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BRIEF ORIGINAL

Proposal of visual strength grading rules for Uruguayan pine timber

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Abstract A previous database with bending and density data of 261 structural size specimens of currently produced Uruguayan slash pine and loblolly pine timber was adjusted to meet testing and characterization requirements of European standards. Visual parameters and mechanical properties for each specimen were evaluated and their relationship was statistically analyzed. Results suggested that all specimens can be grouped in one visual grade with engineered properties similar to those of European C14 strength class. Modulus of elasticity and characteristic bending strength were the defining properties for class assignation.

1 Introduction

In the last 30 years, Uruguay had significantly increased the availability of locally produced timber. A quarter of a total of 1 million planted hectares corresponds to fast growing pine (*Pinus* sp.) intended for sawn lumber and engineered wood products. Lack of strength graded lumber along with the fact that no design specification is available, are the main reasons that prevent timber as a structural material.

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With the aim of promoting the use of wood products for structural applications, the Timber Research Group set up a comprehensive project to propose the technical documents needed to generate a design specification for wood construction in Uruguay. After reviewing the state of the art and the amount of work required to prepare a national specification, it was decided to adopt the set of European standards, ranging from testing methods to design specifications (Baño et al. 2016). This decision implied making adjustments on previous research work to determine design properties. In addition, national grading rules for locally produced timbers need to be developed. For a country with no tradition in timber classification, the simplicity of the rule is of great importance. The objectives of this study were: (1) to propose visual grading rules for Uruguayan loblolly/slash pine timber, and (2) to assign a strength class in accordance with EN 338 (CEN EN 338 2016).

2 Materials and methods

A previous database from a structural characterization project (FMV 2009) was analyzed in accordance with European standards (EN). The database corresponds to representative material of currently produced pine lumber from two commercial and intensively managed plantations in Uruguay: M1, a 25-year-old west and M2, a 15-year-old south-west plantation, both with a mixture of 90 and 10% of slash pine (*Pinus elliottii* Eng.) and loblolly pine (*Pinus taeda* L.), respectively. Trees from M1 had average diameter breast height (DBH) of 450 mm, and an average total height of 25 m, whereas those from M2 had DBH of 300 mm and were 15 m tall. Two samples consisting of 115 and 146 structural size specimens with a mean cross section of 49×147 mm (nominal 50×150×3300 mm) from M1 and M2 were analyzed.

2.1 Database description

Data collected were comprised of: (1) results of load and deformation from four point bending, density and moisture content (MC) tests obtained as per ASTM procedures (ASTM 2011); and (2) records of visual features acquired under dry conditions (with MC = 14–18%) following EN 1310 guidelines (CEN EN 1310 1997). Description and measurements of knots (according to the alternative method described in EN 1310), slope of grain, wane, warp, fissures, density and pith presence for each piece were available.

2.2 Mechanical properties and density adjustment

Density and data from bending tests were adjusted to comply with EN 408 (CEN EN 408 2010) requirements. Characteristic bending strength ($f_{m,k}$) was adjusted to a reference depth of 150 mm and corrected for number of samples and their size, according to EN 384 (CEN EN 384 2010). Mean modulus of elasticity ($E_{0,\,mean}$) and characteristic density (r_k) were adjusted to a reference moisture content of 12% following procedures of EN 384 (CEN EN 384 2010).

2.3 Analysis of the influence of visual features on the structural properties

Visual parameters and their influence on bending strength, stiffness and density were statistically analyzed using Matlab and summarized as follows (Baño et al. 2016):

- Selection of most influential visual parameters on stiffness, bending strength and density.
- Establishment of limits for each visual parameter fulfilling the limitations for strength-reducing characteristics described in Annex A of EN 14081 (CEN EN 14081-1 2016).
- Computation of mean stiffness, characteristic strength and characteristic density, using test data and limits defined in the previous step.
- Evaluation of number of rejected specimens for each combination.
- Selection of limit combination that returns less amounts of rejected specimens on a minimum basis of C14 strength class (CEN EN 338 2016).

3 Results and discussion

3.1 Visual grading

A single visual grade, named EC7 (coniferous structural lumber) was established. Table 1 shows the proposed criteria for visual grading of nominal 50 × 150 mm Uruguayan pine beams, based on two representative samples.

Table 1 Grading rules for assignment of Uruguayan loblolly/slash pine to the visual grade EC7

Parameter	Grade EC7
Knots	
Face knot diameter	d (diameter of knot) ≤2/5 h
Edge knot diameter	d (diameter of knot) ≤2/5 b
Pith	Allowed
Slope of grain	≤1:6 (16.7%)
Fissures	
Not going through the thickness	≤1.0 m ó ≤¼ l
Going through the thickness	≤1.5 m ó ≤½ l
Wane	≤1/5 h
Resin pockets	≤2 h
Biological damage	
Blue stain	Allowed
Fungi decay	Not allowed
Insect's galleries	Holes diameter <2 mm
Warp	
Bow	≤12 mm
Spring	≤9 mm
Twist	≤1.5 mm per 25 mm of h
Cup	No restrictions
Ring width	No restrictions
Density (referred to 12%MC)	>290 kg m^{-3}

Dry grading (with MC <18%)

Percentages of rejected pieces according to Table 1 were 50 and 71% for M1 and M2, respectively. The first reason for rejection was edge knot size, with percentages of 30 and 40% for M1 and M2, respectively. A relation between size of knot and pith presence was observed; larger knots were found in pieces containing pith, compared with knots in pieces lacking pith. This fact could be attributed to the effect of pruning at 3, 5 and 15 years old (Bussoni and Cabris 2010), leading to formation of small knots in pieces extracted from the peripheral zone of the log. Spring was the second reason for rejection, with percentages of 7 and 12% for M1 and M2, respectively. Juvenile wood, detected by the presence of pith in most specimens, could explain the occurrence of warp during drying.

3.2 Characteristic values of mechanical properties and density

Characteristic values of mechanical properties and density for M1 and M2 specimens graded as EC7, with mean cross section of 49 × 147 mm, are shown in Table 2.

Values of mechanical and physical properties of specimens ($E_{0,men}$ = 7.04 kN mm^{-2}, $f_{m,k}$ = 14.6 N mm^{-2} and

Table 2 Characteristic values of mechanical properties and density for the visual grade EC7 according to EN 384 (CEN EN 384 2010)

Source	MC	f_m	COV (%)	$f_{m,05}$[a]	$f_{m,k}$	E_0[b]	$E_{0,mean}$	r_{05}[b]	r_k
M1	11.9	46.6	37.2	19.6		7.90		368	
M2	11.2	30.0	30.7	14.9		6.04		322	
					14.6		7.04		348

MC moisture content, in %, f_m mean value of bending strength, in N mm^{-2}, $f_{m,05}$ 5th percentile of bending strength, in N mm^{-2}, E_0 mean value of the global modulus of elasticity, in kN mm^{-2}, r_{05} e 5th percentile of density, in kg m^{-3}

[a]Adjusted to a reference depth of 150 mm and corrected for number and size of sample

[b]Adjusted to a reference moisture content of 12%

r_k = 348 kg m^{-3}) correspond to C14 strength class established in EN 338 (CEN EN 338 2016). Mean modulus of elasticity and characteristic bending strength were the defining properties for class assignment.

Since the ring width is associated with density, further work including definition of limits of annual ring width might improve the grading criteria presented herein.

4 Conclusion

With the aim of establishing the basis for a grading rule of Uruguayan pine timber, a previous database was analyzed according to European standards. The main visual parameters and their influence on the mechanical properties were determined. Knot size and spring were the most relevant singularities for visual strength grading. Specimens were grouped in one visual grade, named EC7 with engineering properties similar to those of C14 strength class. Modulus of elasticity and characteristic bending strength were the defining properties for class assignment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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