Visual Grading and Structural Properties Assessment of Large Cross-Section *Pinus radiata* D. Don Timber

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The use of large cross-section timber for structural purposes has increased in Spain, and knowledge of its properties is strategically necessary. The Spanish visual strength-grading standard UNE 56544 (2011) efficiency applied to large cross-section structural timber was analyzed using a sample of 363 specimens of radiata pine (*Pinus radiata* D. Don.) from the Basque Country and Catalonia, Spain. Different sizes were tested (80 × 120 × 2400 mm^3, 150 × 250 × 5600 mm^3, 150 × 250 × 4300 mm^3, and 200 × 250 × 5000 mm^3). Bending strength, modulus of elasticity, and density were obtained, and characteristic values were determined in order to assign strength class according to European standard EN 338 (2010). Knots and twists were the most relevant singularities for visual strength grading. It was concluded that large cross-section Spanish radiata pine timber was suitable for structures, and it was assigned to the C20 strength class.

Keywords: Characterization; Singularities; Bending strength; Modulus of elasticity; Density; Pinus radiata

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INTRODUCTION

According to Spanish Forest Inventory data (IFN3 2007), the area occupied by radiata pine is 4.4% of the total of Spanish coniferous wood (287,771 ha), although it is the most widely used coniferous tree in forest plantations in this country. It is found mainly in Northern Spain in Basque Country (2.3%), Galicia, Cantabrian, and Catalonia. This species amounts to 25% (1,552,850 m^3) of total lumber production. There is a strong industrial sector based on wood transformation, and particularly its use as a structural timber, which improves the economic profitability of sawmills and forest owners.

Most research on the structural properties of timber from Spanish species has been on specimens up to 200 × 70 mm^2 in cross-section. These studies included *Pinus pinaster* (Aiton) (Ortiz *et al.* 1990), *Pinus radiata* (D. Don) (López de Roma *et al.* 1991; Ortiz and Martínez 1991), *Pinus sylvestris* (L.) (Fernández-Golfín *et al.* 1997; Hermoso 2001; Hermoso *et al.* 2003), and *Pinus nigra* subsp. salzmannii (Dunal) Franco (Fernández-Golfín *et al.* 2000; 2001; Conde 2003). However, most structural uses of sawn timber in Spain use larger cross-sections than those studied.

The influence of specimen dimensions on mechanical properties has been covered in several studies (Rosowsky and Fridley 1997; Fernández-Golfín *et al.* 2002; Hermoso *et* *al*. 2002; Morel *et al.* 2002; Íñiguez 2007; Montón 2012; Hermoso *et al.* 2013), but it is unclear whether variation in mechanical properties is due to depth, width, or both (Newlin and Trayer 1924; Curry and Tory 1976; Madsen 1992; Böstrom 1994; Fernández-Golfín *et al*. 2002). Generally, strength decreases as the volume of a specimen increases, as a consequence of higher fragility (Morel and Valentin 1996). As a result, standards set reference values (a depth of 150 mm) to define timber properties. It is therefore necessary to characterize large cross-section timber of the species used the most in construction.

Based on the research of Íñiguez (2007), the new edition of the Spanish visual strength grading standard incorporates new specifications for large cross-section timber, namely quality MEG (madera estructural de gran escuadría, *i.e*., large cross-section structural timber).

This work evaluated the efficiency of the current version of the Spanish visual grading standard (UNE 56544 2011) for radiata pine MEG and characterized mechanical properties to assign visual quality to a strength class according to EN 338 (2010).

EXPERIMENTAL

Materials

A total of 363 specimens of *Pinus radiata* D. Don large cross-section structural sawn timber were assessed. They were supplied, dried, and planed from several sawmills to represent the sources and variability of this Spanish species. Radiata pine timber is being supplied from managed forests, where usually it is logged every 32 to 35 years, with the application of silvicultural techniques.

Table 1 shows the number of specimens, cross-sections, average length, mean and coefficient of variation (COV) of moisture content, and the source of each sample. The final moisture content of the sample was 8% to 18% according to EN 384 (2010).

Table 1. Sample Characteristics

Sample	No. of specimens	Cross-section (mm)	Average length (m)	Moisture content (%)		Source
				Mean	COV	
A	148	80 ×120	2.40	10.5	6.5	Catalonia
B	75	150 × 250	5.60	14.4	11.5	Basque Country [1)]
C	70	150 × 250	4.30	10.5	11.0	Basque Country [2)]
D	70	200 × 250	5.00	10.8	11.1	Basque Country [2)]
Total	363					

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Methods

The Spanish standard UNE 56544 (2011) establishes three visual grades: ME-1, ME-2, and MEG. ME-1 and ME-2 are for small cross-section pieces, *i.e*., pieces with a thickness less than or equal to 70 mm, and the MEG grade is for pieces thicker than 70 mm (large cross-section pieces).

The Spanish standard sets a thickness of 70 mm as the threshold between small and large cross-section pieces because the mechanical properties of Spanish species were obtained, until approximately 2003, from tests carried out on pieces with a thickness equal to or less than 70 mm. Therefore, small cross-section mechanical properties could not be assigned to large cross-section pieces. Since 2004, large cross-section timber has been included in testing campaigns in Spain, due to the increasing use of these sawn timber sizes for structural purposes. The samples analyzed in this work were visually graded according to MEG specifications (thickness greater than 70 mm), as shown in Table 2.

Table 2. Specifications for MEG Visual Grading of Structural Coniferous Sawn Timber with Thickness Greater Than 70 mm in Accordance With UNE 56544 (2011)

Specifications		MEG
Face knot diameter (d):		d≤2/3 of “h”
Edge knot diameter (b):		d≤ 2/3 of “b”
Maximum width of annual ring(1): *Pinus sylvestris* L. *Pinus nigra* Arn. *Pinus pinaster* Ait. *Pinus radiata* D. Don		 Unlimited Unlimited Unlimited Unlimited
Fissures:	Seasoning checks(2),(3) Other types	f≤ 3/5 Not accepted
Ring shakes:		Not accepted
Resin and bark pockets:		Accepted if its length is ≤ 1.5·”h”
Compression wood:		Accepted 2/5 of the cross-section
Slope of grain:		1:6 (16.7%)
Wane:	Length Width and thickness	≤1/3 of “L” G≤1/3
Pith(1):		Accepted
Biological damage:	Mistletoe Blue stain Fungi decay Insect’s galleries	Not accepted Accepted Not accepted Not accepted
Distortions(4):	Bow Spring Twist Cup	≤ 20 (10) mm over a length of 2 m ≤ 12 (8) mm over a length of 2 m ≤ 2 (1) mm per 25 mm width over a length of 2 m Unlimited

(1) These specifications are considered when wet timber is commercialized.
(2) These specifications are not considered in wet grading.
(3) Referred to 20% MC. Seasoning checks only will be measured if their length is greater than the smallest of the following values: 1/4 of “L” or 1 m
(4) Values in brackets are the limitations for strength classes above C18.

b: thickness, h: width, L: length

According to EN 408 (2011), to determine modulus of elasticity and bending strength, pieces were tested simply supported and symmetrically loaded in bending at two points over a span of 18 times the depth. Load was applied at a constant rate, and deformation was measured at the centre of the span and from the centre of the tension edge. The density of the test pieces was determined on a full cross section slice, free from knots and resin pockets and it was cut as close as possible to the fracture zone.

The characteristic values of former properties were required to assign strength class according to EN 338 (2010). To determine these characteristic values, EN 384 (2010) was used to establish the following parameters, all measured in N/mm^2: f_m, bending strength; f_{mean}, sample mean value of strength; f_{SD}, standard deviation of strength; f_{05}, sample 5-

percentile value of strength; and *Adjusted* f_{05}, k_h adjusted sample 5-percentile value of strength.

Bending strength was adjusted to the 150 mm depth by dividing by the factor k_h (Eq. 1),

$$k_h = \left(\frac{150}{h}\right)^{0.2} \qquad (1)$$

where when h = 120, k_h = 1.046, and when h = 250, k_h = 0.903.

The span factor, k_l, was determined when the bending test arrangement was not specified in EN 408 (2011) (*i.e.*, span, l, is 18 h and the distance between inner load points, a_f, is 6 h). The bending strength was adjusted by dividing by the factor k_l (Eq. 2),

$$k_l = \left(\frac{48h}{l_{et}}\right)^{0,2} \qquad (2)$$

where $l_{et} = l + 5a_f$; a_f and l have the respective values for the test. In this study k_l = 1 *y* k_{l1} = 1.01 (where l_1 = 16 *h*).

The characteristic value of strength f_k (N/mm^2) was obtained by applying also the k_s factor according to the number and size of samples and k_v factor according to type of grading used (mechanical or visual), where k_s = 0.95 and k_v = 1.0 in this case.

The bending modulus of elasticity of the sample was determined through the following parameters, all in N/mm^2 and adjusted to 12% moisture content: E_{mean}, mean value of modulus of elasticity; E_{SD}, standard deviation of modulus of elasticity; and $E_{0,mean}$, mean characteristic value weighted according to the number of specimens in each sample. The last parameter included an adjustment to pure bending modulus of elasticity, as determined by Eq. 3:

$$E_{pure} = 1.3 * E_{mean} - 2690 \qquad (3)$$

Finally, the characteristic value of global density ρ_k, in kg/m^3 was determined and adjusted to 12% moisture content, weighted according to the number of specimens in each sample and using ρ_{05}, 5-percentile value of global density distribution.

One of the more relevant singularities in visual grading is knottiness (see Fig. 2), which was evaluated by a simplified parameter known as concentrated knot diameter ratio (CKDR) (Divos *et al*. 2005).

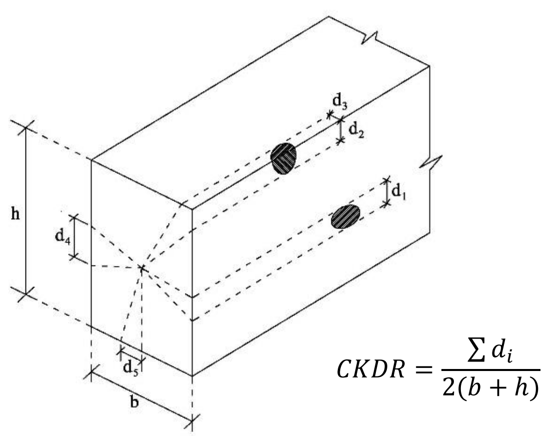

Fig. 2. Concentrated knot diameter ratio

The knot diameter ratio (KDR) is the knot diameter divided by the depth or width of the piece. The CKDR is the sum of the KDRs of the knots existing in any 15 cm length of timber without overlapping. The maximum CKDR, which includes all four faces, represents the quality of the piece (Fig. 2). This value of CKDR is obtained for the worst cross-section along the whole length of the piece.

RESULTS AND DISCUSSION

Results and Yield of Visual Strength Grading

Table 3 shows the results obtained from the application of the visual grading standard. The main causes of rejection were analyzed; Fig. 1 shows the percentage for each timber singularity considered in visual grading and for each sample.

Table 3. Specimen Number and Yield Resulting from the Application of the UNE 56544 Standard

Sample	MEG		Reject	
	Number of pieces	Percentage (%)	Number of pieces	Percentage (%)
A	78	53	70	47
B	63	84	12	16
C	53	76	17	24
D	41	59	29	41
Total	235	65	128	35

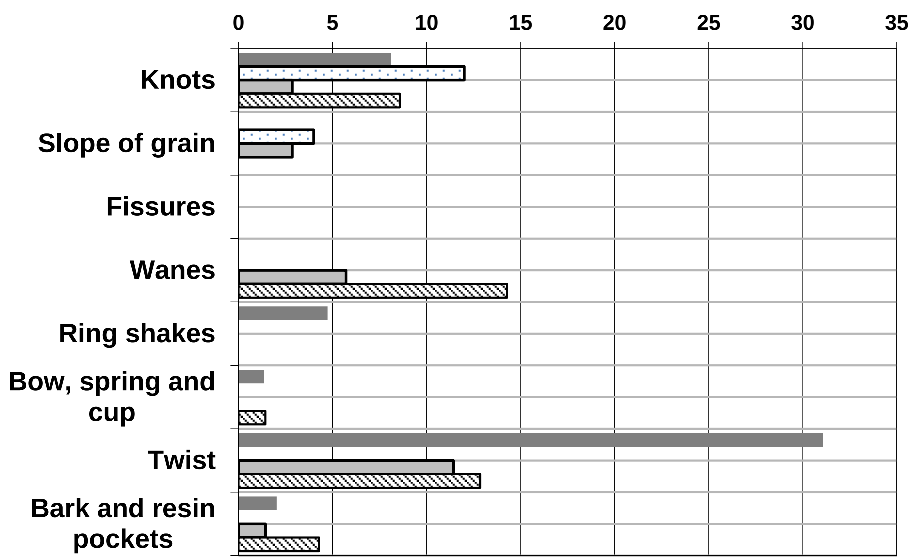

Fig. 1. Percentage of rejected specimens for each singularity for sample A (dark grey), sample B (dotted), sample C (grey), and sample D (diagonal lines)

The presence of twists in the specimens was the main cause of rejection in three of the samples studied and mainly in the smallest cross-section sample (sample A with a percentage of 31%). This singularity used to be strongly associated with juvenile wood and its offset.

This result can be explained because in large cross-section specimens it may not be possible to avoid the presence of pith (and juvenile wood associated around it) because of the sawn pattern applied to obtain this cross-section size. If pith is more or less centered in the section, then the drying stresses due to the different behavior of juvenile wood are balanced, and then twist is minimized. When cross-sections are smaller (sample A), then the sawn pattern can provide specimens with pith close to the face of the section or without it, but with juvenile wood in high proportion of the cross-section, therefore the balance is not produced and the presence of twist increases. However, this phenomenon can be avoided through careful sawing.

Furthermore, deformations and defects, especially twists, have no relevant effect on mechanical properties (Montón *et al.* 2015).

Table 4 shows the average CKDR values for each sample. It can be seen that the CKDR of MEG grade was similar for all four samples (0.27 to 0.31). Additionally, the CKDR in the rejected pieces was not far from that of MEG grade pieces in samples C and D, although in the smaller cross-section sample (A) the difference was greater.

Table 4. Average CKDR Values

Sample	MEG	Rejected
A	0.28	0.37
B	0.31	0.39
C	0.29	0.30
D	0.27	0.29

Mechanical Properties and Strength Class Assignment

Mechanical properties are shown in Table 5.

Applying visual strength grading according to standard UNE 56544 (2011), the MEG grade did not always present mechanical properties that were clearly differentiated from reject ones. The mean bending strength value of sample A was about 34% higher in the MEG grade compared with rejected specimens, while this value fell to less than 3% on average for samples B, C, and D. Similarly, the modulus of elasticity of MEG was 26% higher than the rejected pieces in sample A, and was less than 1% on average in samples B, C, and D.

These results agree with knottiness values shown in Table 4. Samples A and B showed notable differences of knottiness between MEG graded timber and rejected pieces (about 33% more in rejected pieces). On the other hand, samples C and D showed similar knottiness in MEG grade and rejected pieces (only 4% more in rejected pieces). Nevertheless, comparing mechanical properties of samples A and B, with similar knottiness differences between grades, a relevant difference can be observed: sample A showed a strong decreasing of properties in rejected pieces, but sample B showed no relevant differences between graded and rejected timber. These results are explained because the knottiness effect is tempered in bigger sections (sample B) in comparison to smaller ones (sample A).

According to the EN 338 (2010) standard, timber is assigned to a strength class if its characteristic values of bending strength and density equal or exceed the values for that strength class, and its characteristic mean modulus of elasticity in bending equals or exceeds 95% of the value for that strength class.

Table 5. Mechanical Properties

Bending Strength (N/mm^2)						
Sample	MEG			REJECT		
	No. specimens	f_{mean}	COV (%)	No. specimens	f_{mean}	COV (%)
A	78	48.8	26	70	36.4	31
B	63	30.4	29	12	27.7	19
C	53	40.8	23	17	39.7	9
D	41	39.2	27	29	41.6	16
Modulus of Elasticity (N/mm^2)						
Sample	MEG			REJECT		
	N	E_{mean}	COV (%)	N	E_{mean}	COV (%)
A	78	9921	21	70	7871	19
B	63	9825	15	12	9515	12
C	53	10933	12	17	10704	14
D	41	11046	16	29	11282	26
Density (kg/m^3)						
Sample	MEG			REJECT		
	N	ρ_{mean}	COV (%)	N	ρ_{mean}	COV (%)
A	78	526	10	70	474	11
B	63	508	8	12	497	6
C	53	508	7	17	499	4
D	41	523	7	29	546	8

The strength class assigned to the specimens of Spanish radiata pine graded as MEG was C20. This assignment was determined by strength and stiffness, while the density requirement was easily met, as is usual in Spanish coniferous timber.

Table 6 shows the mechanical characterizations for each sample. All calculations and coefficients used to obtain the characteristic values were applied in accordance with the EN 384 (2010) standard.

Table 6. Characteristic Values According to EN 384 (2010) for Large Cross-Section Radiata Pine

Sample	A	B	C	D	All
Visual Grade	MEG				
Thickness (mm)	80	150	150	200	
Depth (mm)	120	250	250	250	
Sample size	78	63	53	41	235
f_{mean} (N/mm^2)	48.8	30.4	40.8	39.2	
f_{SD} (N/mm^2)	12.7	8.9	9.4	10.6	
f_{05} (N/mm^2)	28.8	16.7	21.6	22.2	
Adjusted f_{05} (N/mm^2)	27.5	18.5	23.7	24.6	
f_k (N/mm^2)					21.1(*)
E_{mean} (N/mm^2)	9921	9825	10933	11046	
E_{SD} (N/mm^2)	2083	1499	1384	1758	
$E_{0,mean}$ (N/mm^2)	10207	10083	11523	11670	10726
ρ_{05} (kg/m^3)	448	447	455	453	
ρ_k (kg/m^3)					450

(*) The adjusted f_{05} result for all the samples was 23.72 N/mm^2, although 1.2*18.49 N/mm^2 (the minimum value of the adjusted f_{05} sample) was 22.19 N/mm^2, which was lower. Thus, the k_s adjustment factor was applied to the lower value, giving 21.1 N/mm^2.

CONCLUSIONS

1. Large cross-section of Spanish radiata pine timber for structural purposes graded as MEG (UNE 56544:2011) was assigned to strength class C20 according to the EN 338 (2010) standard.
2. Cross-section size had a relevant difference in the mechanical properties of timber pieces. Smaller cross-section pieces showed a difference in MEG grade mechanical properties compared with rejected pieces, while this difference was very small in large cross-section pieces.
3. Twist was revealed as the key singularity for the visual grading result, mainly in the smaller cross-section size.
4. Knottiness (CKDR) was high in general because of radiata pine is a whorled species, but it has different influence on mechanical properties depending on the cross-section size. For bending strength results it was indicated that in larger cross sections the influence is less than in smaller ones.

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