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Implications in the design of a method for visual grading and mechanical testing of hardwood structural timber for assignation within the European strength classes

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Abstract

The European strength class system (EN 338:2009) is based on a testing standard (EN 408:2004) that is not easy to use with hardwoods, although some of this type of timber, such as European oak (*Quercus robur* L.), is highly appreciated for construction purposes. This study proposes specifications for sampling design, visual grading and mechanical testing of oak wood. With this aim, 27 adult oaks were felled and sawn into pieces. A sample of quarter-sawn planks was selected, then air-dried and planed to 50 × 100 × 2,000 mm. The beams were visually graded in accordance with ten standards, and were mechanically tested, at an average wood moisture content of 21%. The Spanish visual grading standard UNE 56544:2007 was the most effective for categorizing the pieces. According to this standard, 39% of the sampled beams were suitable for structural use. The mean value of modulus of elasticity (11,702 N mm^{-2}) and characteristic density (714 kg m^{-3}) enable preliminary designation of the wood in visual grade ME-2, to European strength class D40. However, the bending strength was too low for inclusion of the timber in the European strength classes. Criteria are proposed for elaborating visual grading rules for oak wood and for structural beam testing in order to allocate oak visual strength grades into strength classes.

Key words: *Quercus robur* L.; visual grading; sampling design; testing procedure; mechanical properties.

Resumen

Consideraciones en el diseño de un método de clasificación visual y ensayo mecánico de madera estructural de frondosas para su asignación al sistema europeo de clases resistentes

El sistema europeo de clases resistentes (EN 338:2009) se basa en una norma de ensayo (EN 408:2004) que es difícil de aplicar en frondosas, aunque algunas de dichas maderas, como el roble (*Quercus robur* L.), sean muy valoradas en aplicaciones constructivas. En este trabajo se proponen especificaciones para el diseño de muestreo, clasificación visual y ensayo mecánico de la madera de roble. Para el estudio se apearon y aserraron 27 ejemplares adultos de roble. Se seleccionó una muestra de piezas aserradas claramente radiales, que se secaron al aire y se cepillaron hasta unas dimensiones de 50 × 100 × 2.000 mm. Las viguetas obtenidas se clasificaron visualmente según diez normas de clasificación y fueron sometidas a ensayo mecánico con un contenido de humedad medio del 21%. La norma española UNE 56544:2007 fue la más eficaz en la clasificación visual de las piezas. Según dicha norma, el 39 % de las viguetas muestreadas eran aptas para su empleo en estructuras. El modulo elástico medio (11.702 N mm^{-2}) y la densidad característica (714 kg m^{-3}) permitirían una asignación preliminar de la madera de la clase visual ME-2 a la clase resistente europea D40. No obstante, la resistencia a flexión era demasiado baja como para la inclusión de la clase visual en el sistema europeo de clases resistentes. Se proponen criterios a considerar en la elaboración de una futura norma de clasificación visual para madera de roble y en el ensayo mecánico de piezas de tamaño estructural, para asignar clases visuales de roble a clases resistentes.

Palabras clave: *Quercus robur* L.; clasificación visual; diseño de muestreo; método de ensayo; propiedades mecánicas.

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Introduction

Oak (*Quercus robur* L.) wood has traditionally been used for structural purposes because of its mechanical strength and acceptable durability (Van Acker *et al*., 1999; Riesco Muñoz, 2001). It has commonly been used in Spain to construct flooring and roofing on fabric or stone structures (Nassar, 1996). In the 20th century, use of oak in structures decreased due to the increased presence of concrete, steel and graded coniferous wood. An additional restriction to the use of oak is the large variability in the species with regard to density and other characteristics related to quality (Zhang *et al*., 1994; Degron and Nepveu, 1996).

However, the demand for good quality oak is now increasing (Iglesias, 1998). Likewise, sawn oak timber of Spanish provenance is expected to be sold on the European market in light of the predicted deficit in hardwood timber in the intermediate term, as a result of the destruction of broadleaved forests outside of Europe (Bermúdez, 1997).

The most common uses for sawn oak timber in the construction sector are for prefabricated buildings, agricultural buildings and storehouses. It may also be used in new buildings where a traditional appearance is desired (exposed ceiling beams, rustic doorways and decorative facings), and also in the restoration of old buildings to replace pieces and for calculating the strength of pieces in building work (Arriaga, 1998, personal communication).

Selection of Spanish oak as a construction material should be based on detailed knowledge of the physical and mechanical properties of the wood. Following characterization of the main types of coniferous timber in Spain (Hermoso Prieto *et al*., 2003; Fernández-Golfin Seco *et al*., 2004; Adell Almazán *et al*., 2008) and of eucalyptus for construction (Fernández-Golfin *et al*., 2007) in EN 1912:2005+A2:2008 standard, the current needs as regards the visual grading rules for deciduous timber must be addressed. This will allow the inclusion of Spanish oak in the European strength class system.

The Spanish standard for visual grading of hardwood timber for structural purposes (UNE 56546:2007) only considers eucalyptus timber, although it would be desirable to include oak and chestnut timber in the future to enable their assignation in the international system for classifying strength (European standards EN 338:2009 and EN 1912:2005+A2:2008). Other provenances of European oak, such as French oak, are pending inclusion in the European system, while the visual strength grade determined for German oak (LS 10) has already been assigned to strength class D30, a low class for broadleaved species, in the EN 1912: 2005+A2:2008 standard.

The aim of the present study is to present criteria for visual grading and mechanical testing of oak timber of Spanish origin destined for construction, to enable assignation of the visual qualities to the European system of strength classes outlined in the European standard EN 338:2009.

Material and methods

For use in the present study, a total of 27 oak trees (*Quercus robur* L.) were felled in Galicia (northwestern Spain), a region producing 95% of the national harvested volume of oak wood. Oak is the top deciduous tree in the region in terms of volume harvested (MARM, 2008; Xunta de Galicia, 2001). In the tree selection, care was taken to include as much between-site variability in the species as possible (Fig. 1). A number of trees that amply covered the requirements of the UNE 56528:1978 and EN 384:2004 standards were chosen to include the expected high inter-individual variability in oak timber properties (Zhang *et al*., 1994; Riesco Muñoz, 2001). Specimens suitable for sawing were sampled, *i.e.*, those with straight stems, more than 3 m of merchantable wood, breast height diameter greater of 30 cm and absence of any apparent rot. Specimens of breast height diameter greater of 60 cm were rejected as these are preferred for sliced veneering and because they are more likely to have internal rot. The age of the sampled trees was between 33 and 96 years.

Each stem was cut into logs of 210 cm long, and between one and four logs were obtained per tree. All logs were then sawn in a similar way, with a simplified radial sawing pattern, although adapted to the dimension and quality of each. The aim was to obtain quarter-sawn planks of thickness 70 mm, width 120 mm and longitude of more than 2 m, dimensions somewhat larger than those finally achieved for the tested beams (50 × 100 × 2,000 mm). The general sawing pattern consisted of two parallel cuts along the longitudinal axis of the trunk, parallel to each other and approximately radial. In the central unedged board thus obtained, of some 70 mm thick, cuts were made perpendicular to the face of the piece, to obtain several pieces of width 120 mm. The two half logs initially obtained were sectioned by parallel sawing and approximately

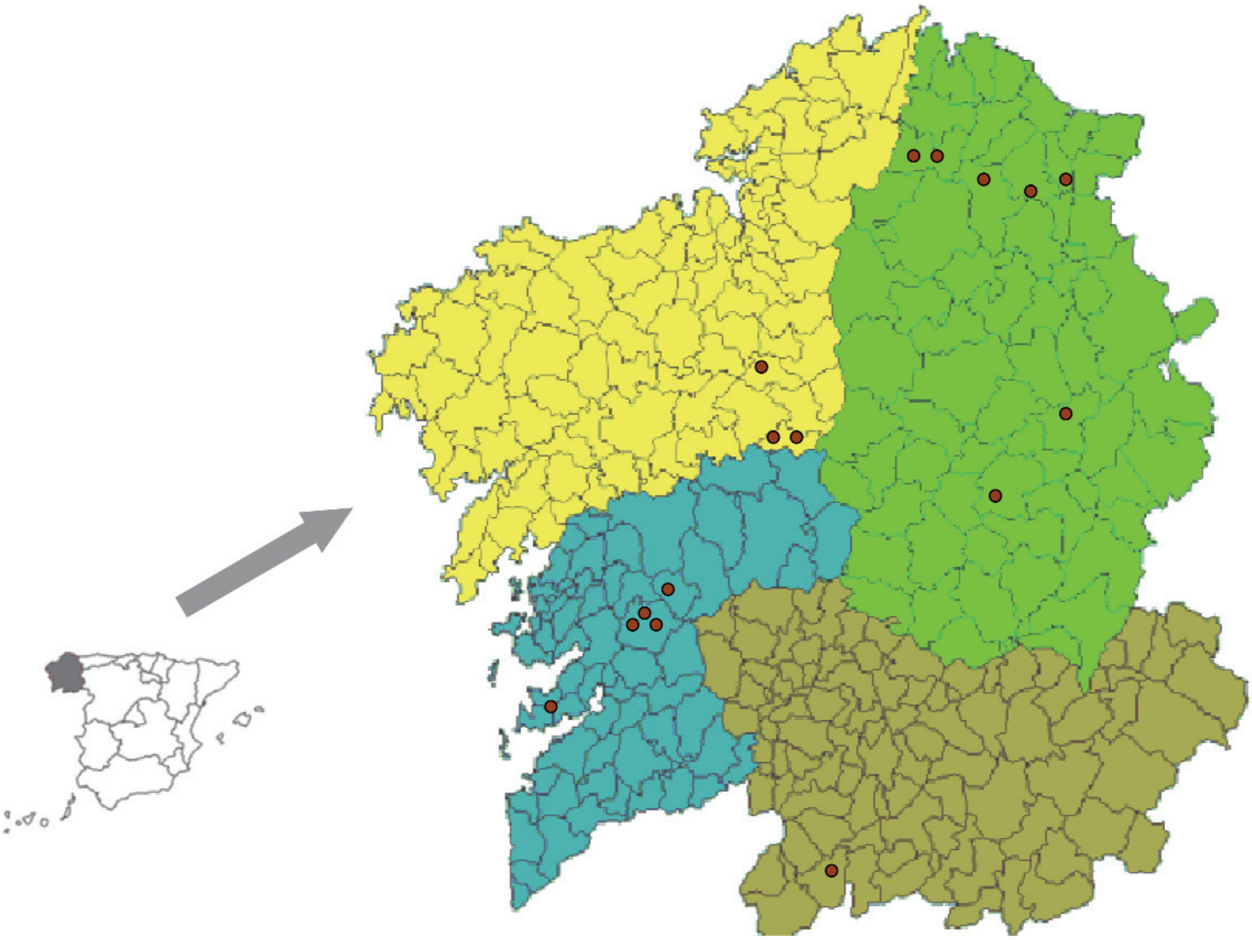


Figure 1. Location of the oak trees sampled from the different provinces and municipalities in Galicia (Spain).

radial cuts to obtain pieces of structural dimensions (Fig. 2).

The 76 planks with the most clearly radial orientation were selected as in these the sapwood tends to be located at the edge and these pieces are dimensionally more stable on drying. Selection of planks for tests was made examining solely the cutting plans in order to avoid the exterior appearance of the planks influencing the choice. The selected planks were air-dried for on average 745 days (range 302-910 days). The aim of the slow air-drying was to avoid the checks and warping that occur readily in rapidly dried oak timber. The programmed drying time was considered sufficient because, according to Collardet and Besset (1992), the air-drying time for 50 mm-thick oak pieces is 455 days.

After the planks were dried they were butted-off and planed to the target dimensions (50 × 100 × 2,000 mm) for carrying out the visual grading of beams (spars). The dimensions of each beam were measured and beams

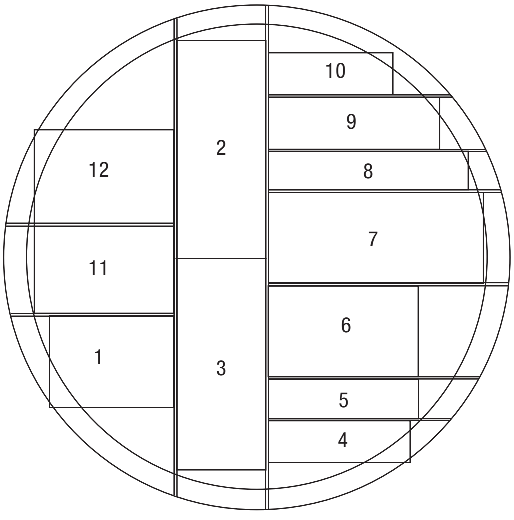


Figure 2. Example of simplified radial sawing, with two cutting lines and live sawing of the two half logs. In the scheme twelve sawn pieces were obtained, seven of structural dimensions (numbers 1, 2, 3, 6, 7, 11 and 12).

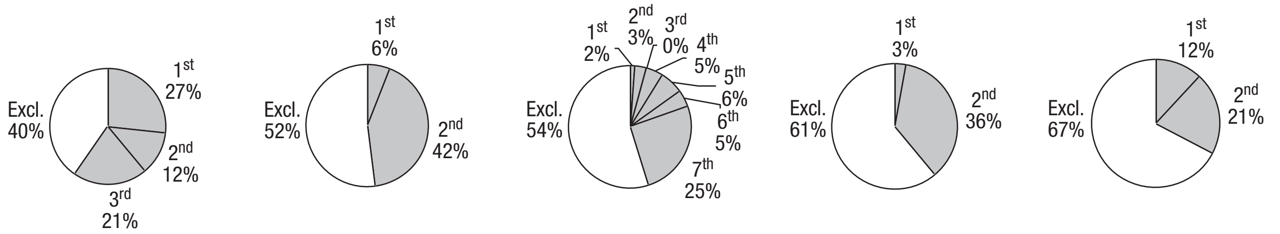
were visually graded according to seven grading standards for structural pieces. In accordance with the accepted standards, the beams were graded on the basis of certain characteristics and by the relative dimensions of these relative to the dimensions of the beam. Three such standards (UNE 56544:2007, 56546:2007 and NF B 52-001-4) were applied in two different ways (considering or not considering checks and distortions as defects in the classification criteria) and the remaining four standards were applied in a single way. Therefore a total of 10 methods of classification were tested (Fig. 3).

After visual grading, the local modulus of elasticity in bending and the bending strength were obtained for each beam, in accordance with EN 408:2004 (Fig. 4). A universal test machine (IBERTEST, model ELIB-100-CO) with a mobile cross loading-head that can generate a force of 100 kN was used for the mechanical test. To maintain the isostatic forces in the system (beam simply supported), steel plates were placed between the supports and the surface of the wood to prevent local indentation of the beams on the supports. Lateral stops were used to prevent buckling or the beams overturning, although the latter was unlikely as the ratio between the height of the beam (depth of the cross-section) and the thickness was less than four, as recommended by Desch and Dinwoodie (1996), and the slenderness ratio was much lower than the maximum recommended value of 50 (Breyer *et al.*, 2007).

To calculate the modulus of elasticity in static bending, the vertical deformation of the elastic curve was measured with a steel lath supported on the ends of the central segment of each beam. The lath was fitted with a sensor that measures differences in vertical deformation between the ends of the segment and the central point (Fig. 4). The sensor-codifier fitted in the transmission system of the machine was used as deformation sensor in the test of static bending strength to failure. The curve obtained for forces (in kilonewton) against deformations (in millimetres) was recorded for each static bending test, for 500-1,000 pairs of values.

Wood moisture content and apparent density were determined in accordance with EN 13183-1:2002 on a slab of width 20 mm, taken from the complete transverse section of the tested beam, in a knot-free area.

Analysis of variance of each mechanical variable with the quality grade factor was carried out to determine which visual grading method best predicts the modulus of elasticity in bending and bending strength. The method that provided most significant differences between classes for the mean values of the mechanical



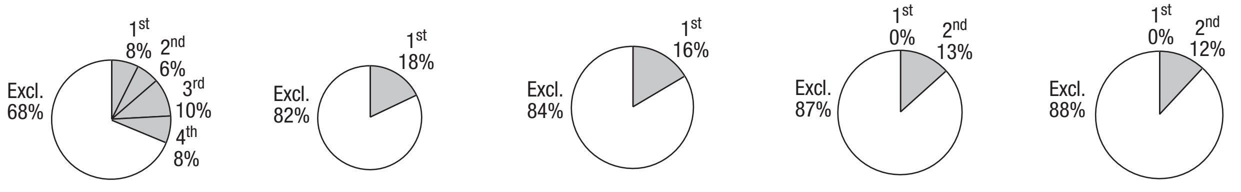
Norme CEE recommandee pour le classement des sciages resineux selon la resistance

UNE 56544:2007 (Visual grading of sawn wood for structural use) n.d.c.

UNE 56525:1972 (Grading of sawn wood for construction)

UNE 56544:2007 (Visual grading of sawn wood for structural use) c.d.c.

BS 5756:2007 (British standard specification for visual strength grading of hardwood)



Standard proposed by Argüelles and Arriaga (1988)

UNE 56545:2007 (Visual grading of sawn wood for structural use. Hardwood timber) n.d.c.

UNE 56545:2007 (Visual grading of sawn wood for structural use. Hardwood timber) c.d.c.

NF B 52-001-4 (Régles d'utilisation du bois dans les constructions) n.d.

NF B 52-001-4 (Régles d'utilisation du bois dans les constructions) c.d.

Figure 3. Distribution of structural specimens of oak by visual classes in accordance with the 10 grading standards. These are ordered by the level of requirements as regards acceptance of the pieces for structural use. Excl.: excluded from classification. n.d.c.: not considering distortions and checks as defects. c.d.c.: considering distortions and checks as defects. n.d.: not considering distortions as defects. c.d.: considering distortions as defects.

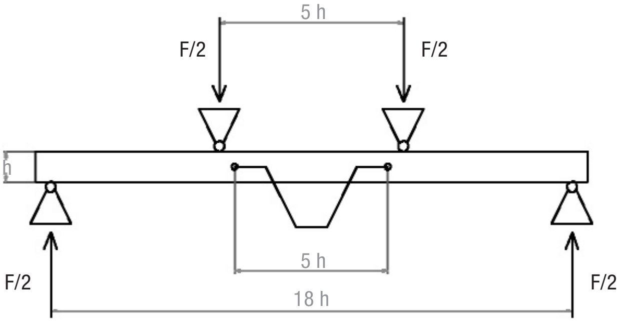


Figure 4. Diagram of the test device for determination of the modulus of elasticity in bending in accordance with EN 408:2004 European standard. *F:* test load. *h:* piece depth (100 mm).

properties analysed was considered the best. This analysis was complemented by examination of the overlap between the distributions of results by quality classes. The simplicity of the standard was also taken into account, as regards three aspects: i) use of few characteristics of the beams in the classification; ii) use of easy-to-measure, objective characteristics; iii) definition of few visual classes.

Finally, the mean and characteristic values were obtained in accordance with EN 384:2004 to determine whether the visual grades, obtained according to the visual grading method chosen, could be assigned to the European strength classes (EN 338:2009).

Results

A total of 67 mechanical tests were found to be valid after rejecting nine of the tests (12%) due to deficiencies in the operational process: recording errors, fracture at the start of the bending test and test times outside the range established in the standard method.

The buckling phenomenon was unexpected as the height/thickness ratio of the test specimens was two or three (less than four) and the slenderness ratio was much less than 50 (Desch and Dinwoodie, 1996; Breyer *et al.*, 2007) but the high strength of some test specimens gave rise to lateral instability due to buckling in some preliminary tests with 50 × 150 ×3,000 mm members, and thereafter the tests were only carried out with beams of lower depth/thickness ratio: dimensions 50 × 100 × 2,000 mm.

The air-drying process was very slow because of the thickness of the planks and their radial orientation (which hampered movement of the water). Thus the moisture content of approximately only one third of the pieces decreased to less than or equal to 20% (see entire sample in Table 1), the reference value considered in visual grading standards UNE 56544:2007, UNE 56546:2007, NF B 52-001-4, BS 5756:2007, EEC standard and in EN 408:2004 standard for mechanical tests. When drying 70 mm thick planks it is therefore advisable either to extend the air-drying period to more than two years or to use kiln drying.

As the moisture content of the timber was higher than the recommended level, lower bending strength was expected. However, bending strength and moisture content were not significantly related because in flawed structural timber, the defects determine the bending performance to a greater extent that the moisture content, and drying produces an increase in bending strength, compensated by the appearance of drying-related defects (Freas, 1995). On the other hand, the lack of a significant relationship between the mechanical property and moisture content of the sample may have been due to the limited range of moisture content allowed in the standard test, which prevents detection of any relationships between these variables.

For dense hardwood timber, in which it is difficult to reach the reference moisture content, ruling EN 408: 2004 establishes that the test should be carried out at another moisture content, which should be recorded. However, the moisture content in the bending strength test must not exceed 25% because at higher values, failure may occur as a result of axial compression (Farmer, 1972). In the present study, only one of the four test beams in which the moisture content exceeded the threshold value broke as a result of axial compression.

The results of bending strength and modulus of elasticity revealed high and unexpected dispersion (as measured by the coefficient of variation), despite the homogeneity of the specimens as regards density (see entire sample in Table 1). The variation in mechanical properties of structural timber may therefore be only partly explained by the variation in density and the characteristics of the material must be taken into account in explaining its mechanical behaviour.

Discussion

The distribution of the specimens in quality grades, in accordance with the 10 visual grading rules (Fig. 3), indicated that on average, the visual grading rulings excluded approximately two thirds of the test pieces (68.5%) for structural purposes. The most restrictive

Table 1. Descriptive statistics for the variables analysed. Visual grading carried out in accordance with UNE 56544:2007 (considering checks and distortions) and structural tests in accordance with EN 408:2004

Visual class	Variable	*n*	Mean	*CV* (%)	Characteristic value	Tentative strength class
Entire sample	*MOE*	67	9,528	34.4		
	MOR	67	44.9	35.5		
	ρ	67	813	9.0		
	H	67	21.3	12.7		
ME-1	*MOE*	2	6,748	86.3		
	MOR	2	36.7	35.9		
	ρ	2	837	2.6		
	H	2	20.0	0.9		
ME-2	*MOE*	24	11,071	32.4	11,702[1]	D40
	MOR	24	51.8	34.4	16.1[2]	Not assignable
	ρ	24	820	7.9	714,0[3]	D60
	H	24	21.8	17.3		
Excluded	*MOE*	41	8,761	30.2		
	MOR	41	41.3	33.1		
	ρ	41	807	9.8		
	H	41	21.1	8.9		

n: sample size. *CV:* coefficient of variation. *MOE:* modulus of elasticity in bending (N mm^{-2}). *MOR:* bending strength (N mm^{-2}). ρ: density (kg m^{-3}). *H:* moisture content (%). [1] Mean value ($E_{0,\text{mean}}$) calculated in accordance with EN 384:2004, without correction for moisture content, which was more than 18% in all cases. Reduction due to number of samples not applied. [2] Characteristic value of the 5-percentile (f_{05}) calculating by non parametric method, corrected to standard dimensions (edge = 150 mm) by dividing by $k_h k_l = 1.084$, in accordance with EN 384:2004. Reduction due to number of samples not applied. [3] Characteristic value of 5-percentile (ρ_{05}) calculated by parametric method, in accordance with EN 384:2004, with apparent density corrected to 12% moisture content.

visual grading standard was the French NF B 52-001-4 ruling, which excluded almost 90% of the pieces from the grades and did not include any of the specimens in the top quality. In contrast, the ruling that excluded fewest pieces and included most in the top quality was the European (EEC) standard based on the KAR (Knot Area Ratio) method.

As regards the predictive value of the visual grading for properties related to strength and rigidity, there were significant differences between grades for both mechanical properties in four of the 10 grading methods analysed (Table 2). Standard UNE 56544:2007 was most effective as regards distinguishing the beams with the best mechanical characteristics on the basis of apparent defects. This result was expected as this standard includes the greatest number of characteristics for consideration. In fact, when checks and distortions were not included as classification criteria in this method, the differences between mean values for the modulus of elasticity were less significant.

The standard grading method UNE 56544:2007, considering distortions and checks as defects, was finally selected considering that: i) this method resulted in the greatest (most significant) differences between grades in the analysis of variance; ii) it is one of the standards that included the greatest number of beams for structural use (Fig. 3), and iii) it is feasible to apply as only two visual grades are considered. The results of the mechanical tests for the quality grades defined in accordance with this standard, considering checks and distortions as defects in the classification, are shown in Table 1.

The statistically unsatisfactory results obtained with the EEC standard, mainly designed for conifers, and with BS 5756:2007, a general standard for hardwoods from temperate zones, can be explained by the fact that the methods were not originally developed for oak. However, the poor performance produced by application of the French NF B 52-001-4 standard was unexpected as the corresponding test is specifically designed for *Quercus robur* and *Q. petraea* (Table 2).

The visual grading was not expected to be very accurate as regards distinguishing pieces with different structural properties, because of the subjectivity in the evaluation of some timber characteristics, amongst other factors (*e.g.,* Green and Kretschmann, 1997; Vignote

Table 2. Analysis of variance for the variables modulus of elasticity (N mm^{-2}) and bending strength (N mm^{-2}), obtained in accordance with EN 408:2004, with visual quality grade as the source of variation

Standard	Modulus of elasticity in bending		Bending strength	
	F	*p*	*F*	*p*
Norme CEE recommandee pour le classement des sciages resineux selon la resistance	n. s.	n. s.	n. s.	n. s.
UNE 56544:2007 (Visual grading of sawn wood for structural use) n.d.c.	4.517	0.015	4.576	0.014
UNE 56544:2007 (Visual grading of sawn wood for structural use) c.d.c.	5.063	0.009	3.833	0.027
UNE 56525:1972 (Grading of sawn wood for construction)	n. s.	n. s.	2.544	0.037
BS 5756:2007 (British standard specification for visual strength grading of hardwood)	n. s.	n. s.	n. s.	n. s.
Standard proposed by Argüelles and Arriaga (1988)	3.565	0.011	2.621	0.043
UNE 56546:2007 (Visual grading of sawn wood for structural use. Hardwood timber) n.d.c.	4.833	0.031	5.312	0.024
UNE 56546:2007 (Visual grading of sawn wood for structural use. Hardwood timber) c.d.c.	4.435	0.039	n. s.	n. s.
NF B 52-001-4 (Régles d'utilisation du bois dans les constructions) n.d.	n. s.	n. s.	n. s.	n. s.
NF B 52-001-4 (Régles d'utilisation du bois dans les constructions) c.d.	n. s.	n. s.	n. s.	n. s.

n.d.c.: not considering distortions and checks as defects. c.d.c.: considering distortions and checks as defects. n.d.: not considering distortions as defects. c.d.: considering distortions as defects. n. s.: not significant. *F*: ratio between mean square of the model and mean square error. *p*: significance level.

Peña and Martínez Rojas, 2006). In fact UNE 56544:2007 standard, selected as the most effective method, produced important overlaps between the structural class and the subsample of rejected specimens (Fig. 5). Use of this standard led to several pieces being rejected for structural purposes because of large face and edge knots, as reported by Courchene *et al*. (1998), even though the pieces showed good properties as regards elasticity and strength. The grading rule would therefore be more effective for predicting mechanical behaviour if it included a less restrictive criterion for knot size.

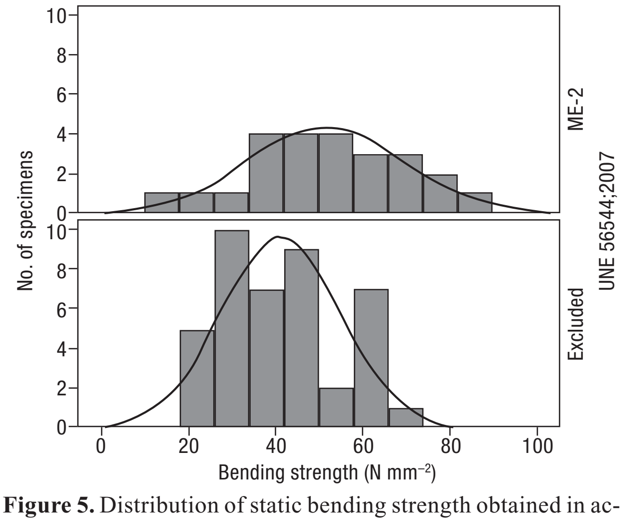


Figure 5. Distribution of static bending strength obtained in accordance with EN 408:2004 European standard, for the oak wood sample visually graded in accordance with UNE 56544:2007.

Some beams were visually graded as apt for structural use but proved to have poor elasticity and strength-related properties, which are important safety considerations in construction. The only defects of any importance in all of these pieces were checks, bow, spring and twist. The mean properties of visual class ME-2 are slightly decreased (MOE reduction: 1.8%; MOR reduction: 0.8%) if distortions and checks are not included as classification criteria. Therefore a more restrictive criterion than that included in UNE 56544:2007, as regards checks and distortions, should be applied.

Establishment of specific tolerances for knot size (Green and Kretschmann, 1997) is essential in the design of a future standard for oak as in the specimens analysed there was a significant relationship between maximum knot size and mechanical strength: inverse correlation between the diameter of the largest edge knot and the static bending strength ($R^2 = 0.23$; $p = 0.001$). However, the correlation was not sufficiently high to justify proposal of a predictive model for mechanical behaviour of the beams on the basis of knot size. The different treatment of knots depending on their position —face or edge— should be maintained as a classification criterion, as the closer knots are to edges, the more undesirable they are (Schaffer, 1995; Courchene *et al*., 1998).

The requisites included in UNE 56544:2007 standard are very restrictive with regard to the presence of wane, which if present even in a low proportion immediately relegates the beam to grade ME-2 or excludes pieces with good mechanical properties from structural use (Courchene *et al.*, 1998). It is recommended that a less restrictive criterion is applied for this character or that the criterion included in UNE 56544:2007 is only applied to the central area of the span, as the quality depends on this critical section (Green and Kretschmann, 1997), which should always be comprised between the loading points (EN 384:2004).

On the other hand, the properties of specimens with wavy fibres extended throughout the beam were very poor in terms of elasticity and strength and therefore in any future visual grading rule for oak, this defect should be considered as a criterion for exclusion.

The coefficient of variation obtained in the subsample for visual grade ME-2 (Table 1) was used as an estimator of the visual class dispersion. The same inference was not performed with top quality (ME-1) pieces due to their scarcity in the study. It is assumed the random sampling of the specimens and the normality of the distributions of density, bending strength and modulus of elasticity in a larger sample size for visual class ME-2. On these assumptions (randomness of sampling, normality of distributions of properties), the minimum number of specimens in a sample needed to ensure the assignation of a visual class to a strength class was obtained (Fig. 6). The number of specimens was calculated as a function of the expected accuracy of the estimations, measuring the accuracy by the maximum admissible error. The variable exhibiting highest dispersion was bending strength (Table 1) and the number of specimens was therefore calculated for this variable. If the admissible error was half of the lowest interval between characteristic values in the EN 338:2009 standard (2.5 N mm^{-2}; relative error 4.8%) and the p-value is 0.05, the number of 50 × 100 mm section specimens to be tested would be at least 198. As the results of the study revealed that 12% of the tests were not valid, the proposed sample size increases to 225. The number of specimens required for other sections (vg. 50 × 150 mm) is expected to be lower due to the reduction in dispersion as the volume of the specimen increases. Similarly, the number of specimens necessary for characterizing a sample of plainsawn planks is also expected to be lower because these pieces include less of the pith-to-bark variation in wood properties. However, from a conservative point of view, a similar number of specimens for each type of section was also proposed, and up to a maximum of five types of section, as established in EN 384:2004. Additionally, a sample size of 40 specimens, the minimum established in EN 384:2004, would lead to an error of 5.5 N mm^{-2} (relative error 10.6%), according to Figure 6.

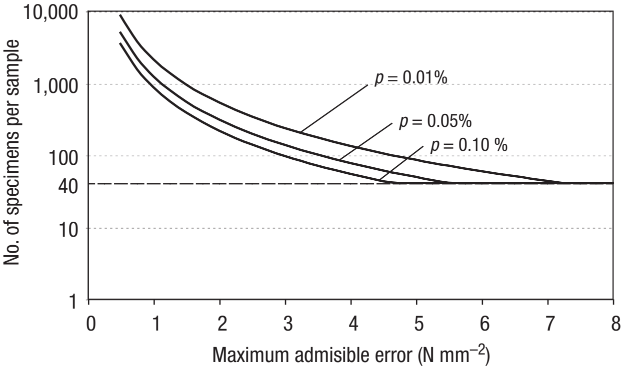


Figure 6. Proposed sample size necessary for the assignation of an oak timber visual class to the international strength class system (EN 338:2003) as a function of the admissible error in the estimation of characteristic bending strength.

The number of valid tests per sample (198) was slightly higher than the maximum number of specimens per sample (193) used in the characterization of Spanish provenances of Scots pine (Hermoso Prieto *et al.*, 2003) and laricio pine (Fernández-Golfín Seco *et al.*, 2004).

An estimation of the possible characteristic values (EN 384:2004) were calculated for the data set for visual grading class ME-2, due to the small number of pieces classified as top quality (ME-1). The results and the tentative assignation of grade ME-2 to the European classes (defined in EN 338:2009) when the reduction due to sample size was not applied are shown in Table 1 (the reduction should have been applied in this case as only one sample —a 50 × 100 mm cross-section— and only 24 structural specimens classified as grade ME-2 were included in this sample). Considering the sample results, the grade ME-2 pieces would be assigned respectively to strength classes D40 and D60, in light of their modulus of elasticity and their corrected density for 12% moisture content. However, the poor bending strength results determined that the sample was finally not even assigned to class D18, the lowest grade for hardwoods.

The low bending strength quality of the sampled oak timber, in contrast with the acceptable elastic properties, may be due to the calculation of the characteristic value of bending strength based on the non parametric method, which strongly penalises small samples. The moisture content of the test specimens, which was somewhat higher than the reference value considered in European standard EN 338:2009, must also be taken into account, although as already indicated, no important variation in bending strength in relation to moisture content appeared to occur in this case.

Conclusions

The visual grading standard of highest predictive value from amongst the 10 analysed was Spanish standard UNE 56544:2007, although it tends to provide erroneous predictions as regards the strength of the piece due to excessively restrictive criteria for certain types of defects (knots, wane) and excessively lax for others (checks, distortions). Visual grading standards for structural wood members should therefore be elaborated in collaboration with the relevant institutions and timber industries, with specific criteria for oak timber. With this aim and in light of the results obtained, the following are proposed:

i) A new criteria should be established for the visual grading of oak timber destined for construction, similar to the existing UNE 56546:2007 Spanish standard for hardwoods.

ii) Wider tolerances should be established for the size of knots on the beam face (to admit healthy adherent face knots of diameter less than or equal to three fifths of the depth of the face in pieces of up to 150 mm depth, to quality grade ME-2).

iii) Wider tolerances should be established for the size of edge knots (to admit healthy adherent edge knots of diameter less than or equal to three quarters of the thickness of the piece, to quality grade ME-2).

iv) Wider tolerances should be established for wane size (to admit wane of width less than or equal to half the thickness of the piece, to quality grade ME-2).

v) A more restrictive criterion should be applied as regards distortions (establish for quality grade ME-2 the same restrictions currently applied to quality class ME-1 for bow and spring).

vi) The presence of wavy fibres should be considered as a criterion for exclusion, whether extended throughout the beam or only in the central zone.

In the estimation of the characteristic bending strength, a minimum of 225 members must be tested in each section (each sample).

With beams of thickness 70 mm more and up it is recommended to extend the air-drying period to more than 745 days or to use kiln drying.

Owing to its rigidity and density, the second visual grade for oak (ME-2), defined under the prevailing standard (UNE 56544:2007), could be at least assigned to intermediate strength classes. However, the low bending strength of grade ME-2 prevents preliminary assignation of the sample to the European strength classes.

Lateral instability phenomena were not produced in mechanical strength test EN 408:2004, carried out with quarter-sawn beams of depth of the cross-section two times greater than the thickness, but lateral instability phenomena appeared with deeper beams despite the lateral stops used to prevent buckling. Therefore, in future studies with oak timber, the depth should be reduced to less than 150 mm, the value established as a reference in the European standard, because the alternative of increasing the thickness of the specimens would enlarge the air-drying phase excessively for practical terms.

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References

ADELL ALMAZÁN F.J., HERMOSO PRIETO E., ARRIAGA MARTITEGUI F., RICHTER C., 2008. Comparison of the Spanish visual strength grading standard for structural sawn timber (UNE 56544) with the German one (DIN 4074) for Scots pine (*Pinus sylvestris* L.) from Germany. Holz als Roh-und Werkst 66(4), 253-258.

AENOR, 1972. UNE 56525:1972. Clasificación de la madera aserrada de construcción. AENOR, Madrid. 2 pp.

AENOR, 1978. UNE 56528:1978. Preparación de probetas para ensayos. AENOR, Madrid. 3 pp.

AENOR, 2005. EN 1912:2005+A2:2008. Madera estructural. Clases resistentes. Asignación de calidades visuales y especies. AENOR, Madrid. 22 pp.

AENOR, 2007a. UNE 56544:2007. Clasificación visual de la madera aserrada para uso estructural. Madera de coníferas. AENOR, Madrid. 26 pp.

AENOR, 2007b. UNE 56546:2007. Clasificación visual de la madera aserrada para uso estructural. Madera de frondosas. AENOR, Madrid. 24 pp.

AFNOR, 1992. NF B 52-001-4. Régles d'utilisation du bois dans les constructions. AFNOR, La Plaine Saint-Denis. 24 pp.

ARGÜELLES R., ARRIAGA F., 1988. Curso de diseño y cálculo de estructuras de madera. Colegio Oficial de Arquitectos, Madrid, Spain. 173 pp.

BERMÚDEZ J.D., 1997. La industria de transformación de la madera de Galicia. CIS Madera 0, 7-14.

BREYER D.E., FRIDLEY K.J., COBEEN K.E., POLLOCK D.G., 2007. Design of wood structures-ASD/LRFD, 6th ed. McGrawHill Inc, New York, United States.

BRITISH STANDARDS INSTITUTION, 2007. BS 5756: 2007. Visual grading of hardwood. Specification. BSI, London. 20 pp.

COLLARDET J., BESSET J., 1992. Bois commerciaux (vol. II). Feuillus des zones tempérées. H Vial and CTBA, France. 399 pp.

COURCHENE T., LAM F., BARRETT J.D., 1998. The effect of edge knots on the strength of SPF MSR lumber. For Prod J 48(4), 75-81.

DEGRON R., NEPVEU G., 1996. Methodology of microdensitometric measurement for oak wood (*Quercus robur* L. and *Quercus petraea* Liebl): proposal for a representative sampling of oak wood density within ring. Holzforschung 50(6), 491-496.

DESCH H.E., DINWOODIE J.M., 1996. Timber. Structure, properties, conversion and use. MacMillan Press Ltd, Hong-Kong. 306 pp.

EUROPEAN COMMITTEE FOR STANDARDIZATION, 2002. EN 13183-1:2002. Moisture content of a piece of sawn timber - Part 1: Determination by oven dry method. CEN, Brussels. 8 pp.

EUROPEAN COMMITTEE FOR STANDARDIZATION, 2004a. EN 384:2004. Structural timber. Determination of characteristic values of mechanical properties and density. CEN, Brussels. 17 pp.

EUROPEAN COMMITTEE FOR STANDARDIZATION, 2004b. EN 408:2004. Timber structures. Structural timber and glued laminated timber. Determination of some physical and mechanical properties. CEN, Brussels. 33 pp.

EUROPEAN COMMITTEE FOR STANDARDIZATION, 2010. EN 338:2009. Structural timber. Strength classes. CEN, Brussels. 12 pp.

FARMER R.H., 1972. Handbook of hardwoods, 2nd ed. Her Majesty's Stationery Office, London, UK. 243 pp.

FERNÁNDEZ-GOLFÍN SECO J.I., DÍEZ BARRA M.R., HERMOSO PRIETO E., CONDE GARCÍA M., 2004. Mechanical characterization of timber from Spanish provenances of laricio pine according to European standards. Wood Sci Technol 38(1), 25-34.

FERNÁNDEZ-GOLFÍN J.I., DÍEZ M.R., HERMOSO E., BASO C., CASAS J.M., GONZÁLEZ O., 2007. Caracterización de la madera de *Eucalyptus globulus* para uso estructural. Boletín del CIDEU 4, 91-100.

FREAS A.D., 1995. Wood properties. In: Wood engineering and construction handbook, 2nd ed (Faherty K.F., Williamson T.G., eds). McGrawHill Inc, New York, United States. pp. 1-29.

GREEN D.W., KRETSCHMANN D.E., 1997. Properties and grading of southern pine timbers. For Prod J 47(9), 78-85.

HERMOSO PRIETO E., FERNÁNDEZ-GOLFÍN SECO J.I., DÍEZ BARRA M.R., 2003. Mechanical characterization of timber according to European standards from Spanish provenances of Scots Pine. Invest Agrar: Sist Recur For 12(3), 103-110.

IGLESIAS A., 1998. Comercio exterior de industrias de la madera en los países de la UE: análisis del período 61-95 y modelización econométrica. Doctoral thesis. Universidad de Santiago de Compostela, Santiago de Compostela.

MARM, 2008. Anuario de Estadística Agroalimentaria y Pesquera 2007. Ministerio de Medio Ambiente, y Medio Rural y Marino, Madrid, Spain. 1002 pp.

NASSAR D., 1996. La construcción de madera en España. El campo 134, 295-302.

RIESCO MUÑOZ G., 2001. Estudio de las propiedades físico-mecánicas de la madera de roble (*Quercus robur* L.) de Galicia en relación con las variables del medio. Doctoral thesis. Universidad Politécnica de Madrid, Madrid.

SCHAFFER E.L., 1995. Preliminary design considerations. In: Wood engineering and construction handbook, 2nd ed (Faherty K.F., Williamson T.G., eds). McGrawHill Inc, New York, United States. pp. 30-60.

UNITED NATIONS. ECONOMIC COMMISSION FOR EUROPE, 1988. Norme CEE recommandee pour le classement des sciages resineux selon la resistance. United Nations, Genève. 25 pp.

VAN ACKER J., MILITZ H., STEVENS M., 1999. The significance of accelerated laboratory testing methods determining the natural durability of wood. Holzforschung 53(5), 449-458.

VIGNOTE PEÑA S., MARTÍNEZ ROJAS I., 2006. Tecnología de la madera. Mundi-Prensa, Madrid, Spain. 687 pp.

XUNTA DE GALICIA, 2001. O bosque galego en cifras. Consellería de Medio Ambiente, Santiago de Compostela, Spain. 226 pp.

ZHANG S.Y., NEPVEU G., OWOUNDI R.E., 1994. Intratree and intertree variation in selected wood quality characteristics of European oak (*Quercus petraea* and *Quercus robur*). Can J Forest Res 24(9), 1818-1823.