

Mechanical characterization of visually classified, small-diameter laricio pine round timber

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Abstract

This work reports the mechanical characterization of small-diameter logs (diameter < 23 cm) of laricio pine (*Pinus nigra* subsp. *Saltzmanii*) from the forests of Cuenca, Spain. Some 445 machine-rounded small logs with final diameters of 8, 10, 12 and 14 cm were examined in accordance with the standard EN 14251, and the conclusion reached that ungraded material can be assigned a strength class of C14 (according to EN 338), while graded material can be assigned to different combinations of strength classes (C18/C14 or C20/C16) depending on the visual grading standard used. Grading yields were examined using three different standards, DIN 4074, VPS-SRT-2 and prEN 14544, and the results obtained with each compared to those provided by the optimal ranking methodology set out in standard EN 14081-2. VPS-SRT-2 appeared to be the most suitable visual grading standard. There is a need to design mixed grading methods based on the use of non-destructive tests and the visual evaluation of specific wood features.

Additional key words: European standards, *Pinus nigra*, strength classes, structural round-timber, visual evaluation.

Resumen

Caracterización mecánica de la madera en rollo delgada de pino laricio, clasificada visualmente

En el presente trabajo se presentan los resultados de la caracterización mecánica efectuada sobre madera en rollo delgada (diámetro inferior a 23 cm) de pino laricio (*Pinus nigra* subsp. *Saltzmanii*) procedente de los Montes de Cuenca, España. Se ensayaron, de acuerdo con la norma EN 14251, un total de 445 rollizos torneados con diámetros finales de 8, 10, 12 y 14 cm, concluyéndose que el material sin clasificar puede ser asignado a una clase de resistencia de C14 (según EN 338), mientras que el clasificado puede ser asignado a diversas combinaciones de clases de resistencia (C18/C14 ó C20/C16) en función de la norma de clasificación empleada. Se analizó el rendimiento clasificatorio y la asignación de clases de resistencia a clases de calidad obtenidas empleando tres normas de clasificación visual: DIN 4074, VPS-SRT-2 y prEN 14544. Los resultados obtenidos con cada norma de clasificación visual, expresados en forma de rendimientos clasificatorios, fueron confrontados con los obtenidos mediante la metodología de la «Clasificación Óptima» contenida en la norma EN 14081-2. Se concluye sobre la superioridad de la norma VPS-SRT-2, así como sobre la necesidad de proceder a diseñar métodos mixtos de clasificación basados en el empleo de técnicas de ensayo no destructivas y de evaluación visual de determinados caracteres.

Palabras clave adicionales: clases de resistencia, estándar europeo, evaluación visual, madera en rollo estructural, *Pinus nigra*.

Introduction

Small-diameter round timber is defined as coming from trees whose normal diameter is < 23 cm (Wolfe, 2000). These small-diameter logs are mainly obtained during thinning operations in natural and artificial forests (mainly conifer forests). They may also derive

from end-logs and treetops, products which are not suitable for sawing.

Good forest management is necessarily associated with thinning operations at different points in the growth cycle. Unfortunately, the high cost of these operations, coupled with the lack of profitable resultant products, can hinder or even prevent them being undertaken. The failure to do so, however, exacts a cost in terms of forest health and quality-profits at the end of the cycle become reduced since the quality of the timber is poorer. A priority of research should be to find tech-

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nically and economically viable alternatives for the use of the small-diameter logs obtained during these operations. Profit-making applications for this material could help recover the costs of extraction work, provide rural populations with income and industrial opportunities, help improve the health of forests, and minimise the risk and size of forest fires (Levan-Green and Livingston, 2001; Hernández *et al.*, 2005).

Although the economic advantages of thinning operations have been clear to forest managers for decades, it was not until the 1980s that they were fully recognised by political authorities. This explains the relatively small amount of research undertaken in this area, a fact reflected by the limited literature published on the subject until the 1990s. Only then were research projects designed to investigate new and more profitable applications for the material obtained. The intense work on the industrial characterisation of this material during the 1950s and 1960s should be highlighted, but it is important to point out that these research efforts had the aim of using this material in the manufacture of particle boards and cellulose paste-applications that have turned very low profits for forest owners (Piqué and Romá, 2000). A clear demonstration of change was seen during the 1990s, when, aware of the above-mentioned problems, the USDA Forest Service reoriented a large part of its research resources towards a huge programme aimed at developing more efficient uses of small-diameter logs obtained during thinning operations (FPL, 1998). Since 1993 the Forest Products Laboratory (USDA Forest Service) has been working on a new programme, not based on large industrial solutions that require prohibitive infrastructures and investments by the sector, but on approaches at the near-rural scale, developing processes that supply local markets and create products with high added value.

In accordance with the above, the greatest technical developments in this field have taken place in the USA, although mainly in the wood-based panel and cellulose industries. Structural products made with small diameter-log material [composed of particles (of different lengths) and adhesives] include oriented strand boards (OSBs), parallel strand lumber (PSL), and scrimber, etc., all of which are now commonplace in the timber market. A recent study by Hernández *et al.* (2005) opened up the possibility of using small-diameter logs as a raw material in the manufacture of glue-laminated timber.

The current situation with respect to the use of this material in Europe in general, and in Spain in particular, is very similar to that of the USA at the beginning of

the 1990s. In Spain, small-diameter logs are basically used as biomass, in small rural applications (for making fence posts etc.), and for the manufacture of particle and fibre boards, cellulose paste and pallets, all of which produce only small profits for forest owners (Piqué and Romá, 2000). The income derived often does not even cover the cost of extraction, grading and transport. It should not be forgotten, however, that in 1964 the Timber Characteristics and Applications Section of the Forest Research Institute of Spain (IFIE, 1964) started a vast and ambitious 4-year programme entitled «*Work plan for rationalisation of the exploitation and transformation of logs for sawmilling and small-dimension timber*». This dealt with the optimisation of techniques for the handling of the raw material and its industrial transformation into containers, packaging, particle and fibre boards, and plywood panels. This led to profits being made since the national wood-based panel and pulping industries, as well as the packaging and manufacturing industries, started to use this raw material on a mass scale. This situation remained unchanged until recently, when the recycling of raw materials began in earnest, especially in the wood-based panel and pulping industries.

In Europe, Ranta-Maunus (1999) undertook a study of the European situation. This author's report drew some very important conclusions and was seen as a breakthrough. The most important was that small-dimension logs were able to fulfil the requirements of the Directive on Products for Construction (DPC). Nevertheless, a number of problems were detected that had to be overcome in order to achieve the efficient use of this construction material, such as the need to determine its mechanical properties by species and origin, the update of selection and processing methods, the design of efficient connection systems, and the solution of construction problems.

In 2001, the present authors began to study the mechanical characterization of small-diameter logs of *Pinus nigra* in Spain to assess their potential for building purposes. The importance of this species is based on the fact that a physical/mechanical and technological characterisation (finally published by Conde, 2003) of its sawn wood has shown it to be the country's most competitive timber (in terms of strength) for the construction market. Recently, the study of the properties and structural applications of round timber, and their implications in terms of technology and processes, has been the focus of a number of studies (Schmoltdt *et al.*, 1995; Schad *et al.*, 1996; Boren and Barnard, 2000; Erikson *et al.*, 2000; Wolfe, 2000; Wolfe and Moseley,

2000; Levan-Green and Livingston, 2001; Lindstrom *et al.*, 2002; Green *et al.*, 2004). The aim of the present work was to assess the mechanical properties of small logs of *P. nigra*, and the most suitable way of grading this material. To determine the best classification system, log samples were classified visually using three different standards—prEN 14544, DIN 4074 and VPS-SRT-2—and the results compared to those obtained with the optimal ranking system (OPTR) established by European standard EN 14081-2. Replacing the latter with one of these classification systems would be helpful since OPTR requires the destruction of the wood; its industrial applications are therefore limited.

Material and Methods

The work of Conde (2003) showed that there are no significant differences between the physical and mechanical properties of sawn lario pine timber from its two main areas of origin in Spain as defined by Catalán Bachiller *et al.* (1991): Region 7 («Iberian System») and Region 8A («Cazorla-Alcaraz»). Given the collaboration secured with the company «Ayuntamiento de Cuenca Maderas SA», and the work permission granted by the Cuenca City Council, the selection of samples and their preparation was undertaken in the «Montes de Cuenca» (the forests of Cuenca, in Region 7).

Before selecting and preparing the samples, an analysis was made of the tree-marking processes undertaken in the Montes de Cuenca over the last five years. This showed that between 20 and 23% of marked trees could be defined as small-diameter round timber (normal diameter of <23 cm).

Test samples (n = 445) were selected randomly from trees already marked for thinning in 2002. The prepara-

tion (debarking, longitudinal cutting, machine rounding, air drying under cover and treatment) of the test samples was performed at the collaborating company's sawmill. A total of 445 machine-rounded logs (Table 1) were prepared with diameters of 8, 10, 12 and 14 cm, and lengths of 2, 2.5 and 3 m. The material was air-dried under cover to a final moisture content of 14%.

Before the mechanical testing of the samples they were all inspected to record their defects and peculiarities (maximum, minimum and average diameters, size and distribution of the knots, length and depth of cracks, presence and position of whorls, presence of juvenile wood, average and maximum size of the growth rings, etc.) in accordance with the methodologies established by standard EN 1310. The aim of this exhaustive qualitative inspection was to be able to later grade the material according to any possible standard.

Along with the visual inspection of all samples, the velocity of their transmission of ultrasound was measured using a SYLVATEST DUO apparatus (ConceptBoisTechnologie).

After visual inspection, all samples were subjected to a mechanical test up to failure point. Testing was performed according to the methodology of European standard EN 14251. To avoid the logs rolling during the test a system of wedges (with a concave shape in the contact zone) was necessary, both for the lower support of the pieces and for the force transmission heads. To measure the deformation in the logs, the apparent modulus of elasticity was determined by suspending a lightweight yoke between two nails driven into the logs' neutral axis (in line with external supports) and attaching an LVDT deflector to the centre of the yoke with the upper part of its stem attached to a nail driven into the log (also on the neutral axis) (Fig. 1). The following values were then calculated: maximum

Table 1. Average mechanical properties of the samples (n = 445) with respect to diameter class

Sample data and mechanical properties							
Diameter (cm)	Length (m)	No.	Density (kg m ⁻³)		E_g^1 (N mm ⁻²)	f_m^2 (N mm ⁻²)	
			Mean	Characteristic ^c		Mean	Characteristic ³
8	2	120	460.5	390.5	6,574	39.2	24.0
10	2.5	120	447.5	378.9	7,031	39.9	25.0
12	2	105	472.8	401.1	7,970	44.3	24.7
14	3	100	456.5	370.1	7,109	43.6	22.3
Total	—	445	462.2	398.1	7,100	41.2	24.6

¹ E_g : global modulus of elasticity in bending. ² f_m : bending strength. ³ Characteristic value: non parametric 5th percentile.

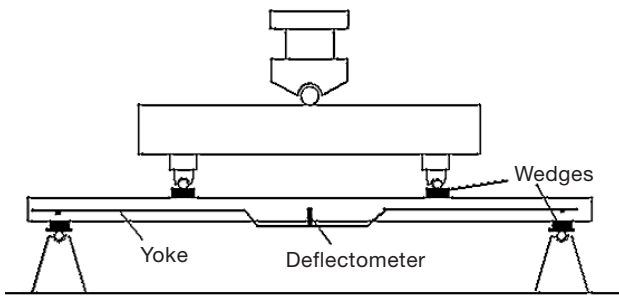


Figure 1. UNE-EN 14251 test apparatus.

bending stress (f_m), global modulus of elasticity (E_g), and density (assessed close to the rupture section).

To provide the strength properties in terms of quality grades (as in sawn timber), the test materials were graded into homogenous lots using different visual standards. One of these was European standard prEN 14544, which provides the anatomical and physical characteristics to be taken into account by grading standards developed at national levels. This harmonised standard contemplates three different visual grades: A, B and C. The recording of the physical characteristics was performed according to the methodologies outlined in standard EN 1310. This system of characterization is the same as that proposed for sawn timber. The other two standards used were DIN 4074 (Germany) and VPS-SRT-2 (Finland), the only standards for small round logs that exist in Europe at the present time. A methodological problem in terms of result comparison was that these standards do not have the same number of quality grades. While DIN 4074 and prEN 14544 contemplate three quality grades (plus rejects), VPS-SRT-2 contemplates only two. Thus, to allow comparison of the results, it was decided to present only two quality grades per standard (plus rejects). ANOVA was therefore performed to identify the overlapping grades. The calculation of the characteristic values was performed following the criteria of standard EN 384. The assignation of quality grades to strength classes was performed according to standard EN 338.

To assess which of the three grading standards provided the best results, it was necessary to compare their grading yields with those of an optimal grading system (known as optimal ranking or OPTR) performed taking into account the real strength, elasticity and density by testing according to EN 14251 (unfortunately OPTR is not directly applicable in the industrial setting since it destroys the wood). For this, the methodology described in standard EN 14081-2 was followed. As its name suggests, optimal ranking is that which

would be obtained if using an optimal grading standard. The optimal ranking results for the combinations of strength classes C18/C14/Reject and C20/C16/Reject were compared to the results obtained by the three visual grading standards.

In order to compare the grading behaviour of every grading standard the following scoring method was used:

- For each small log graded correctly (agreement with OPTR): 1 point.
- For each small log undervalued by one grade: -0.5 points.
- For each small log undervalued by two grades: -1 point.
- For each small log overvalued by one grade: -1 point.
- For each small log overvalued by two grades: -2 points.

Given that grading errors associated with the first quality material can have more serious consequences than those associated with the second quality material, and that grading errors associated with the latter material are more serious than those associated with reject material, the score obtained for first quality grading was multiplied by a risk factor weighting of 3, the second quality score by 2, and the reject score by 1.

All statistical tests were performed using STATGRAPHICS v. 5.0 software.

Results

Table 1 shows the results obtained for the mechanical properties and densities of the logs, expressed with respect to diameter class.

Figures 2A and 2B show the ANOVA results involving bending strength as the indicator property. Three homogeneous groups can be seen for standards DIN 4074 and prEN 14544; this allows the number of quality grades to be reduced from three to two, plus the reject grade.

Table 2 shows the results expressed in terms of grading standard and quality class. The two classes contemplated per standard were identified in agreement with the principles outlined in Figures 2A and 2B.

Table 2 shows that, from the point of view of grading yields, standard VPS-SRT-2 provides the best results, standard prEN 14544 provides notably poorer results, and standard DIN 4074 provides intermediate results. If this comparison were performed taking into account the characteristic values of strength, elasticity and

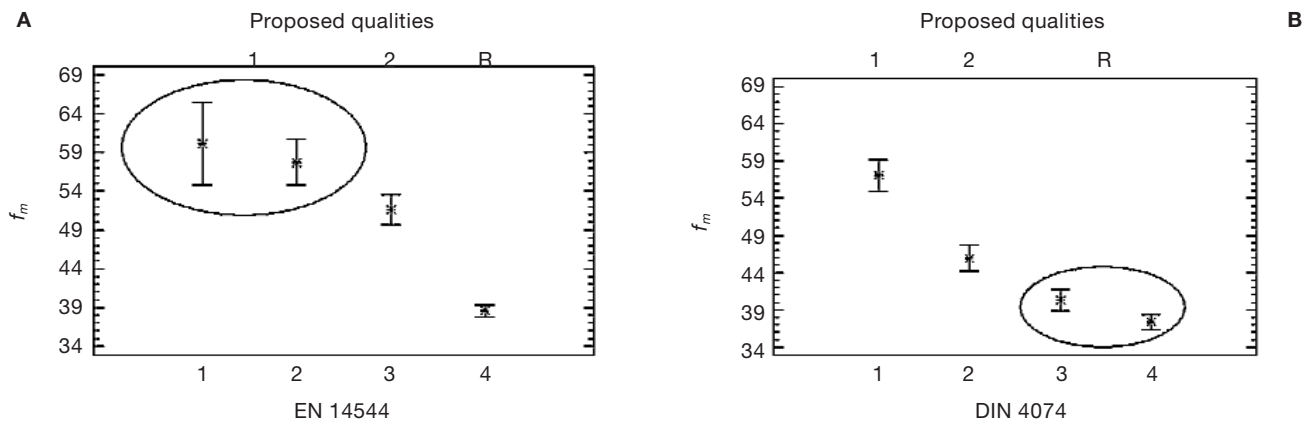


Figure 2. ANOVA analysis and possible groupings according to bending stress (f_m): A) prEN 14544 (initial qualities 1 and 2 grouped into the new final quality 1). B) DIN 4074 (initial qualities 3 and Reject grouped together into the new Reject quality).

density it would be concluded that prEN 14544 standard gives the best results, DIN 4074 the second best, and VPS-SRT-2 the poorest.

Table 3 shows the OPTR results obtained according to EN 14081-2. When the target strength class combination C18/C14/R suggested by this standard (top line, Table 3) was used in this analysis, up to 80% of the small diameter logs appeared apt for structural use (apt being defined as material assigned to any strength class contemplated in EN 338); 27.6% of the samples showed a mechanical behaviour assignable to a strength class of C18, which is very common for sawn timber. When, however, the C20/C16/R combination was used, only 49% of the material appeared to be apt for structural use, although up to 32.4% of this would have a strength as high as C20.

Table 3 shows that the modulus of elasticity is that which led this timber to be classified as belonging to lower strength classes; the true resistance is actually higher.

To determine whether the visual grading standards employed might be considered acceptable, the assigned class and grading yields obtained with each (Tables

4A, 4B and 4C) were compared to those obtained with the OPTR method. This was performed according to the methodology described in standard EN 14081-2.

Table 4A shows that European standard prEN 14544 did not correctly grade this material. Although it identified rejects correctly (see the R-R cell), it either overvalued or undervalued the strength class of many samples.

Table 4B shows that the DIN 4074 standard identified the first quality pieces reasonably well (57.7%), but undervalued 22% of true first quality pieces by one class and 20.3% by two classes. With respect to second quality pieces, this standard provided much poorer results: it correctly identified only 15.9% of true second quality material, overestimating 24% by one class and underestimating 60.1% by one class. The same standard correctly identified 74.1% of the rejects but overvalued the strength of 12.4% of true rejects by one class and 13.5% by two classes.

With respect to the grading of the first quality timber, Table 4C shows that the VPS-SRT-2 standard correctly identified 77.2% of these pieces, undervaluing 13.8%

Table 2. Yields and mechanical properties per grading standard

	DIN 4074			VPS-SRT-2			prEN 14544		
	1 st	2 nd	R	1 st	2 nd	R	1 st	2 nd	R
No. samples	139	75	231	189	90	166	34	58	353
Yield (%)	31.2	16.9	51.9	42.5	20.2	37.3	7.6	13.1	79.3
f_k (N mm ⁻²)	26.9	21.5	22.5	25.8	21.4	22.5	36.7	27.2	22.6
E_m (N mm ⁻²)	8,428	7,581	6,786	8,289	7,173	6,600	9,447	8,545	6,624
$Density_k$ (kg m ⁻³)	353.9	387.1	364.0	357.7	384.1	361.8	395.7	380.5	357.4
<i>S. Class EN338</i>	C18	C14	<C14	C18	C14	<C14	C20	C16	<C14

R: rejects.

Table 3. Grading yields and mechanical properties per optimal strength class combination

Optimal assignment Target Optimal S. Class	C18/C14/Reject			C20/C16/Reject		
	C18	C14	R	C20	C16	R
No. samples	123	233	89	144	74	227
Grading yield (%)	27.6	52.4	20.0	32.4	16.6	51.0
f_k (N mm ⁻²)	36.3	25.9	19.7	36.0	31.0	21.3
E_m (N mm ⁻²)	8,590	7,121	5,425	9,280	7,627	6,197
$Density_k$ (kg m ⁻³)	406.9	391.5	289.1	407.5	371.7	376.0
Final Optimal S.Class	C18	C16	<C14	C20	C16	<C14

R: rejects.

by one class and 9% by two classes. For second quality pieces, this standard showed similar behaviour to DIN 4074, correctly identifying 24.9% of such pieces but overvaluing 32.2% (more than that seen with DIN 4074) and undervaluing 42.9% (less than with DIN 4074). The rejects were better identified: 61.8% were correctly identified, 16.9% overvalued by one class and 21.3% overvalued by two classes.

Table 5 shows the scores attained with each grading system taking into account the proposed scoring system.

If the same scoring methodology were applied to the results of the optimal grading reported in Table 3, the following results would be obtained (which would therefore be the optimum values):

— Grading by C18/C14/R: 924 points; C18: 369 points, C14: 466 points, R: 89 points.

— Grading by C20/C16/R: 807 points; C20: 432 points, C16: 74 points, R: 227 points.

Thus, the VPS-SRT-2 standard grading model was the best of those studied, although its results were still far from the optimum; its associated errors mostly

involved the identification of second quality material, and to a lesser extent reject material.

Discussion

Tables 1, 2, and particularly 3, show that small-diameter round timber has a high mechanical strength (in terms of OPTR results), although its poorer elastic behaviour overshadows this to a certain extent. Nonetheless, both its strength and elasticity are perfectly adequate for structural applications. This observation is in line with that indicated by Ranta-Maunus (1999), Piqué and Romá (2000) and Wolfe (2000), that laricio pine small-round timber fulfils the minimum requirements for structural use.

The prEN 14544 visual grading standard exaggerated the number of rejects, greatly underestimating the real strength of this material.

The DIN 4074 grading standard identified the first quality timber acceptably and correctly graded reject timber. However, it performed poorly with the second

Table 4. Comparison of visual grading standards (No. of pieces assigned and grading yield, in %). A) prEN 14544 vs. OPTR. B) DIN 4074 vs. OPTR. C) VPS-SRT-2 vs. OPTR

	A					B					C						
	OPTR C20/C26/R					OPTR C18/C14/R					OPTR C18/C14/R						
	1	2	R	Total		1	2	R	Total		1	2	R	Total			
prEN 14544	1	29	4	1	34	DIN 4074	1	71	56	12	139	VPS-SRT-2	1	95	75	19	189
		20.1%	5.4%	0.4%				57.7%	24.0%	13.5%				77.2%	32.2%	21.3%	
	2	34	11	13	58		2	27	37	11	75		2	17	58	15	90
		23.6%	14.9%	5.8%			22.0%	15.9%	12.4%			13.8%	24.9%	16.9%			
	R	81	59	213	353		R	25	140	66	231		R	11	100	55	166
		56.3%	79.7%	93.8%				20.3%	60.1%	74.1%			9.0%	42.9%	61.8%		
Total	144	74	227	445	Total	123	233	89	445	Total	123	233	89	445			

Table 5. Index scoring given by grade and standard

Quality grade	prEN 14544	DIN 4074	VPS-SRT-2
1 st	-207	97.5	226.5
2 nd	-45	-178	-48.4
Reject	198	-31	2
Total score	-54	-49.5	180.1

quality grade, strongly underestimating its quality and misclassifying many second class pieces as rejects.

The VPS-SRT-2 standard correctly identified the first quality material and adequately graded reject material. However, second quality material was undervalued or overvalued, almost to the same extent. According to Tables 2, 4B and 4C, the VPS-SRT-2 standard not only identified a greater percentage of timber as first quality than did the DIN 4074 standard, it also identified a smaller percentage of reject timber. The most evident errors with both standards therefore involve the identification of second quality material, although these errors are of lesser importance with DIN 4074 since it undervalues rather than overvalues material.

DIN 4074 and VPS-SRT-2 both provided better results than prEN 14544 for visually grading small log resistance. VPS-SRT-2 is, however, the better choice since it identifies fewer rejects and provides a total score (Table 5) closer to that achieved with the OPTR method, although much improvement is required.

Comparison of the data in Table 5 with the optimal grading results shows that new and more efficient grading systems are required, in agreement with Wolfe (2000), Wolfe and Moseley (2000) and Green *et al.* (2004).

It should be highlighted that visual grading is tedious due to the number of variables to be measured, and not very efficient given the high number of rejects obtained. The most suitable course of action might be to focus on designing mixed grading systems (as used for sawn timber), integrating measurements made using non-destructive systems (ultrasounds, penetrometers, etc.) and rapid visual evaluations of different features (knottiness, curvature, and the presence of juvenile wood, etc.).

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