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Mechanical characterization of timber according to European standards from Spanish provenances of Scots Pine

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Abstract

The Scots pine (*Pinus sylvestris* L.) is the third most important species in Spain with an annual production of 800,000 m^3 of roundwood with bark. This timber is usually used in Spain for structural and decorative purposes.

In this work, a mechanical characterization of Scots pine timber from different Spanish provenances and several sizes ranging from 100×40×2,500 mm to 200×70×4,500 mm, is carried out. A total of 3,085 boards have been tested in accordance with EN 408, and their mechanical values have been obtained in accordance with EN 384 and EN 338 standards.

According to the possible provenances of Scots pine timber in Spain, the samples were selected from regions that make up the three most important zones in terms of productivity (Central, Iberian and Pyrenean Systems).

The material was graded in accordance with the Spanish visual strength grading standard UNE 56.544, which sets two grades: ME1 and ME2.

The results showed that Spanish Scots pine grade ME1 can be assigned to strength class C27, and that ME2 graded material can also be assigned to C18.

The relationships between the strength and the possible predictor variables ($E_{m,g}$, E_{cen}, ρ, RW) were also studied, concluding that neither the rate of growth nor the density are accurate predictors of bending strength.

Key words: scots pine, timber characterization, *Pinus sylvestris*.

Resumen

Caracterización mecánica de la madera de diversas procedencias españolas de Pino silvestre, de acuerdo con las normas europeas

El pino silvestre *(Pinus sylvestris* L.) es en España la tercera especie más productiva, con una producción anual de 800.000 m^3 con corteza. Esta madera es habitualmente usada en España tanto para aplicaciones estructurales como decorativas.

En este trabajo se lleva a cabo una caracterización mecánica de diversas procedencias españolas del pino silvestre, empleando para ello diversas dimensiones, que varían entre 100×40×2.500 y 200×70×4.500 mm. Se ensayó un total de 3.085 piezas, siempre de acuerdo con la norma EN 408, siendo los valores mecánicos calculados de acuerdo con lo establecido en las normas EN 384 y EN 338.

Tomando en consideración las posibles procedencias oficiales del pino silvestre en España, las muestras fueron seleccionadas de las tres regiones más productivas (Sistema Central, Ibérico y Pirenaico).

El material fue clasificado de acuerdo con la norma española de clasificación mecánica visual UNE 56.544, la cual establece dos clases de calidad: ME1 y ME2.

Los resultados habidos demuestran que la calidad ME1 del pino silvestre español puede ser asignada a la clase de resistencia C27 y que la clase ME2 lo puede ser a la C18.

También se estudiaron diversas relaciones de tipo estadístico establecidas entre la resistencia y diversas variables predictoras ($E_{m,g}$, E_{cen}, ρ, RW), concluyendo que ni la tasa de crecimiento anual ni la densidad son predictores precisos de la resistencia a la flexión del material.

Palabras clave: pino silvestre, caracterización de madera estructural, *Pinus sylvestris*.

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Introducción

The Scots pine is present in Europe from Siberia to the South of Spain, covering a distance (East-West) of 14,000 km. Its southernmost limit can be found in Sierra de Gata, located in the south of Spain.

In Spain the Scots pine covers a total area of approximately 920,000 Ha in natural (435,000 Ha) and artificial stands, distributed among 4 zones: the Pyrenean, Iberian, Central and Penibetic systems and their foothills, plus a number of smaller, scattered patches which generally coincide with areas of afforestations that began at the end of the last century and have continued through to today (Montero, 1993). This distribution area of 920,000 Ha represents 17% of the total area covered by conifers in Spain, thus ranking this species as the third most important Spanish conifer.

This species can be found in Spain at altitudes between 400 and 2,000 metres, with optimum regenerative production occurring between 1,200 and 1,600 m. Forests above these limits are usually protective, giving very low, poor timber production.

Forests located between 800 and 1,200 metres are usually highly productive (1.5 to 6 m^3/ha/year) and represent, as an average, 76% of the total surface. Their normal sylviculture is usually shelterwood systems.

The estimated roundwood harvest with bark is 800,000 m^3/year (Tolosana *et al.,* 2000).

Due to their good appearance, straight grain, density, relatively few knots and high mechanical strength values, the Scots pine, together with the Laricio pine timber, are considered to be the best conifer timbers in Spain for decorative and structural purposes.

There are 17 regions of provenance for the Scots pine in Spain (Catalan *et al.*, 1991). Of these 17 regions, six can be considered to be protective zones, and four are relictic areas or forests, which are strongly conditioned by environmental or ecological criteria, an thus the timber production is marginal. Therefore, only seven of the above-cited Spanish regions of provenance can be considered as possible areas for commercial timber production. These productive areas can be found in three different mountain systems: Pyrenean, Iberian and Central (Fig. 1).

Spanish conifer timbers (Radiata, Pinaster, Laricio and Scots pines) are visually graded by means of the UNE 56544 standard, which sets two different grades, First (ME1) and Second (ME2).

At present, the European EN 408, EN 384, EN 338 and EN 1912 standards have already been adopted as Spanish UNE standards, with their testing, calculus and assignation methodologies following the normal procedures used in the Spanish timber characterization processes.

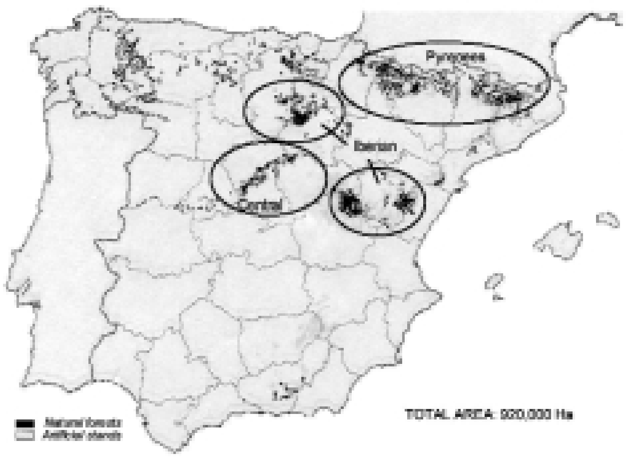

Figure 1. Most important areas of distribution of Scots pine in Spain.

The Spanish Forest Research Centre (CIFOR-INIA), which belongs to the Ministry of Science and Technology, has, since 1992, been carrying out the characterization of the most important structural timbers growing in Spain (Fernández-Golfín *et al.*, 1998), in order to introduce their grades in the European standard EN 1912.

The European EN 1912 standard is probably one of the most important standards for ensuring the free commerce of structural timbers within the European Union's market, in terms of mechanical reliability. This standard sets forth the assignment of visual grades (in accordance with the different national visual grading standards) and species to strength classes for the different timbers and grading standards present in the European market.

The Spanish Radiata and Pinaster pine timbers have already been characterized (Fernández-Golfín *et al.*, 1998) and included in standard EN 1912. This present work summarizes the results of the mechanical characterization of Spanish Scots pine, and its inclusion in EN 1912 will also be requested.

Material and methods

The characterization of Spanish Scots pine focussed on the timber really available in the market. As a result of this, sampling was only carried out in the productive zones of this species.

In the three main productive areas of this species (Pyrenean, Iberian and Central systems) different and representative samples were taken, in accordance with EN 384 and EN 408 requirements.

According to the variability of quality observed in previous studies on this species (Fernández-Golfín *et al.*, 1998) five different samples were taken, all of them coming from different regions of provenance within every sampling area:

— Central System (Reg. 10 Sierra Guadarrama).

— Iberian System (Reg. 2 Alto Ebro, Reg. 8 Soria-Burgos and Reg. 12 Montes Universales).

— Pyrenean System (Reg. 3 Navarra).

All the samples together cover 65% of the area of distribution, and 84% of the harvested volume for this species.

The sampling process took place both in forests and sawmills. In the forest sampling (Regions 2 and 8), effects that could disturb the representation of the sample were avoided. Tree sampling was randomly selected from different harvesting zones, including all the stand qualities in the sample, reflecting the diameter classes and collected in different periods. In the sawmill sampling, the timber was directly graded and selected in the timber yards of three different sawmills (Regions 3, 10 and 12) and were also taken at different intervals. This selection system permitted a variety of cutting patterns and log sources of the material present in the market. The characteristics and sizes of the samples are summarized in Tables 3 and 4.

Material coming from forest sampling (Regions 2 and 8) was obtained in a previous study (Fernández-Golfín *et al.*, 1997) aimed at analysing the influence of sylviculture on the mechanical properties and the quality of sawn timber. This material was sawn to a unique size of approximately 150 × 50 × 3,500 mm, but it is included in this work in order to find more accurate characteristic values for this species in Spain.

Material coming from sawmill samplings includes different sizes in order to consider the size effect on the mechanical properties. In accordance with EN 384, the total number of specimens in every sub-sample has always been over 40.

Both material (sawmill and forest) were selected in green condition, air dried up to 30% moisture content, and finally kiln dried up to a final moisture content (mc) of 12%. After drying, all the suitable material was planned complying with the requirements of tolerance class 2 of EN 336.

At the time of testing, the average moisture content was 11.5% ± 1.5%, evaluated in accordance with the procedure given in prEN 13183-2 (Electrical resistance method).

All the material was visually graded in accordance with the Spanish visual strength grading standard UNE 56.544, which sets forth two different quality grades, ME1 and ME2. The specimens that do not come under any of these grades are classified as rejects (MER).

All the boards with excessive deformations, measured in accordance with the procedure given in EN 1310 (also included in the Spanish UNE 56544 standard), were removed from the sample.

The bending tests were carried out in accordance with the EN408 procedure. Reject graded material, but apt from the viewpoint of deformations, was also tested in order to determine accurate relationships between the testing variables. The average rate of growth was measured in compliance with EN 1310.

All the calculations were made in accordance with EN 384, and the assignation of strength classes to visual grades in accordance with EN 338 criteria.

The standard EN 408, in its most recent version (Nov. 2000), sets forth two different testing procedures to determine the Modulus of Elasticity in Bending: the Local (E_{cen}) and the Global ($E_{m,g}$), both were carried out in this study, although the assignment of visual grades to strength classes, in compliance with EN 338, was carried out using the calculated values of Local Modulus of Elasticity ($E_{m,l}$), by means of the expression given in EN 384.

In order to determine the global modulus of elasticity ($E_{m,g}$), the deformation was measured at the centre of the span and at the neutral axis, with the final value being the mean of the measurements made on both sides of the test piece. The deformation was also measured at the centre of the tension edge, but this value was not taken into consideration to calculate the final value of global modulus of elasticity ($E_{m,g}$).

Results and Discussion

Table 1 includes a brief summary of the average grading results, in accordance with the visual grading standard UNE 56.544.

According to the results included in Table 1, the conclusion can be drawn that the «Cuenca» sample gives the poorest yield of ME1 material (15.6%) and the highest amount of rejected material (28.8%). On the other

Table1. Grading summary (%)

Region	Sample	Grades UNE 56.544		
		ME1	ME2	Reject
2. Alto Ebro	Forest/Alava	24.4	57.1	18.5
3. Pirineo Navarro	Sawmill/Navarra	20.7	52.0	27.3
8. Soria-Burgos	Forest/Navaleno, Quintanar	27.9	49.5	22.6
10. S.ª Guadarrama	Forest/Valsaín	24.5	63.1	12.4
	Sawmill/Valsaín	60.7	30.6	8.8
	Forest/Rascafría	23.9	51.4	23.9
12. Mtes. Universales	Sawmill/Cuenca	15.6	55.6	28.8

hand, the «Valsaín» sample gives a very high yield of ME1 material (60.7%), and a very low level of rejects (8.8%), in accordance with the reputation that this timber has in the market. The rest of the samples reflect very closed values in terms of grading yields.

Table 2 reflects the most important linear relationships among the properties studied (f_m, E_{cen}, $E_{m,g}$, ρ, RW), taking into account not only ME1 and ME2 material, but rejects as well. All the models were fitted by linear regression, with all of them being significant at 99% confidence level.

The results of the mechanical characterisation per sampling zone and region, along with the assignment of ME1 and ME2 visual grades to strength classes are given in tables 3 and 4.

In accordance with the requirements of EN 384 (Item 10), Figure 2 includes the distributions of relative knot size (face and thickness at the critical section), rate of growth and density.

The terminology used in tables 2, 3 and 4 is as follows:

Grade: grade in accordance with the Spanish visual grading standard UNE 56.544.

RW: average ring width.

t: thickness of cross section in mm.

h: depth of cross section in mm.

n: sample size (number of tested boards).

Table 2. Relations among testing variables

Model	R^2 (%)	Level of significance	
		Intercept	Slope
$f_{m,c}$ = –8.86+0.00489*$E_{cen,c}$	55.32	***	***
$f_{m,c}$ = –4.74+0.00559*$E_{m,g,c}$	58.96	***	***
$f_{m,c}$ = –28.66+0.14259*ρ	18.42	***	***
$f_{m,c}$ = 49.9325-4.8692*RW	5.12	***	***
$E_{cen,c}$=1.28377* $E_{m,g,c}$–2765.57	74.36	***	***

*** Significant at 99% confidence level. ** Significant at 95% level. * Significant at 90% level. NS: not significant.

mc: moisture content (%).

f_{mean}: sample mean value of bending strength (in N/mm²).

s: standard deviation.

f_{05}:sample 5-percentile value of bending strength (in N/mm²).

k_h:depth factor. k_h= $(150/h)^{0.2}$.

f_{05h}: the h-adjusted sample f_{05} value, f_{05h}= (f_{05}/k_h).

$\overline{f_{05}}$: mean value of f_{05h} of several samples (in N/mm²). $\overline{f_{05}} = \frac{\sum f_{05hj} * n_j}{\sum n_j}$.

k_s: factor for adjusting $\overline{f_{05}}$ according to the number and size of samples (Figure 1 in EN 384).

f_k: characteristic value of bending strength (in N/mm²). f_k= ($\overline{f_{05}}$ *k_s), being this value the minimum of $\overline{f_{05}}$ and 1.2*Min(f_{05h}).

$E_{m,g}$: global modulus of elasticity in bending (in N/mm²). $E_{m,g,c}$ is the value corrected by moisture content.

$E_{m,l}$: local modulus of elasticity in bending (in N/mm²). $E_{ml,c}$ is the value corrected by moisture content.

$\overline{E_{mg,12}}$: sample mean global modulus of elasticity adjusted to 12% mc (if needed).

$\overline{E_{cen,12}}$: sample mean of tested local modulus of elasticity adjusted to 12% mc (if needed).

$\overline{E_{ml,12}}$: sample mean of calculated local modulus of elasticity adjusted to 12% mc (if needed). This value is calculated as follows (EN 384): $\overline{E_{ml,12}}$ = 1.3 * $E_{mg,12}$ – 2690

$E_{0,l/g,mean}$: mean characteristic value of local (calculated)/global modulus of elasticity parallel to grain (in N/mm²) of several samples, $E_{0,mean} = \frac{\sum \overline{E_{ml/g,12,j}} * n_j}{\sum n_j}$

Table 3. Characteristic values in accordance with EN 384 (ME1 quality)

Sample	Sampling	Grade	RW	t	h	n	mc	f_{mean}	S	f_{05}	k_h	f_{05h}	$\overline{f_{05}}$	f_k	$\overline{E_{g,12}}$	s	$E_{0,g,mean}$	$\overline{E_{cen,12}}$	$\overline{E_{l,12}}$ ***	$E_{0,t,mean}$	$\bar{\rho}$	s	ρ_{05}	ρ_k
Total Reg. 2	Forest	ME1	2.4	56	150	40	12	58.1	15.3	32.9	1.000	32.9	32.9	32.9	—	—	—	12894	—	—	570.1	61.6	468.5	468.5
Total Reg. 3	Sawmill	ME1	2.8	50	150	40	12	66.9	15.0	33.0	1.000	33.0	33.0	33.0	12449	2127	12449	12761	13494	13494	567.3	55.0	473.9	
Total Reg. 8	Forest	ME1	1.9	55	150	53	12	61.8	20.4	30.4	1.000	30.4	30.4	30.4	—	—	—	12163	—	—	539.3	63.1	435.2	
RAS	Forest	ME1	1.9	50	150	40	12	59.3	16.0	30.4	1.000	30.4			—	—		13122	—		534.3	65.3	426.5	
VAL	Forest	ME1	1.8	50	150	75	12	61.5	15.3	31.0	1.000	31.0			—	—		13852	—		512.6	55.2	421.5	
VAL	Sawmill	ME1	1.2	40	150	68	12	62.2	10.5	44.1	1.000	44.1			12055	1650		12612	12982		526.0	48.1	446.6	
	Sawmill	ME1	—	50	150	65	12	63.7	15.6	31.8	1.000	31.8			—	—		12053	—		513.1	45.8	437.5	
	Sawmill	ME1	1.2	70	150	67	12	67.0	11.7	46.2	1.000	46.2			12029	1765		12333	12948		512.3	69.8	397.1	
	Sawmill	ME1	1.3	50	200	68	12	49.6	8.3	33.9	0.944	35.9			11508	2064		12445	12270		513.1	69.2	398.9	
	Sawmill	ME1	—	70	200	85	12	64.0	12.4	43.2	0.944	45.8			11916	2236		12118	12801		517.3	59.4	419.3	
Total Reg. 10		ME1											38.6	36.5*			11878.8	12616		12753				436.8
CU	Sawmill	ME1	1.4	40	100	45	12	60.2	19.9	25.8	1.084	23.8			11188	2540		12374	11854		496.2	53.5	407.9	
	Sawmill	ME1	1.3	50	100	46	12	58.4	16.2	34.9	1.084	32.2			10905	2113		11655	11487		514.0	53.3	426.1	
	Sawmill	ME1	1.1	40	150	47	12	50.5	15.4	24.3	1.000	24.3			11980	2807		11752	12884		484.4	46.7	407.3	
	Sawmill	ME1	1.2	50	150	40	12	55.1	16.0	26.1	1.000	26.1			11214	1924		11462	11888		492.1	43.2	420.8	
	Sawmill	ME1	1.2	70	150	40	12	53.4	14.5	26.0	1.000	26.0			11258	1959		11870	11945		526.5	71.0	409.3	
	Sawmill	ME1	1.4	50	200	40	12	40.3	7.0	28.2	0.944	29.9			9790	1862		10062	10037		497.2	26.3	453.8	
	Sawmill	ME1	1.4	70	200	40	12	51.7	12.3	29.6	0.944	31.4			10585	1733		11211	11071		512.5	59.7	414.0	
Total Reg. 12		ME1											27.3	27.3*			11175.2	11697		11838				415.9
Total		ME1												27.3**						11838				416

* More than 5 samples and minimum size of samples > 40 boards then $k_s = 1.0$. $k_v = 1$. The selected value of f_k is the lower of and $1.2 \cdot \mathrm{Min}(f_{05h})$. ** Minimum values for both regions. *** Calculated in accordance with EN 384 expression ($E_{ml} = 1.3 \cdot E_{mg} - 2690$).

Table 4. Characteristic values in accordance with EN 384 (ME2 quality)

Sample	Sampling	Grade	RW	t	h	n	mc	f_{mean}	S	f_{05}	k_h	f_{05h}	$\overline{f_{05}}$	f_k	$\overline{E_{g,12}}$	s	$E_{0,g,mean}$	$\overline{E_{cen,12}}$	$\overline{E_{l,12}}$ ***	$E_{0,t,mean}$	$\bar{\rho}$	s	ρ_{05}	ρ_k
Total Reg. 2	Forest	ME2	3.1	56	150	68	12	36.1	12.9	18.1	1.000	18.1	18.1	18.1	—	—	—	11117	—	—	518.8	62.3	416.0	416.0
Total Reg. 3	Sawmill	ME2	2.9	50	150	78	12	46.5	13.2	25.6	1.000	25.6	25.6	25.6	10828	2081	10828	11022	11386	11386	542.1	42.9	471.3	471.3
Total Reg. 8	Forest	ME2	2.2	55	150	94	12	33.8	13.9	18.1	1.000	18.1	18.1	18.1	—	—	—	10127	—	—	523.5	58.9	426.3	426.3
RAS	Forest	ME2	2.0	50	150	73	12	34.9	14.2	16.8	1.000	16.8			—	—		10039	—		479.9	50.6	414.4	
VAL	Forest	ME2	2.1	50	150	193	12	47.8	14.7	24.6	1.000	24.6			—	—		12207	—		491.4	46.1	415.3	
VAL	Sawmill	ME2	1.2	40	150	40	12	48.2	12.2	23.6	1.000	23.6			11129	1940		11158	11778		520.4	50.1	437.7	
	Sawmill	ME2	—	50	150	40	12	50.3	18.1	23.8	1.000	23.8			—	—		11168	-—		506.6	48.8	426.1	
	Sawmill	ME2	1.3	70	150	42	12	54.5	16.3	27.9	1.000	27.9			12323	2308		12451	13336		514.6	59.9	415.8	
	Sawmill	ME2	1.5	50	200	40	12	43.9	9.2	26.1	0.944	27.6			10598	1898		11563	11087		517.0	57.8	421.6	
	Sawmill	ME2	—	70	200	40	12	52.2	14.5	24.6	0.944	26.1			10472	1225		11066	10924		501.3	44.0	428.7	
Total Reg. 10		ME2											23.8	20.2*			11309.6	11579		11789				419.2
CU	Sawmill	ME2	1.4	40	100	95	12	39.1	16.0	17.3	1.084	16.0			9645	2071		9703	9924		497.3	51.7	412.0	
	Sawmill	ME2	1.5	50	100	96	12	41.7	12.3	23.1	1.084	21.3			9202	1794		9443	9586		477.0	44.2	404.1	
	Sawmill	ME2	1.4	40	150	128	12	38.9	14.1	20.0	1.000	20.0			10857	2441		10478	10931		489.3	43.4	417.7	
	Sawmill	ME2	1.5	50	150	130	12	36.0	13.7	19.4	1.000	19.4			10071	2426		10094	10432		488.0	48.8	407.5	
	Sawmill	ME2	1.4	70	150	158	12	39.2	15.1	19.2	1.000	19.2			9773	2113		9926	10214		495.9	59.2	398.2	
	Sawmill	ME2	1.7	50	200	42	12	30.1	8.9	19.0	0.944	20.1			8700	1632		8800	8750		485.7	54.9	395.1	
	Sawmill	ME2	1.6	70	200	156	12	34.6	12.1	18.6	0.944	19.7			9549	1854		10005	10317		494.1	58.9	396.9	
Total Reg. 12		ME2											19.4	19.2*			9811.5	9913.3		10065				404.7
Total		ME2												18.1**						10065				405

* More than 5 samples and minimum size of samples > 40 boards then $k_s = 1.0$. $k_v = 1$. The selected value of f_k is the lower of and $1.2 \cdot \mathrm{Min}(f_{05h})$. ** Minimum values for both regions. *** Calculated in accordance with EN 384 expression ($E_{ml} = 1.3 \cdot E_{mg} - 2690$).

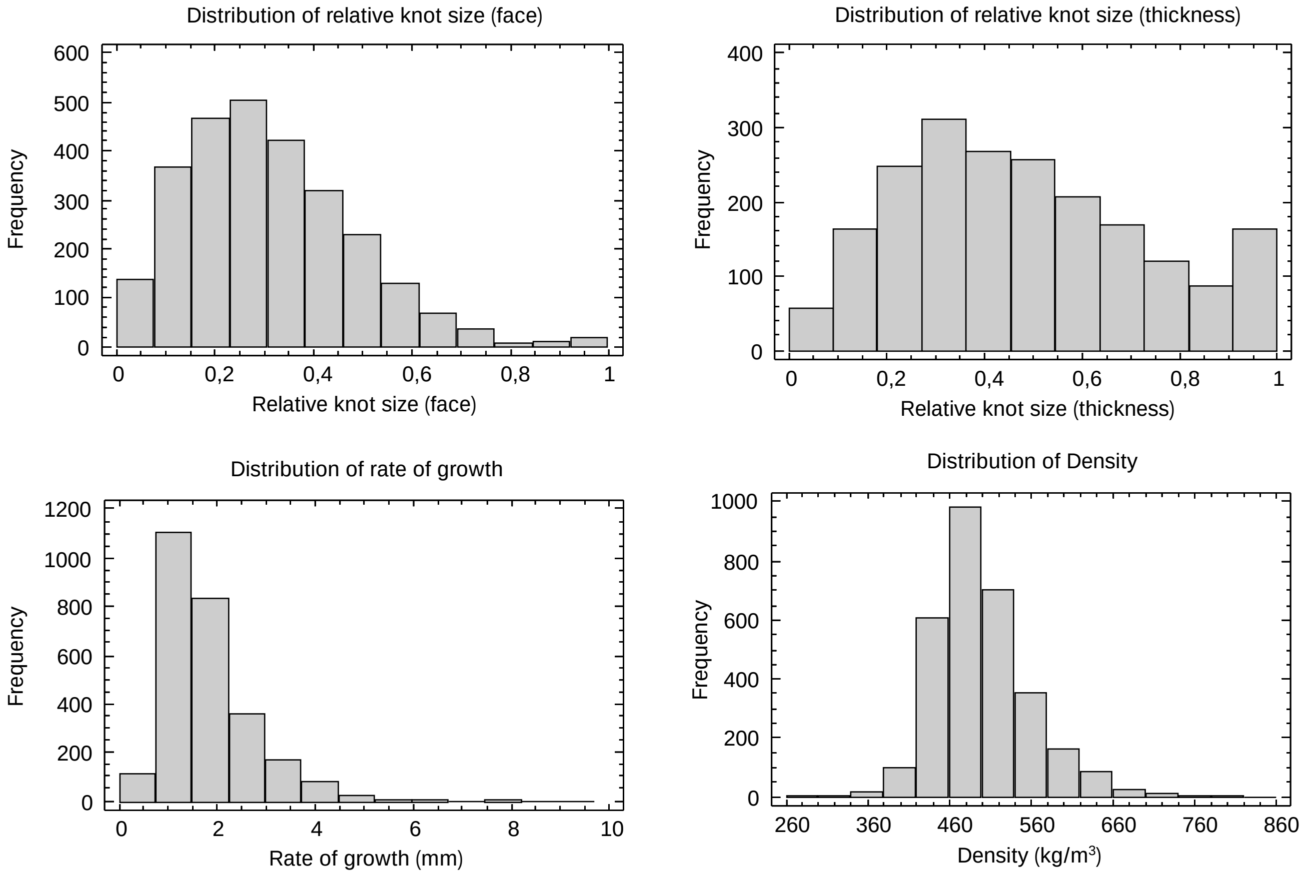

Figure 2. Distributions of relative knot size (face and thickness), rate of growth and density.

ρ: density value (in kg/m^3). ρ_c is the value corrected by moisture content.

$\bar{\rho}$: mean density value for one sample (in kg/m^3).

ρ_{05}: 5-percentil adjusted (to 12% mc) density for a sample (in kg/m^3).

ρ_k: characteristic density (in kg/m^3).

f_m: bending strength (in N/mm^2). $f_{m,c}$ is the value corrected by depth factor.

The calculations and coefficients used to obtain the characteristic values included in Tables 3 and 4 have been applied in accordance with EN 384. In compliance with this standard, the selected characteristic values for each region (f_k) have been the minimum value among the average values for the samples ($f_{05h,I}$) included in the region and 1.2 times the extreme minimum sample value ($f_{05h,I}$). Due to the fact that timber markets in Spain are usually very local, and in order to avoid any risk, the final characteristic value for bending strength at species level (f_k) was the minimum of the regional values, instead of the total mean weighted according to the number of pieces tested in every region.

Based on the results of Tables 3 and 4, it can be concluded that ME1 grade can be assigned to C27 class and ME2 grade to C18 in accordance with the EN 338 standard, as therefore all second graded timber (ME2) from Spanish-grown pines (Scots, Laricio, Radiata and Pinaster) would be C18.

When studying the results of Table 3, it can be clearly seen that the «Cuenca» sample has very poor mechanical qualities, compared with the rest of regions. This fact has had a great effect on the characteristic bending strength value at species level that could have been over 30 Mpa, and could have given an assignation of a C30 mechanical class. These surprising results could be explained by the fact that this is an area very close to the southern limit for this species, and grows in zones with calcareous soils.

The models given in Table 2 demonstrate the low degree of influence of the rate of growth and density, at species level, on the bending strength of the timber. These results partially confirm the conclusions reached in previous studies on the same species, but using a different sample (Fernández-Golfín, J.I. and Díez, R., 1996).

As far as the relationship between bending strength and modulus of elasticity, as was expected, the global modulus of elasticity seems to be a better predictor of the mechanical quality of timber than the local modulus of elasticity.

The relationship between local and global modulus of elasticity seems to be of the same order of magnitude that suggested by the EN 384 standard to calculate local modulus (E_{ml}) by means of global modulus (E_{mg}).

As previously cited, it should be stressed that the global modulus of elasticity ($E_{m,g}$) is a better indicator of the bending strength than the local modulus of elasticity (E_{cen}), with its testing being considerably less complex and more accurate.

It is also important to point out that, due to the fact that the variability for the bending strength of Scots pine timber is extremely high (coefficient of variation of up to 42%), the non-parametric method procedure followed by EN 384 standard to calculate the characteristic value of this variable is sometimes complicated, since it is occasionally necessary to interpolate between extremely distant values, especially when sample sizes are small, close to 40-60 pieces.

Conclusions

Based on the results, the following conclusions may be drawn:

— According to the results, the first grade (ME1) of Spanish Scots pine timber, graded in accordance with the Spanish UNE 56.544 visual strength grading standard, can be assigned to the C27 mechanical class of the EN 338 standard. In the same way, second grade (ME2) can be assigned to C18.

— At species level, the growth rate only explains 5.1% of the variability of bending strength, and so does not seem to be a useful indicator of the mechanical quality of timber.

— As expected, the global modulus of elasticity seems to be a better predictor of the bending strength of timber than the local modulus of elasticity (R^2 of 57.1% vs. 54.4%). This fact, combined with the lower variability observed in the data for global modulus of elasticity, and the good relationship ($R^2 = 74.36\%$) between local and global values, suggest the avoidance of using local modulus of elasticity for systematic timber bending testing.

— Due to the high value of the coefficient of variation of bending strength (up to 42%), the application of the non-parametric procedure given in EN 384 to calculate characteristic values is sometimes problematic when the number of pieces is close to the minimum value of 40, due to the need to interpolate between very distant values. This therefore leads to the conclusion that either the minimum number of 40 specimens specified in the EN 384 standard should be increased, or the interpolation should be avoided.

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