Warp Requirements and Yield Efficiency in the Visual Grading of Sawn Radiata Pine Timber

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Three samples of sawn Radiata pine (*Pinus radiata* D. Don) timber, consisting of 150 pieces with dimensions of 80 mm x 120 mm x 2400 mm, 80 pieces with dimensions of 150 mm x 200 mm x 4500 mm, and 75 pieces with dimensions of 150 mm x 250 mm x 5600 mm, were visually graded according to the Spanish standard UNE 56544 (2011) to analyze the influence of visual grading requirements on both the grading yield and mechanical properties. The resulting percentages of the rejected pieces stood at 19 and 28% for 150 x 200 mm and 150 x 250 mm cross-section pieces, respectively. That percentage increased to 73% for 80 x 120 mm cross-section pieces. The grading yield and mechanical properties were then analyzed to determine the influence of warp defects. Three different criteria for limiting warp defects were considered, reducing the standard specifications. The modulus of elasticity, bending strength, and density were obtained. The results concluded that loosening specified requisites improves the visual grading output in the smallest cross-section, with no significant reduction in the mechanical properties. A proposal for a less rigorous specification of twist defects in the Spanish visual grading standard has been introduced.

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INTRODUCTION

The visual grading of timber for structural use is based on the inspection of pieces to assess singularities (*i.e.,* knots, slope of grain, and bark and resin pockets). Some other defects in connection with sawing (*i.e.,* wanes), drying (*i.e.,* bowing, springs, twists, cup fissures, and ring shakes), biotic damage (*i.e.,* xylophages insects and rot), and moisture content are also considered. Finally, the combination of all of these factors determines the visual grade and strength class.

In Europe, the EN 1912 (2012) standard indicates the strength class assignment for the combinations of species and visual grades obtained by a national grading standard. Many of the strength classes assigned by the EN 1912 (2012) standard were obtained using test pieces with a cross-sectional area smaller than 100 mm x 200 mm. This standard therefore sets some limitations regarding the cross-section size. For instance, the Italian standard UNI 11035-1/-2 (2010) includes some restrictions on the cross-sectional dimensions for strength classes assignment of Douglas fir (*Pseudotsuga menziesii* Franco) (maximum width and thickness of 100 mm), and for sweet chestnut (*Castanea*

sativa Mill.) (maximum thickness of 100 mm). In a similar way, the strength class assigned to species and grades according to the Spanish visual grade standard for hardwoods UNE 56546 (2013) limits the assignment of Eucalyptus (*Eucalyptus globulus* Labill.) to pieces with a 60 mm maximum thickness and a maximum width of 200 mm. A recent study examined the strength class assignments of sweet chestnut species using this standard, taking the size effect into consideration (Vega *et al.* 2013).

On the other hand, some visual grade standards set different limitations for timber singularities depending on dimensions of the cross-section for a given sample, as shown in the following examples. The Spanish visual grading standard for coniferous species UNE 56544 (2011) distinguishes between small and large cross-section pieces (with a minimum thickness and width of 70 mm). The French standard NF 52-001 (2007) establishes different limitations for the edge knot size in Spruce (*Picea abies* Labill.) depending on whether the cross-sectional area is less than or greater than 20000 mm^2. The standard also sets different edge and face knot sizes for Douglas Fir when the cross-section area is smaller or larger than 18000 mm^2, and for pine, poplar, and larch the visual grading rules are only valid for cross-sectional areas below 20000 mm^2. The Nordic standard for visual grading (INSTA 142 2009) proposes different rules for samples with cross-sections above and below 45 mm x 70 mm. Even the North American visual grading standard (NGRDL 2008) sets different grading categories depending on the size and uses of timber pieces (*e.g.,* structural joists and planks, structural light framing, light framing, and studs).

Similarly, some standards include different limits for timber defects, and even different criteria for measurement, depending on the utilization of the piece. Accordingly, the German standard DIN 4074 (2003) defines three categories of timber pieces: edge bending pieces (joists-"kantholz"), flat bent boards, and battens (with a cross-sectional area less than or equal to 3200 mm^2).

The effect of size on the Spanish visual grading standard was first studied for Scots pine (*Pinus sylvestris* L.) and Laricio pine (*Pinus nigra* Arnold) (Íñiguez *et al.* 2007). Specific criteria for large cross-section grading were established. Recently, the suitability of these criteria have been studied, specifically for large cross-sectioned pieces of Radiata pine (*Pinus radiata* D. Don).

In the last 30 years, Radiata pine has become one of the most heavily studied species in both Spain and the world. There are over four million Ha of planted Radiata pine worldwide with the largest plantation in Chile, New Zealand, and Australia, and in a moderate scale in Spain (1.5 million m^3 of sawlogs annual production, equivalent to 20% of Spanish conifer cut) and South Africa (Mead 2013). Radiata pine is a fast growing species and it has a great potential as sawn timber for structural use in Spain. The first Spanish research into the physical and mechanical properties of Radiata pine took place in the 1980's, and used small clear wood specimens (Vignote 1984; Vignote *et al.* 1993). A short time later, this study was repeated using the new approach of applying standards and analyzing properties according to structural size (Seoane and Ortiz 1989).

Recent work published on Spanish Radiata pine include small cross-section (Hermoso *et al.* 2007a,b), large cross-section (Iñiguez *et al.*; 2005; 2007; Iñiguez 2007), plywood (Arriaga *et al.* 2008), a summary of 25 years of work with radiata pine (Fernández-Golfín *et al.* 2008), and to complete the study of Radiata pine in Spain, a study on timber from Catalonia (Montón 2012). Some recent work on the application of non-destructive techniques for the grading of Radiata pine timber have also been conducted (Arriaga *et al.* 2014).

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Singularities (or defects) in timber that are associated with drying are fissures and warping (*i.e.,* bow, spring, twist, and cup). According to the European standard EN 14081-1 (2005), which specifies the minimum requirements for visual grading standards in Europe, stricter limitations for these defects are applicable when the strength class assigned is above C18, in accordance with the EN 338 (2009) standard.

Although the Spanish visual grading standard UNE 56544 (2011) specifies maximum warp limitations, it should only be considered when the timber is dry graded. Furthermore, deformation defects are only present in dried timber. The maximum ring width is measured for wet graded timber (the average ring width in the first five rings from the pith). The reason for limiting the scope for detecting warp or average ring width is that the standard focuses on the juvenile wood in the samples.

Defects related to warping may have undesirable consequences in the assembly of structural components, but often these problems are not insurmountable obstacles in practice. The question that may arise is whether or not these defects have a negative effect on the mechanical properties of the pieces in question. The aim of this work is to analyze the influence of piece drying deformation in regards to the visual grading parameters on the yield grading efficiency and mechanical properties, with respect to the cross-sectional size.

EXPERIMENTAL

Materials

The test materials were composed of three samples of sawn Radiata pine (*Pinus radiata* D. Don) timber. They consisted of 150 pieces (80 mm x 120 mm x 2400 mm; sample A) from Santa Coloma de Farners (Girona, Spain), 80 pieces (150 mm x 200 mm x 4500 mm; sample B), and 75 pieces (150 mm x 250 mm x 5600 mm, sample C) from Vergara (Guipúzcoa, Spain). The pieces were randomly selected from commercial batches.

Methods

Moisture content

The moisture content for the specimens were measured according to the procedure of the EN 13183-1 (2002) standard, as specified in the EN 408 (2010) standard. It was obtained by oven dry weight of a slice of the whole cross-section of each specimen, cut from the area close to rupture zone. The mean moisture content was 10.5% with a coefficient of variation (CoV) of 6.5% for sample A, 14.8% with a CoV of 11.1% in sample B, and 13.9% with a CoV of 11.2% in sample C.

Visual grading

Visual grading was carried out according to the Spanish standard UNE 56544 (2011). This standard establishes three visual grades: ME-1, ME-2, and MEG. The first two visual grades are for small cross-sectional pieces (*i.e.*, pieces with a thickness less than or equal to 70 mm), while the MEG grade is for pieces with a thickness greater than 70 mm (large cross-section pieces).

The Spanish standard borderline thickness of 70 mm between small and large cross-sections is due to the fact that until approximately 2003, the mechanical properties of Spanish species were obtained from tests on pieces with a thickness less than or equal

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to 70 mm. Therefore, the mechanical properties of samples with a small cross-sectional area could not be assigned to large cross-section pieces. Beginning in 2004, the testing procedure now used on large cross-section pieces was created (with a thickness of 100 to 200 mm), which is more representative of sawn timber production for structural use in Spain.

The samples analyzed in this work were visually graded according to the MEG specifications for samples thicker than 70 mm. These three samples, each with different cross-sections, were selected to analyze the influence of warp defects, while also taking cross-sectional size into account.

The UNE 56544 (2011) standard specifies some limitations regarding piece deformation or warp defects (bow, spring, twist, and cup), which become more strict when the assigned strength class, in EN 1912 (2012) standard, is higher than C18. This criterion is made necessary by the European reference standard for grading, EN 14081-1 (2005+A1:2011). Annex A of the European standard states: "Requirements for strength reducing characteristics for visual grading standards" specifies the minimum limitations for warping during visual stress grading according to the European standards given in Table 1.

Table 1. Maximum Warp (in mm) Over 2 m of Length According to Standard EN 14081-1 (2005+A1:2011)

Type	Maximum permissible warp corresponding to strength classes	
	C18 and below	Above C18
Bow	20	10
Spring	12	8
Twist	2 mm per 25 mm width	1 mm per 25 mm width
Cup	No restrictions	
For other lengths the requirements shall be adjusted pro-rata		
Strength classes according to standard EN 338 (2009)		

The strength class assigned to MEG grade Radiata pine is C20 (above C18) according to European standard procedure, EN 338 (2009), EN 384 (2010), and EN 1912 (2012) standards. The samples were dry graded, after which the strictest warp limitations found in Table 1 were used. Table 2 shows that there is a great difference in the visual grading output between samples with different cross-sectional sizes. Finally, the rejection percentage in sample A (the smallest cross-section) is too high for practical purposes (73%).

Table 2. Yield of Visual Grading for Samples According to Standard UNE 56544 (2011)

Sample	Grade	Percentage of pieces (%)
Sample A	MEG	27
	Rejected	73
Sample B	MEG	81
	Rejected	19
Sample C	MEG	72
	Rejected	28

Determination of density

The density of the specimens was calculated according to the procedure proposed in standard EN 408 (2010), by measuring the mass and volume on a slice of the whole cross-section taken from the specimen after the bending test, and from a place close to the rupture area. The values obtained were corrected to a reference moisture content of 12%, according to standard EN 384 (2010) (a 0.5% decrease in density for each 1% decrease in moisture content).

Determination of the global modulus of elasticity and bending strength

The global modulus of elasticity (MOE) and bending strength (MOR) were obtained *via* mechanical testing that was performed according to standard EN 408 (2010). Each test piece was supported and symmetrically loaded, causing it to bend at two points over a span equivalent to 18 times its depth, as shown in Fig. 1. The modulus of elasticity in measured bending is denoted the global MOE, since it is determined by the deformation of the piece, measured from the center of the span. The rate of moving of the loading head was not greater than $0.003 \cdot h$ mm/s (being h the specimen depth) for MOE determination and reaching the rupture load within 300 ± 120 s for MOR determination. No special devices were required to prevent lateral stability, even in sample A pieces with a higher cross-section slenderness (except safety measures).
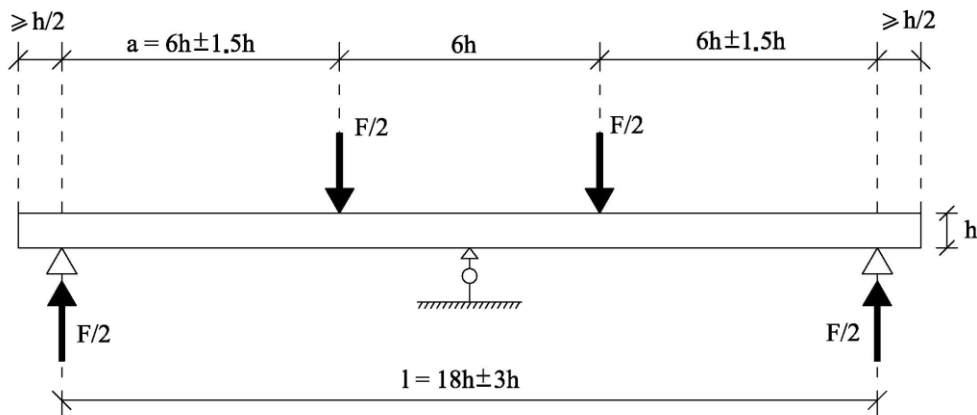

Fig. 1. Test arrangement for measuring the global modulus of elasticity and bending strength

The equation used for determination of global modulus of elasticity, E_{glo}, was the following, EN 408 (2010),

$$E_{glo} = \frac{3al^2 - 4a^3}{2bh^3 \left(2\dfrac{w_2 - w_1}{F_2 - F_1} - \dfrac{6a}{5Gbh} \right)}$$

(1)

where the difference F_2-F_1 is an increment of load on the regression line with a correlation coefficient of 0.99 or better, w_2-w_1 is the increment of deformation corresponding to F_2-F_1, and G is the shear modulus. The shear influence has been ignored by taking G as infinite, according to EN 408 (2010).

The obtained values were adjusted to a reference moisture content of 12%, in accordance with standard EN 384 (2010). For the MOE, the necessary corrections for the moisture content, according to EN 384 (2010), is a 1% increase in the MOE for each 1%

decrease in moisture content. The MOR was not corrected for moisture content, because it was below 18%, according to the aforementioned standard.

RESULTS AND DISCUSSION

To analyze the main causes for rejection, Fig. 2 shows the percentage for each different timber defect, considered in visual grading for each sample. The knots and slope of the grain have more influence in samples with a large cross-sectional area than they do in samples with small ones. On the contrary, warp defects have a remarkably greater influence in small cross-sectional pieces. This phenomenon is most apparent in sample A, specifically regarding twists, with a 39% rejection percentage.
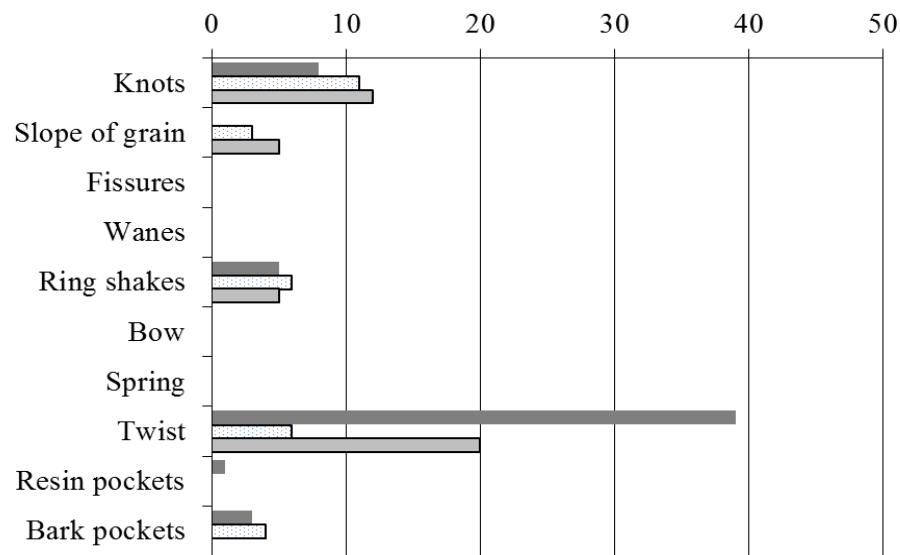

Fig. 2. Rejected percentage of specimens for each singularity for the MEG visual grade. Sample A (dark grey), sample B (dotted), and sample C (light grey)

Table 3 summarizes the results of the visual grade output, mechanical properties, and density obtained for each sample. Furthermore, Table 3 classifies the results according to the following three grading criteria: I, using the criterion established for MEG grade included in the UNE 56544 (2011) standard (fulfilling all warp limitations according to EN 14081-1 2005+A1 2011); II, using the warp (bow, spring, twist, and cup) limitations for strength class less than or equal to C18 (the lower limitations of Table 1); and III, without any limitations due to warp defects. Criteria II and III are less restrictive than EN 14081-1 (2005+A1:2011) recommendations.

As is shown in Fig. 3, the visual grading output in sample A increased noticeably when the warp requirements were reduced. However, in samples B and C, no notable change was observed. Furthermore, the MOR and MOE in sample A decreased when the warp limitations were not considered (criteria III), while in samples B and C they remained constant. Finally, there were no changes in the density for any sample graded according to the three criteria. There were no statistically significant differences within a sample for criteria (except for MOR), but there were significant differences between samples.

Table 3. Yield of Visual Grading Output and Physical-Mechanical Properties for Each Sample and According to Grading Criteria: I, Complete Warp Limitations, II, Intermediate, and III, Without Any Limitations Due to Warp Defects

Criteria	Sample	Grade	% of pieces	MOR $f_{m,mean}$ (CoV) $f_{m,k}$	MOE E_{glo} (CoV)	Density ρ_{mean} (CoV) ρ_k
I	A	MEG	27	49.66 (25) 28.18	10279 (16)	524 (11) 425
		Rejec.	73	40.46 (32) 18.25	8468 (25)	493 (12) 411
	B	MEG	81	24.57 (28) 15.07	7939 (18)	494 (8) 443
		Rejec.	19	23.12 (28) 15.99	7709 (24)	486 (10) 396
	C	MEG	72	31.46 (28) 15.59	10099 (14)	513 (7) 450
		Rejec.	28	26.23 (21) 17.34	8943 (14)	489 (7) 452
II	A	MEG	53	48.82 (26) 28.85	9921 (21)	526 (10) 448
		Rejec.	47	36.40 (31) 18.05	7871 (19)	474 (11) 406
	B	MEG	84	24.65 (28) 15.07	7962 (18)	495 (8) 443
		Rejec.	16	22.48 (29) 15.99	7553 (26)	482 (11) 396
	C	MEG	84	30.44 (29) 17.34	9825 (15)	508 (8) 450
		Rejec.	16	27.67 (19) 19.07	9515 (12)	497 (6) 457
III	A	MEG	83	44.49 (30) 22.98	9137 (24)	502 (12) 415
		Rejec.	17	35.34 (32) 17.68	8012 (22)	496 (11) 419
	B	MEG	84	24.65 (28) 15.07	7962 (18)	495 (8) 443
		Rejec.	16	22.48 (29) 15.99	7553 (26)	482 (11) 396
	C	MEG	84	30.44 (29) 17.34	9825 (15)	508 (8) 450
		Rejec.	16	27.67 (19) 19.07	9515 (12)	497 (6) 457

$f_{m,mean}$ mean value of bending strength, in N/mm^2
CoV   coefficient of variation, in %
$f_{m,k}$ characteristic value (5th percentile) of bending strength, in N/mm^2
E_{glo} mean value of global MOE referred to 12% MC, in N/mm^2
ρ_{mean} mean value of density referred to 12% MC, in kg/m^3
ρ_k characteristic value (5th percentile) of density referred to 12% MC, in kg/m^3

The increased percentage of rejection due to twists in smaller cross-section pieces could be explained by the way the pieces are sawn. Figure 4 shows typical sample cross-sections.

In the larger cross-sections of samples B and C, pith is present in the majority of the pieces (68% and 80%, respectively), and is situated close to the geometric center of the section. On the contrary, in sample A, the pith is present in only 35% of the pieces.

It is known that twisting of timber pieces depends on ring curvature and distance to pith. Annual growth ring curvature has the greatest impact on the final amount of twist (Straže *et al.* 2011). Twist is well correlated to growth ring curvature and together with spiral grain angle explains about 70% of twist variation in spruce timber (Johansson *et al.* 2001). This relationship was shown theoretically by Stevens and Johnston (1960).

Twist can also be influenced by the cross-section size of timber pieces. The higher are dimensions of pieces (samples B and C compared with sample A), the higher is the restraint during drying period, due to the external load of pieces stored at a high position in the stack (Arganbright *et al.* 1978).
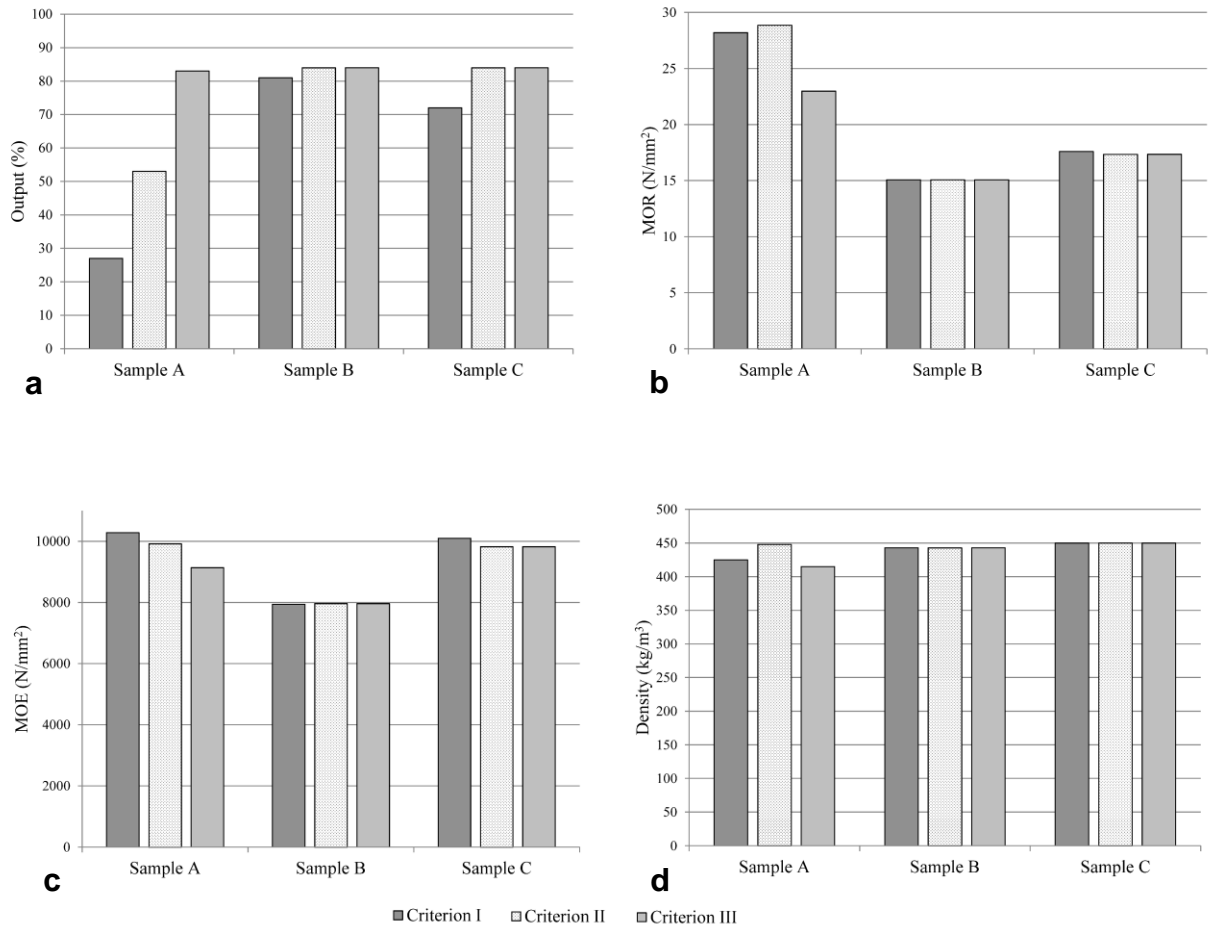
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Fig. 3. Graphic results for the (a) visual grading output, (b) MOR (5th percentile), (c) MOE (mean), and (d) density (5th percentile), for each sample and grading criterion
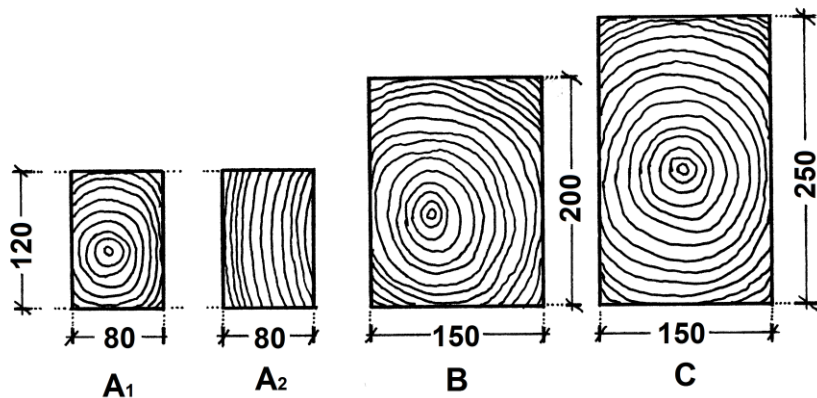

Fig. 4. Cross-sections of pieces from sample A (A1: pith present; A2: pith not present), sample B, and sample C. Note: All dimensions are in mm

If sample A is divided into two subgroups based on the presence or absence of pith (A1: pith present; A2: pith not present), the visual grading output, according to criterion I, changes. In A1, the rejected percentage amounts to 87%, while in A2 it falls to

52%. On the other hand, the MOR (5th percentile) is 22.84 and 19.29 N/mm^2; MOE (mean) is 7570 and 9694 N/mm^2; and the density (5th percentile) is 402 and 443 kg/m^3, in A1 and A2, respectively. This means that specimens with small cross-sectional areas and no pith exhibit better physical and mechanical properties, as well as output results.

According to these results, it is clear that the twist specifications for the Spanish visual grading standard UNE 56544 (2011), which is also mandated by the European standard EN 14081-1 (2005) (1 mm/25 mm width, for 2 m length), has different consequences depending on the cross-sectional size. The smallest size gives rise to an excessively high percentage of rejected pieces for practical purposes.

In order to minimize this circumstance, two possibilities can be proposed. The first possibility is to reduce the twist specifications in the visual grading standard (at least to the intermediate criterion of 2 mm/25 mm width, for every 2 m length). Along these lines, the new value for the twist specifications proposed in the draft version of prEN 14081-1 (2013), coincides with the intermediate criterion analyzed in this work. The second option is to include a new specification in the visual grading standard, excluding small cross-section pieces that contain pith. In this case it is necessary to define "small cross-sectional area", to include a borderline value for the width of the cross-section.

CONCLUSIONS

1. The Spanish visual grading standard for coniferous timber (UNE 56544 2011) gives an acceptable percentage for rejected pieces with large cross-sections of Radiata pine (19 to 28% in 150 mm x 200 mm and 150 mm x 250 mm), but it leads to an excessive percentage (73%) of rejection in small cross-section pieces (80 mm x 120 mm). The main reason for rejection was found to be twist defect (39% in 80 mm x120 mm).

2. Two limiting criteria for twist defects were considered, relaxing the present standard criteria. The reduction of limitations for twist defects improves the visual grading output for samples with the smallest cross-sections (rejection percentage values decreased from 47 to 17%) with no significant reduction in physical and mechanical properties.

3. For the samples with small cross-sectional areas, the rejected percentage is high (87%) when pith is present. This percentage falls to 52% in pieces without pith. Small cross-section pieces that do not contain pith show better physical and mechanical properties, as well as improved output.

4. Some criteria have been proposed for less rigorous specifications governing twist defects in the Spanish visual grading standard, and in the European reference for national standards of visual grading.

ACKNOWLEDGMENTS

REFERENCES CITED

Arganbright, D. G., Venturio, J. A., and Gorvad, M. (1978). "Warp reduction in young-growth ponderosa pine studs dried by different methods with top-load restraint," *Forest Prod. J.* 28, 47-52.

Arriaga, F., Peraza-Sánchez, F., and García-Esteban, L. (2008). "Characteristic values of the mechanical properties of Radiata pine plywood and the derivation of basic values of the layers for a calculation method," *Biosystems Engineering* 99(2), 256-266. DOI: 10.1016/j.biosystemseng.2007.10.004

Arriaga, F., Montón, J., Segues, E., and Iñiguez-Gonzalez, G. (2014). "Determination of the mechanical properties of Radiata pine timber by means of longitudinal and transverse vibration methods," *Holzforschung*, 68(3) 299-305. DOI: 10.1515/hf-2013-0087

DIN 4074 Teil 1 (2003). "Sortierung von Holz nach der Tragfähigkeit. Teil 1: Nadelschnittholz," *German Institute for Standardization*, Berlin, Germany"

EN 13183-1. (2002). "Moisture content of a piece of sawn timber. Part 1: Determination by oven dry method," *European Committee for Standardization* Brussels/Belgium.

EN 14081-1:2005+A1:2011. (2005). "Timber structures. Strength graded structural timber with rectangular cross section. Part 1: General requirements," *European Committee for Standardization* Brussels/Belgium.

EN 338. (2009). "Structural timber. Strength classes," *European Committee for Standardization* Brussels/Belgium.

EN 384. (2010). "Structural timber. Determination of characteristic values of mechanical properties and density," *European Committee for Standardization* Brussels/Belgium.

EN 408. (2010). "Timber structures. Sawn timber and glued laminated timber for structural use. Determination of some physical and mechanical properties," *European Committee for Standardization* Brussels/Belgium.

EN 1912. (2012). "Structural Timber - Strength classes - Assignment of visual grades and species," European Committee for Standardization Brussels/Belgium.

prEN 14081-1. (2013). Draft version. Timber structures. "Strength graded structural timber with rectangular cross section. Part 1: General requirements," *European Committee for Standardization* Brussels/Belgium.

Fernández-Golfín, J. I., Conde, M, Hermoso, E., and Carballo, J. (2008). "Madera de pino radiata: Conclusiones tras 25 años de trabajos," (Radiata pine lumber: Conclusions after 25 years of work) *Boletín de información técnica de AITIM* (252), 30-36.

Hermoso, E., Carballo, J., and Fernández-Golfín, J. I. (2007a). "Structural characterization of *Pinus radiata* D. Don timber from Pais Vasco (Spain) according to standard modifications," *Maderas: Ciencia y Tecnología* 9(3), 223-232.

Hermoso, E., Carballo, J., and Fernández-Golfín Seco, J. L. (2007b). "Revisión de la caracterización estructural de la madera de *Pinus radiata* D. Don del norte de España acorde a las modificaciones normativas," (Review of the mechanical characterization of *Pinus radiata* D. Don wood from Northern Spain according to the standards changes). II Congreso Iberoamericano de Investigación y Desarrollo de Productos Forestales, pp. 1-10.

Iñiguez, G. (2007). "Clasificación mediante técnicas no destructivas y evaluación de las propiedades mecánicas de la madera aserrada de coníferas de gran escuadría para uso estructural," (Grading by nondestructive techniques and evaluation of mechanical

properties of large cross-section coniferous timber for structural use) Doctoral thesis. Universidad Politécnica de Madrid, ETS de Ingenieros de Montes, Spain. pg. 223. PDF: http://oa.upm.es/415.

Íñiguez, G., Arriaga, F., Barrett, J. D., and Esteban, M. (2007). "Visual grading of large structural coniferous sawn timber according to Spanish Standard UNE 56544," *Forest Products Journal.* 57(10), 45-50.

Iñiguez, G., Arriaga, F., Fernández-Golfín, J. I., Díez, M. R., Hermoso, E., and Mier, R. (2005). "Clasificación visual de la madera de pino radiata (*Pinus radiata* D. Don) en piezas de gran escuadría para uso estructural," (Visual grading of radiata pine (*Pinus radiata* D. Don) in large cross-section pieces for structural use) Proceedings of 4º Congreso Forestal Español, Zaragoza, Spain, 413-425.

INSTA 142 (2009). "Nordic visual strength grading rules for timber," *Norsk Standards*, Oslo, Norway.

Johansson, M., Perstorper, M., Kliger, R., and Johansson, G. (2001). "Distortion of Norway spruce timber. Part 2. Modelling twist," *Holz als Roh- und Werkstoff*, 59, 155-162.

Mead, D. J. (2013). "Sustainable management of *Pinus radiata* plantations," *FAO Forestry Paper* No 170, Rome, FAO.

Montón, J. (2012). "Clasificación estructural de la madera de *Pinus radiata* D. Don procedente de Cataluña mediante métodos no destructivos y su aplicabilidad en la diagnosis estructural," (Structural grading of *Pinus radiata* D. Don timber from Catalonia using nondestructive methods and their applicability in structural diagnosis). Doctoral thesis, *Universitat Politécnica de Catalunya*. Escola Tècnica Superior D'Arquitectura de Barcelona, pp. 160-309. http://hdl.handle.net/10803/96423, Accessed 04/11/2014.

NF B 52-001 (2007 +A1:2009). "Règles d'utilisation du bois dans les constructions. Classement visuel pour employ en structure pour les principales essences résineuses et feuillues, " Association Francaise de Normalisation (AFNOR), France.

NGRDL (2008). "National grading rule for dimension lumber," *American Lumber Standard Committee*, U.S. Department of Commerce

Seoane, I., and Ortiz Gutiérrez, J. (1989). "Características mecánicas de la madera de Pino Radiata obtenidas a partir de ensayos con piezas de tamaño estructural. Comparación entre distintas normas de clasificación," (Mechanical properties of Radiata pine wood obtained from full size specimens. Comparison between different visual grading standards). *Boletín de información técnica AITIM* (136), 66-71.

Stevens, W. C., and Johnston, D. D. (1960). "Distortion caused by spiral grain," *Timber Technology* 68, 217-218.

Straže, A., Kliger, R., Johansson, M., and Gorišek, Ž. (2011). "The influence of material properties on the amount of twist of spruce wood during kiln drying," *Eur. J. Wood Prod.* 69, 239-246. DOI 10.1007/s00107-010-0422-1.

UNE 56544. (2011). "Clasificación visual de la madera aserrada para uso structural. Coníferas," (Visual grading for structural sawn timber. Coniferous timber) Asociación Española de Normalización (AENOR), Madrid, Spain.

UNE 56546. (2013). "Clasificación visual de la madera aserrada para uso structural. Frondosas," (Visual grading for structural timber: Hardwood species) Asociación Española de Normalización (AENOR), Madrid, Spain.

UNI 11035-1/-2 (2010). "Legno strutturale. Classificazione a vista di legnami Italiani secondo la resistenza meccanica," (Structural timber. Visual strength grading for structural timbers) Ente Nazionale Italiano di Unificazione, Milano, Italia.

Vega, V., Arriaga, F., Guaita, M., and Baño, V. (2013). "Proposal for visual grading criteria of structural timber of sweet chestnut from Spain," *European Journal of Wood and Wood Products* 71(4), 529-532. DOI: 10.1007/s00107-013-0705-4

Vignote, S. (1984). "Características físico-mecánicas del pino insignis y su influencia con la edad y el crecimiento," (Physical and mechnical properties of Insignis pine and its influence with age and growth) Doctoral thesis, Universidad Politécnica de Madrid, ETSI de Montes, pg. 293. http://oa.upm.es/7306/.

Vignote, S., Peraza, F., and Perezagua, R. (1993). "Tecnología del aprovechamiento de la madera de pino insignis (*P. radiata* D. Don)," (Technology of timber harvesting of insignis pine (P. radiata D. Don)) *AITIM*, Madrid, Vol. I, (pg. 116) and Vol. II (pg. 186).

Montón *et al.* (2015). "Pine lumber grading," *BioResources* 10(1), 1115-1126.

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