

Mechanical properties of structural maritime pine sawn timber from Galicia (*Pinus pinaster* Ait. ssp. *atlantica*)

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Abstract

The use of maritime pine sawn timber in structural applications requires knowledge of its mechanical properties. Standards have changed, however, since the last research on this timber was performed. In the present study, 491 beams of maritime pine from Galicia, of structural-use size but different cross-section, were tested according to these modified standards. Each beam was visually graded according to standard UNE 56.544 and subjected to a four point bending test. The strength classes assigned by the visual grades awarded suggest this material to have greater structural capacity than that currently assumed. The relationships between the modulus of elasticity, strength and density were also examined.

Key words: visual grading, strength class, mechanical characterization.

Resumen

Propiedades mecánicas de la madera estructural de pino marítimo de Galicia (*Pinus pinaster* Ait. ssp. *atlantica*)

La utilización de madera aserrada de pino marítimo con fines estructurales requiere del conocimiento de sus propiedades mecánicas. La normativa ha evolucionado desde el último estudio realizado sobre una muestra de pino marítimo de Galicia. Por ello en este estudio se han ensayado 491 vigas procedentes de Galicia, con tamaño estructural y de diferentes secciones siguiendo las modificaciones de las normas. Cada viga fue clasificada visualmente siguiendo los criterios de la norma UNE 56.544 y posteriormente se ensayaron a flexión hasta la rotura. Las clases resistentes asignadas a cada calidad visual muestran que el material tiene una capacidad mayor de la normalmente asumida. Finalmente, se obtuvieron modelos de relación entre resistencia, elasticidad, y densidad.

Palabras clave: clasificación visual, clase resistente, caracterización mecánica.

Introduction

Pinus pinaster is widely distributed across Spain, where it occupies around 1,000,000 ha. It grows in areas with different climatic conditions, which has led to the appearance of two subspecies: *P. pinaster* Ait. ssp. *atlantica* the so-called maritime pine or Galician pine, found mostly in Galicia (northwestern Spain) where conditions are damp, and *P. pinaster* Ait. ssp. *mesogeensis*, which grows in Spain's continental and mediterranean regions. Despite this wide distribution, *P. pinaster* timber for structural use is sawn only in some locations in the Province of Cuenca, the Region of Castilla and León, but mainly in Galicia (Alía *et al.*, 1996). In Gal-

icia this timber originates from land originally reforested in the 19th century. The favourable climatic conditions of the area and the good growth of the trees allow a harvesting cycle of about 35-45 years (Riesco and Díaz, 2007).

The maritime pine from Galicia is an important forest resource, with the 0.47 million ha occupied, supplying about 25% of all Spain's conifer timber (MARM, 2008). Sawmills produce beams for auxiliary functions in the construction industry, along with some products destined for structural use (Sanz *et al.*, 2006). Beams that can be marketed as structural material fetch a higher price.

Certain factors now favour the potentiation of sawn timber for structural use. Firstly, the recently introduced

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Spanish *Código Técnico de la Edificación* (CTE: Technical Building Code) highlights how to meet the requirements defined in the Spanish *Ley de Ordenación de la Edificación* (LOE; Building Planning Law). The CTE regulates the calculation of wooden structures via the *Documento Básico de Seguridad Estructural-Madera* (DB-SEM; Basic Document for Structural Safety – Wood), and in Annex C.2 shows the strength classes for the visual qualities of *P. pinaster* defined in standard UNE 56544. In the European setting, the directive concerning construction products (Directive 89/106/CEE) establishes the criteria to be met by material destined for use in construction. That which meets these criteria carries the CE sign; a level of quality demanded of all sawn structural timber as of September 2009. Secondly, the market is becoming conscious of the need to protect the environment and to meet the obligations of the Kyoto Protocol via the use of materials and technologies that cause no pollution during manufacture, use or recycling. Not only do trees not emit greenhouse gases, they actually fix and immobilize atmospheric CO₂, and are by their nature an ecological material, unlike others commonly used in construction. Finally, research has shown that *P. pinaster* wood can be successfully glued and can undergo protective treatments (Lázaro, 2007). It shows good qualities for use in engineered timber products such as glued laminated timber, DUOS or TRIOS, and the ease with which it can be impregnated makes it ideal for exterior use (service class 3) (Sanz *et al.*, 2006).

The characterisation of timber mechanical properties has now been going on for some 20 years. Around 15,000 beams of structural size from Spanish pines have been tested in order to determine their characteristic values and assign a strength class for each visual grade. Studies have been made on *Pinus radiata* (Ortiz and Martínez, 1991; López de Roma *et al.* 1991), *Pinus sylvestris* (Fernández-Golfín *et al.* 1997; Hermoso, 2001; Hermoso *et al.*, 2003) and *Pinus nigra* (Fernández-Golfín *et al.*, 2001; Conde, 2003). The first studies to determine the properties of *Pinus pinaster* for structural use were undertaken by the INIA at the beginning of the 1990s (Ortiz *et al.*, 1990) and allowed the species to be included in the visual grading standard UNE 56.5544 and European standard UNE-EN 1912. These studies sought the representativeness of timber on the market by selecting samples from areas where trees were being harvested. However, only two cross-section sizes were investigated; modifications to standard UNE-EN 384 for the determination of characteristic values

later required the testing of wood with sections representative of the marketed range.

Later work on the *P. pinaster* undertaken by the Dept. of Wood Science at the University of Valladolid (*Proyecto Plan Nacional I+D+I, AGL2002-03386*) involved the use of the most recent modification to standard UNE-EN 384, and 10 cross-section sizes were analysed. The experimental material came from the Gredos Mountains, the Castilian Plain and the Oña-Bureba Hills, all areas where the *mediterranea* subspecies grows (Acuña *et al.*, 2007). Timber from the northwest of Spain (the area with the greatest production of *P. pinaster*) was not included. The aims of the present work, which is a complement of the research mentioned above, were therefore to analyse material from the Spanish northwest, taking into standard UNE-EN 384, and to review the assignment of strength to visual grades according to UNE 56544.

Materials and Methods

Timber samples were randomly selected from sawmills across Galicia. These sawmills used trees (all of harvestable age) from different hillsides. The sample was therefore representative of maritime pine sawn timber from Galicia. A total of 491 beams were tested; Table 1 shows their characteristics.

The moisture content was determined via the measurement of electrical resistance following the procedure described in standard UNE-EN 13183-2.

Each beam was visually graded according to standard UNE 56.544; this standard classifies structural timber (ME – an acronym from the Spanish *madera structural* used in this standard) on the basis of its singularities and defects. Grades of ME-1 or ME-2 are awarded to structurally-apt materials; beams not apt for structural use fall into neither class. The latest version of the standard (2007) has some improvements. For example, the “knot

Table 1. Cross-sections, lengths and number of beams tested

Cross-section (mm)	Length (m)	Number
100x50	3.0	90
150x40	3.5	86
150x50	3.5	63
150x70	3.5	84
200x50	4.0	91
200x70	4.0	77

side” criterion has been removed, and the “resin pocket” length criterion increased to 1.5 times the beam height. The previous version (2003) had a fixed “resin pocket”, which was responsible for downgrading some material (Íñiguez, 2007).

The singularities of each beam were measured, noted and entered into an Access database. This allowed the compliance with tolerance limits of beams showing deformation or wane to be determined.

In addition to the singularities described in the standard, a variable indicative of the knottiness of the beams – the concentrated knot diameter ratio (CKDR) - was also measured. This is best determined in the part of the beam with the greatest incidence of knots; a visual inspection was therefore made to detect these areas. The diameter of each knot was then measured and their sum calculated. The ratio represents this sum divided by the total perimeter of the beam (Fig. 1).

The mechanical properties of the beams were determined using the four point bending test as established by standard UNE-EN 408. Each beam was supported at two points over a span of 18 times its height. Loading heads were placed at the $F/2$ positions shown in Figure 2. The deformation of the beam was measured at the centre of the span and at the edge under tension. The extensometer was removed when the test load reached 10-40% of the maximum (4-7 kN) and the test then continued until the failure of the beam; the maximum load was thus recorded. The modulus of elasticity (E_{mg}) and modulus of rupture (f_m) were calculated from the data gathered.

Density (ρ) was determined by sawing out a piece of wood (reflecting the full cross-section of the beam) close to the fracture point, and measuring its dimensions and weight. All test pieces were free of knots and resin pockets.

The physical and mechanical variables recorded were then used to determine the characteristic values of the wood as defined by standard UNE-EN 384. When the moisture content was between 10 and 20%, the mean

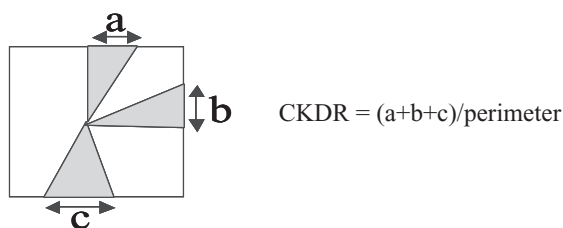


Figure 1. Knot measurement and calculation of the CKDR.

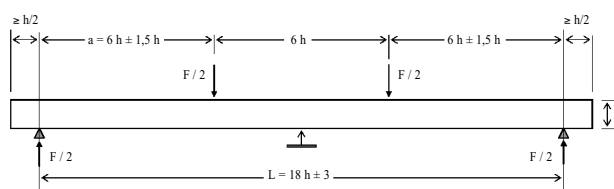


Figure 2. Test for measuring deformation and maximum load UNE-EN 408.

density and elasticity values were adjusted to 12% moisture content. The adjustment factors $k_s=1$ and $k_v=1$ were used in the determination of strength since there were six subsamples (i.e., of different cross-sections) represented by more than 40 beams each. To calculate the local modulus of elasticity (E_{ml}) the following formula was used, which corrects the overall modulus of elasticity recorded in the test:

$$E_{ml} = E_{mg} \cdot 1.3 - 2690$$

The characteristic strength, density and mean elasticity were calculated for visual grades ME-1 and ME-2, and strength classes assigned to each visual grade according to standard UNE-EN 338.

Finally, the relationships between the different properties of the beams were examined by linear regression analysis. Multivariate models were constructed to provide a means of predicting strength and elasticity.

Results

Some 64% of the material studied was classified as being of structural quality according to visual grading. Some 37% of the material fell into the ME-2 class, 27% into ME-1, and 36% was rejected (Fig. 3). The visual grading results obtained for the different cross-sections differed: some 70% of the 150x40 mm beams were rejected, but only 10% of the 100x50 mm and only 15% of the 200x70 mm beams suffered the same fate.

Table 2 shows the mean values of the variables measured in the bending test. The coefficient of variation was greatest for strength (32%) and least for density (11%).

Characteristic strength and density and mean elasticity values were calculated for each visual grade according to standard UNE-EN 384. ME-1 quality was associated with higher characteristic values than ME-2. The rejected beams had still lower values. Strength classes were assigned to each visual grade following standard UNE-EN 338 (Table 3).

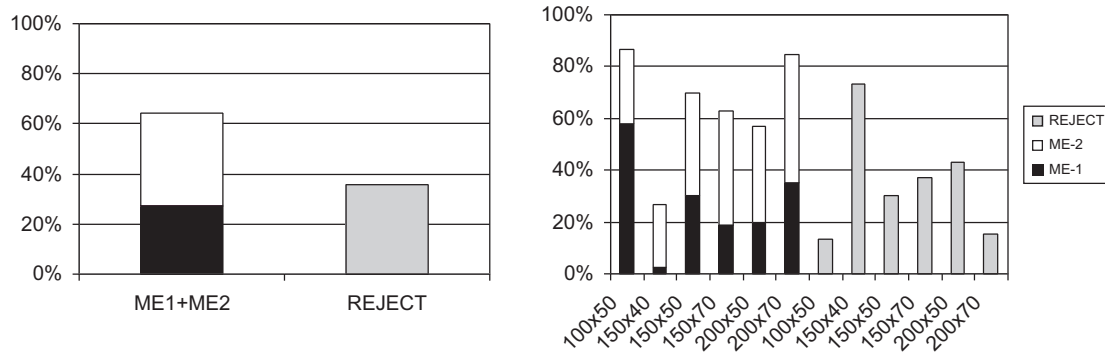


Figure 3. Visual classification of the entire sample (left) and of the different cross-sectional size subsamples (right).

A correlation matrix was produced (Table 4) for elasticity (E_{mg}), strength (f_m), density (ρ), CKDR, height (h) and width (b). The correlation coefficients between E_{mg} , f_m , and ρ were positive and greater than 0.5. CKDR also correlated well with the latter properties, especially strength. As CKDR increased, density decreased. Height and width showed no correlation with any of the other variables.

Regression models between the variables were constructed (Table 5) based on the results of the above matrix. The modulus of elasticity was the best variable with which to estimate strength. When information on the knots was included, the coefficient of determination reached 50%. Some 36% of the variance of strength could be explained by the CKDR and density. Elasticity was little explained by the density or CKDR ($R^2 = 29\%$; Table 5), despite the positive relationships between them.

Discussion

The strength classes assigned for each visual grade in this study were higher than those indicated by standard

UNE-EN 1912. With the latter standard, ME-1 *P. pinaster* material is assigned a strength class of C24, while ME-2 receives C18; in the present work, however, they were assigned classes C30 and C24 respectively (Table 3). From an end-user point of view this would make little difference, but the producers of the present sawn timber would be selling wood of greater resistance than they believed, and therefore selling at lower prices than could be asked. In fact, underestimating material in visual grading is quite common. Numerous studies have analysed visual grading standards and have compared them with other non-destructive techniques (Hermoso, 2002; Conde, 2003; Íñiguez, 2007; Casado *et al.*, 2008), and the results have shown the lower efficiency of the former, although it remains the method normally used. Research into improving non-destructive techniques has therefore increased.

When analysing the present results it should be remembered that the sample timber came only from Galicia. The first study on structural *P. pinaster* material was performed by Martínez (1992), which also involved timber from outside Galicia. The results separated Galician timber from that of other regions, the for-

Table 2. Strength, elasticity and density of the beams measured according to standard UNE-EN 408

CROSS-SECTION (mm ²)	Strength f_m (N/mm ²)	Coefficient Variation %	Elasticity E_{mg} (N/mm ²)	Coefficient Variation %	Density ρ_m (kg/m ³)	Coefficient Variation %
100x50	58	25%	10909	17%	593	11%
150x40	49	39%	12107	21%	565	11%
150x50	63	29%	12966	19%	583	10%
150x70	51	34%	11172	25%	572	13%
200x50	51	38%	12586	20%	556	10%
200x70	62	23%	13603	17%	574	10%
TOTAL	55	32%	12161	21%	573	11%

Table 3. Values for characteristic strength and density and mean elasticity for each visual grade according to standards UNE-EN 384 and UNE-EN 338

Visual Grade	Beam number		Strength (N/mm ²)		Elasticity (N/mm ²)		Density (Kg/m ³)		Assignment of strength class
	n°	%	f_m	f_k^*	E_{mg}	E_{ml}	ρ_m	ρ_k	
ME-1	134	27%	62.3	30.7	12863	14031	589	498	C30
ME-2	181	37%	55.2	25.2	12225	13203	574	469	C24
Reject	176	36%	49.9	22.8	11552	12328	560	462	C22

*characteristic strength, f_k , was calculated according to standard UNE-EN 384, using the coefficients: $k_v=1$ y $k_s=1$.

mer showing greater strength and elasticity. Nevertheless, the inclusion of the *P. pinaster* in standard UNE-EN 1912 involved joint calculations for wood from Galicia and the rest of Spain on safety grounds. In addition, the assignments made via standard UNE-EN 1912 were defined using four cross sectional sizes (with 40 beams per size). The correction factor $k_s=0.95$ was therefore used in the determination of characteristic values.

The most recent research on *P. pinaster* from the Spanish Meseta was undertaken by the Dept. of Wood Science at the University of Valladolid (Casado *et al.*, 2008). The results showed that wood visually graded as ME-1 and ME-2 should be assigned strength classes of C24 and C18 respectively (Acuña, 2007), confirming *P. pinaster* from the Spanish Meseta to have inferior mechanical properties than *P. pinaster* from Galicia. But modifications over standard UNE-EN 1912 would be possible only if a representative sample of the whole population of *P. pinaster* in Spain is considered.

The sampling strategies used may help explain the differences in the mechanical properties recorded. Earlier studies (Ortiz and Martínez, 1991) were based on sampling performed on the hillsides and took into account a single sawing method, while the present material came from sawmills. Thus, in the present work, some of the samples may have been classified in the field, others in the wood yard, and yet others at sawing. Further, in the present study the anatomical origin of each beam within its parent tree was unknown.

Visual grading in other studies has been associated with approximately 25%, 50% and 25% distributions for ME-1, ME-2 and reject grades respectively. In the present work, however, these percentages were different (Fig. 3 right), although they could not be explained by

the mean mechanical values of the differently sized beams (Table 2). The singularities of each tree and the sawing method may however, partly explain them. Some 70% of the 150x40 mm beams were rejected, but in 44% of cases because of wane - a defect caused by sawing that normally has no influence on the strength of the piece (Arriaga *et al.*, 2007). Consequently, the mean strength of the rejected wood was high, owing to the contribution of wood that could have been classed as ME-1 or ME-2.

Beams of large dimensions must originate from the lower part of the trunk, and the knots they contain are unlikely to be big enough to demand the rejection of such material. In the present work only two knots in the 200x70 mm beams were found to exceed the ME-2 100 mm diameter rejection threshold (Fig. 3 right). The same was seen for the 100x50 mm beams; very few were rejected for this reason.

The correlation matrix shown in Table 4 was used to construct regression models. Since the r values of the beams were low (see Table 4), their dimensions were not included. The coefficients of determination (R^2) of the regression models shown in Table 5 agree with those reported for maritime pine from Galicia by other authors (Martinez, 1992; Ortiz and Martínez, 1991).

Table 4. Correlation matrix for the main properties recorded (r values)

	E_{mg}	f_m	CKDR	P	h
f_m	0.6335 **	-			
CKDR	-0.2661 **	-0.4746 **	-		
ρ	0.5263 **	0.5130 **	-0.3267 **	-	
h	0.2701	-0.0217	0.0544	-0.1658 **	-
b	0.0251	0.0751	-0.1186 **	0.0046	0.3309 **

** $P < 0.05$.

Table 5. Regression models for f_m and for E_{mg} as dependent variables

Model	Coefficients			R ²
	A	B	C	
<i>Strength</i>				
$f_m=A+B \cdot E_{mg}$	2.217	0.0044	-	40.12%
$f_m=A+B \cdot \rho_m$	-27.92	0.1451	-	26.31%
$f_m=A+B \cdot ckdr$	67.77	-74.49	-	22.53%
$f_m=A+B \cdot E_{mg}+C \cdot ckdr$	18.25	0.0037	-51.70	50.20%
$f_m=A+B \cdot \rho_m+C \cdot ckdr$	-0.64	0.1133	-53.94	36.87%
<i>Elasticity</i>				
$E_{mg}=A+B \cdot \rho_m$	-676.78	22.42		29.35%
$E_{mg}=A+B \cdot ckdr$	13182.5	-6068		7.00%
$E_{mg}=A+B \cdot \rho_m+C \cdot ckdr$	980.03	20.21	-2403.89	30.05%

They are also similar to those reported in other studies on pine timber of different species and size from other areas of Spain (Hermoso, 2001; Conde, 2003; Íñiguez, 2007). Strength was best predicted by E_{mg} and CKDR. Density was a poor predictor of elasticity, and the CKDR helped little more.

Conclusions

The strength classes assigned to visually graded Galician maritime pine were higher in the present work according to UNE-EN 384 and UNE-EN 338 than those reported for samples with different origin.

Visual standard UNE 56.544 classified 67% of the timber examined as apt for use in construction.

The anatomical origin of the sample in the parent tree and the sawing method influenced the visual grade.

Elasticity is confirmed as a good predictor of strength and accuracy of this model is improve by adding the variable CKDR, while density does not explain the variability in elasticity.

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