in the current standard EN 338:2009 is given in the tables below and based on testing results on Spruce by Denzler and Glos (2006). Contrary to the basic principle of a strength class system, shear strength is not derived from one of the grade determining properties. According to the current standard EN 384:2010 for other strength classes, shear strength is taken from EN 338:2009 for the “most appropriate” bending strength. For higher strength classes the shear strength is a constant 4 N/mm^2, as test results justified higher characteristic values in higher strength classes. In the current revision process a straight line was fitted to the data for bending strength below 24 N/mm^2 ($f_{v,k} = 1.6 + 0.1\ f_{m,k}$) and tension strength below 14 N/mm^2 ($f_{v,k} = 1.2 + 0.2\ f_{t,0,k}$).

Table 2. Formulas to derive properties from grade determining properties (according prEN 384:2013)

Equation valid for		**C classes**	**T classes**
Based on		**edgewise bending**	**tension**
Strength properties in N/mm^2			
Bending	$f_{m,k}$	given	**$1.25\ f_{t,0,k}$**
Tension parallel	$f_{t,0,k}$	**$0.6\ f_{m,k}$**	given
Tension perpendicular	$f_{t,90,k}$	0.4	0.4
Compression parallel	$f_{c,0,k}$	$4.2\ (f_{m,k})^{0.5}$	$5.5\ (f_{t,0,k})^{0.5}$
Compression perp.	$f_{c,90,k}$	$0.007\ \rho_k$	$0.007\ \rho_k$
Shear	$f_{v,k}$	$f_{m,k} \leq 24$: $1.6 + 0.1\ f_{m,k}$ $f_{m,k} > 24$: 4.0	$f_{t,0,k} \leq 14$: $1.2 + 0.2\ f_{t,0,k}$ $f_{t,0,k} > 14$: 4.0
Stiffness properties in kN/mm^2			
Mean MOE parallel	$E_{m/t,0,mean}$	given	given
Char. MOE parallel	$E_{m/t,0,k}$	$0.67\ E_{m,0,mean}$	$0.67\ E_{t,0,mean}$
Mean MOE perp.	$E_{m/t,90,k}$	$E_{m,0,mean}/30$	$E_{t,0,mean}/30$
Mean shear values	G_{mean}	$E_{m,0,mean}/16$	$E_{t,0,mean}/16$
Density in kg/m^3			
Char. density	ρ_k	given	given
Mean density	ρ_{mean}	$1.2\ \rho_k$	$1.2\ \rho_k$

BENDING AND TENSION STRENGTH

If only bending or tension strength is tested, the other property is a conservative estimate. Therefore it is not possible to calculate bending strength from tensile strength by using the reciprocal value of 0.6: $f_{m,k} = 1/0.6\ f_{t,0,k} = 1.67\ f_{t,0,k}$. In the current revision process, the proposal is to use the reciprocal value of 0.8 to get a safe estimate: $f_{m,k} = 1/0.8\ f_{t,0,k} = 1.25\ f_{t,0,k}$. As a consequence the strength profiles are different if they are defined either by bending or tension strength. In Table 3 a comparison is shown between C classes and T classes with identical tensile strength. All calculated values are equal (when rounding to the same accuracy as in the draft standard) except density for high strength classes (by definition) and bending strength. Bending strength in T classes is about 25% lower than in C classes.

Table 3. Comparison between C classes and T classes with equal tensile strength (given values in gray)

	C16	T10	C18	T11	C24	T14	C30	T18	C35	T21	C40	T24
$f_{m,k}$	16	13	18	14	24	18	30	23	35	26	40	30
$f_{t,0,k}$	10	10	11	11	14	14	18	18	21	21	24	24
$f_{c,0,k}$	17	17	18	18	21	21	23	23	25	25	27	27
$f_{v,k}$	3.2	3.2	3.4	3.4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
$E_{m/t,0,mean}$	8000		9000		11000		12000		13000		14000	
ρ_k	310		320		350		380		400	390	420	400

MODULUS OF ELASTICITY IN BENDING AND TENSION

prEN 338:2013 and prEN 384:2013 distinguish for the modulus of elasticity parallel to grain between bending and tension:

- prEN 338:2013 Table 1: $E_{m,0,mean}$, $E_{m,0,k}$ and $E_{m90,mean}$ (defined by bending)
- prEN 338:2013 Table 2: $E_{t,0,mean}$, $E_{t,0,k}$ and $E_{t90,mean}$ (defined by tension)
- prEN 384:2013 Table 2: $E_{m,0,k}$, $E_{m90,mean}$, G_{mean} are derived from $E_{m,0,mean}$ (bending) and $E_{t,0,k}$, $E_{t90,mean}$, G_{mean} are derived from $E_{t,0,mean}$ (tension)

Even if the same values are given for a class in both strength class systems, it may not be possible to consider them as physically equal. Bacher and Krzosek (2013) confirmed the results of Burger and Glos (1995) that the MOE in bending is higher than MOE in tension. According to EN 14080:2013 Table 1 Footnote a) C classes according to EN 338 meet the requirements of the respective T classes ($E_{t,0,mean} = E_{m,0,mean}$). When applying the ratio of 1.09 between (local) bending MOE and tension MOE, it is shown in Table 4 that the difference will be in the same order as between neighboring strength classes. C24 with an average bending MOE of 11000 N/mm^2 will only have an average tension MOE of 10090 N/mm^2, which does not fulfill the requirements of T14, but only of T13. As modulus of elasticity typically is not related to the structural safety, but to the performance of a building (fitness for purpose), equality between them is perhaps assumed for reasons of simplicity.

Table 4. Comparison between C classes and T classes with equal tensile strength (given values are shown in gray)

C class	$E_{m,0,mean}$	$E_{m,0,mean}/1.09$	$E_{t,0,mean}$	T class
C22	10000	9170	10000	T13
C24	11000	10090	11000	T14
C30	13000	11930	13000	T18
C35	14000	12840	14000	T21

STRENGTH GRADING AND PRACTICAL IMPLICATIONS

In strength grading the influence of knots on strength depends on its intended use (edgewise bending or tension). Therefore optimized machine settings were developed for machine grading and in some countries also optimized visual grading rules for different applications.

In INSTA 142:2009 used in Nordic countries are defined three different grading rules:

- T3, T2, T1, T0 grades (timber for general use, d > 45 mm, b > 75 mm)
- T3, T2, T1, T0 grades (small sizes: d ≤ 45 mm, b ≤ 75 mm)
- LT40, LT30, LT20, LT10 grades (d < 50 mm, for glued laminated timber)

In DIN 4074-1:2012 used in Central Europe three different grading rules are defined for three different types of structural timber:

- Joists (timber for general use, tested in edgewise bending)
- Boards and Planks (timber loaded in flatwise bending or tension)
- Battens (small sizes: d ≤ 40 mm, b < 80 mm)

Currently only visual grades using the rule for joists (S7, S10, S13) are assigned to a strength class (C class) in EN 1912:2012+AC:2013. This assignment of visual grades to strength classes is also applicable for boards and planks graded “as joist” (S7K, S10K, S13K). Boards and planks are graded “as joist” if they are intended to be used in edgewise bending. Timber graded “as board and plank” is optimized for tension loading and therefore preferably assigned to a tension strength class (T class) based on a report according EN 384:2010. An overview for the possible assignments of visual grades according to DIN 4074-1 to strength classes is given in Table 5.

It is crucial to distinguish if a board was graded S10 “as joist” or “as board”. A board graded S10 “as joist” is assigned to C24 and a board graded S10 “as board” to T14, as the strength profiles are different. The difference in bending strength (24 N/mm^2 vs 18 N/mm^2) is of most relevance.

Table 5. Possible assignments of visual grades according DIN 4074-1 to strength classes

Product type	Graded	Visual grade name	Strength classes
Joist	"as joist"	S7, S10, S13	C classes (EN 1912)
Board and plank	"as joist"	S7K, S10K, S13K	C classes (EN 1912)
Board and plank	"as board and plank"	S7, S10, S13	T classes (EN 384)

In Poland timber is visually graded according to PN-D-94021:2013 in the visual grades KW, KS and KG. Knot measurements are done by the KAR (knot-area-ratio) method considering total and marginal knots optimized for edgewise bending tests. The grades were assigned based on edgewise bending tests to strength classes in PN-EN 1995-1-1:2010 Table NA.2.

For machine graded timber machine settings are available to grade spruce and pine grown in Poland both to C classes and T classes in the latest CEN TC124 TG1 Initial Type Testing (ITT) reports for MiCROTEC grading machines.

Boards are used for the production of cross-laminated-timber (CLT). As the harmonized European standard FprEN 16351:2013 is not yet available and applicable, CLT is currently produced based on a European Technical Approval (ETA). All ETAs specify to use strength graded boards:

- DIBt, Berlin, Germany (ETA-06/0009, ETA-08/0271, ETA-10/0241) Table 1 (Dimensions and specifications of the elements): "Strength class according to EN 338"
- OIB, Vienna, Austria (ETA-06/0138, ETA-09/0036, ETA-12/0281) Table 1 (Dimensions and specifications): "Boards shall be graded with suitable visual and/or machine procedures to be able to assign them to the strength classes according to EN 338."

For the verification of the mechanical resistance and stability in Table 2 of the above ETAs, the characteristic strength and stiffness values according to EN 338 are used. Currently in EN 338:2009 C-classes are given based on edgewise bending tests. Therefore currently all ETAs formally require boards with a strength profile defined by EN 338. User defined strength profiles are not permitted. For calculations in the design process, civil engineers will use the bending strength value of the declared strength class (typically C24: $f_{m,k}$=24 N/mm^2). If the boards used for CLT were graded and assigned to the tension strength class, the full strength profile needed in the design process is not yet available. When using the strength profile proposed in prEN 384:2013, the bending strength value of the declared strength class (typically T14: $f_{m,k}$=18 N/mm^2).is lower than for the corresponding C-class

FprEN 16351:2013 requires the use of strength graded boards according to EN 14081-1:2009+A1:2011. Requirements on the strength profile are not given. In the examples of marking both bending (C classes) and tension (L classes) strength classes are shown. The future will show what will be accepted by the market.

CONCLUSIONS

Strength profiles defined on bending and tension are similar, but differ significantly regarding the bending strength. The use of tension strength classes is recommended, when tensile strength limits the design and lower values for bending strength are acceptable. This is definitely the case for glued-laminated-timber beams and I-joists. For cross-laminated-timber it depends strongly on the intended use whether the bending strength or the tension strength is limiting the design. Both visual and machine grading methods can optimized for the intended use to provide the best yields and performance.

Table 5. Comparison of available strength class systems regarding tension properties

L classes				LS classes				LD classes				T classes				C classes			
Class	$f_{t,0,k}$	$E_{0,mean}$	ρ_k	Class	$f_{t,0,k}$	$E_{0,mean}$	ρ_k	Class	$f_{t,0,k}$	$E_{0,mean}$	ρ_k	Class	$f_{t,0,k}$	$E_{0,mean}$	ρ_k	Class	$f_{t,0,k}$	$E_{0,mean}$	ρ_k
												T8	8	7000	290	C14	8	7000	290
												T9	9	7500	300				
L16	10	8000	310									T10	10	8000	310	C16	10	8000	310
L17	11	9000	320	LS11	11	9000	N/D	LD11	11	9000	320	T11	11	9000	320	C18	11	9000	320
												T12	12	9500	330	C20	12	9500	330
L23	13	10000	345									T13	13	10000	340	C22	13	10000	340
L24	14	11000	350									T14	14	11000	350	C24	14	11000	350
L25	14.5	11000	350	LS15	14.5	11000	N/D	LD15	14.5	11000	350	T14.5	14.5	11000	350				
												T15	15	11500	360				
												T16	16	11500	370	C27	16	11500	370
L30	18	12000	380	LS18	18	12000	N/D	LD18	18	12000	370	T18	18	12000	380	C30	18	12000	380
L35	21	13000	400									T21	21	13000	390	C35	21	13000	400
L36	22	13000	400	LS22	22	13000	N/D	LD22	22	13000	390	T22	22	13000	390				
												T24	24	13500	400	C40	24	14000	420
L40	26	14000	420	LS26	26	14000	N/D	LD26	26	14000	410	T26	26	14000	410				
L45	27	15000	440									T27	27	15000	410	C45	27	15000	440
												T28	28	15000	420				
												T30	30	15500	430	C50	30	16000	460

Notes:

- L classes were defined by the machine producer MiCROTEC in cooperation with Technical University Munich (TUM) for the optimized production of glulam. The definition started from the tension properties of C classes and for some strength classes considered the higher requirements in EN 1194:1999: L25, L36, L40. For glulam according to the German standard DIN 1052:2008 Table F.10 it is permitted to use the strength classes L16, L24, L30, L35 and L40. For L17 the name L18 would have been more appropriate. The density of 345 kg/m^3 for L23 is slightly higher than for C22 to guarantee the density requirement of GL28c of 380 kg/m^3.
- LS classes and LD classes are based on EN 1194:1999 Table B.1. For LS classes the density values are not taken into account (N/D: not defined) when calculating machine settings or assigning visual grades, because according to the first footnote the density values are indicative properties. LD classes take the density values into account to be able to apply the calculation method to get the density of glulam according to EN 1194:1999 Table A.1 ($\rho_{g,k} = 1.1\ \rho_{g,k}$).
- T classes were defined based on all existing strength classes with the goal of considering everything already in use throughout Europe. For high strength classes (≥T21) the density requirement was reduced to better match the Spruce resource and therefore increase the yield. A higher density may be necessary to fulfil the strength requirements for finger-joints ($f_{m,j,k}$).

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STANDARDS

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Streszczenie: *Klasy wytrzymałości tarcicy w normach europejskich oparte na zginaniu i rozciąganiu.* Aktualny system klas wytrzymałościowych dla drewna iglastego w Europie (klasy C) bazuje na właściwościach drewna przy zginaniu. W celu optymalizacji efektywnego użycia drewna, szczególnie w drewnianych wyrobach inżynierskich, zdefiniowano dodatkowy system klas wytrzymałościowych bazujący na właściwościach drewna przy rozciąganiu (klasy T). System ten będzie uwzględniony w kolejnej nowelizacji normy EN 338. W referacie porównano oba systemy klas wytrzymałościowych. Aktualnie dostępne są urządzenia do sortowania tarcicy według obu systemów klas wytrzymałościowych: C i T.

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