Grading and testing of Maritime pine and larch roundwood

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ABSTRACT

The high variability in the mechanical properties of massive wood members is a significant disadvantage from this material when compared to other construction materials. This variability may be reduced through the implementation of grading procedures, either by visual features (visual grading), or by mechanical properties (mechanical grading). This paper presents work developed in University of Coimbra to characterized and grade, visually and mechanically, Portuguese Maritime Pine.

Two hundred Maritime pine logs were collected in an interior central region of Portugal. After drying, the logs were visually characterized according to the EN 1310. Each log was then subjected to non destructive tests, for the determination of the dynamic modulus of elasticity followed by destructive tests, for the determination of bending and compression strength, following EN 14251.

The correlations between the visual features and the mechanical properties and between the dynamic modulus of elasticity and mechanical properties were determined. Based on the results, conclusions were drawn regarding the most appropriate features to be used in the visual strength grading process. Based on this analysis a proposal was given to visually grade Portuguese Maritime pine. Furthermore, the visual grading results were discussed and compared with the results obtained with the non destructive tests.

The results obtained in this study were compared with results obtained in a similar study undertaken in the Delft University of Technology, with sixty eight Larch round logs collected in three different locations in the Province of Drenthe (Netherlands).

INTRODUCTION

As a material obtained from the growth process of a living being (tree), wood production is affected by many factors, either internal (genetic) or external (soil, wind) which explains the high variability generally associated with its micro-structure. This variability is also reflected in a high variability of mechanical properties, affected also by the effect of the presence of different features (knot, slope of grain, etc.), that penalizes this material when compared with other construction materials (such as concrete or steel) (Machado 2000).

A reliable structural use of timber is possible if suitable strength grading processes (either visual or machine) exist allowing the allocation of each piece of timber to a strength grade associated with a set of characteristic values.

Visual strength grading is probably still the most common strength grading process in-place in sawmills and factories in the world. The grading is based on the relation between timber features and strength and stiffness, being in each visual grade setup a series of limits (for instance maximum slope of grain allowed) that should be fulfilled by a particular piece of timber in order to belong to that grade and then grade's characteristic values can be allocated to that same piece of timber.

Visual strength grading drawbacks are the weak correlation generally obtained between strength and stiffness and features, correlation coefficient around 0,5 for knots and 0,4 for rate of growth (Vries 1998), high variability within each visual grade (coef. of variation generally between 20% and 40%) and the need of trained and skilled graders.

Machine strength grading is currently based on the relation between stiffness and strength, existing in the market different machines. As compared with visual grading, machine grading offers the possibility of measuring directly a wood property (elasticity), property that presents a stronger correlation with strength (coef. of correlation generally between 0,60 and 0,80) than visual features. This fact explains the lower variability of machine strength grades (around 15% to 20%) as regards visual grades. The drawbacks are related with cost of those machines and the costly process of quality control of those same machines.

Presently new machines are being placed in the market based on new technologies like X-rays, ultrasounds or stress waves.

Having in mind assessing the possibility of using small-diameter maritime pine (*Pinus pinaster* Ait.) roundwood for structural uses, a study was carried out with the purpose of developing strength grading processes (visual and machine) that could be suitable to this wood material. The aim of the project was to promote stands thinning operations by providing an extra income to forest owners, creating financial incentives so that proper after-care of forest stands, reducing the amount of wood waste in the forest, and reducing the risk of forest fires.

In the present paper the general quality of small-diameter maritime pine roundwood is discussed having in mind results obtained by different authors for other wood species. Support for visual and machine grading of maritime pine roundwood is also discussed, having in mind the correlations obtained between visual features and mechanical properties, being presented a first proposal for a visual strength grading system.

MATERIALS

Logs selection

The specimens came from a small forest area called "Pinhal Interior Sul" which comprises 5 municipalities (Fig. 1) with a total area of 1906 km^2 from which approximately 51% are forest areas. In each municipality 5 to 8 stands (approximately 0,5 ha) were selected, from each one 20 logs were collected for a total of at least 100 poles per municipally. The specimens were chosen from the available material removed in normal forest thinnings, showing no biological degradation or deep fissures, and with a length equal to 25 times the diameter. The logs were debarked but not machine rounded (Fig. 2).

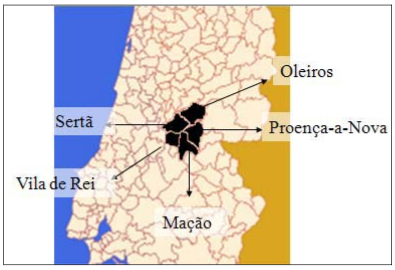

Figure 1: Origin of the logs

Figure 2: Logs of the sample

Seasoning and conditioning

The 500 logs selected were pilled outdoors (Fig. 3), but protected from the direct exposure to sun light or rain, to dry until moisture content below 18% was reached. This moisture content was archived in 6 month, from March to August of 2007 (Fig. 4). The first row of the pile was placed 20cm above the ground and the logs in each row were spaced 5 to 10cm from each other.

After drying under 18% moisture content a new selection was made, based in the diameter of the poles, knots diameter, width of the growth rings, shape of the log and signs of biological degradation. From this selection resulted the 200 final logs, with diameters between 7cm and 19 cm (81% of the logs presented diameter lower than 12cm), that were transported to the climatic chamber, where they were subject to a relative humidity of 65% and 20ºC of temperature during a period of 4 months until constant mass (weight) was achieved.

Figure 3: Pile

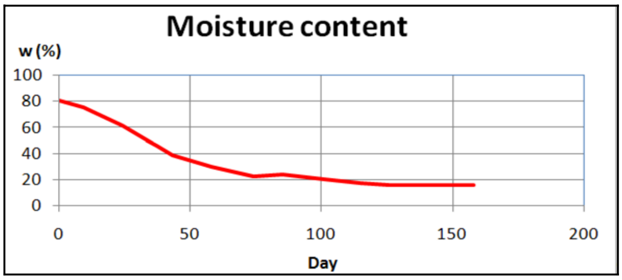

Figure 4: Evolution of the logs moisture content

Visual characterization of poles

During the final period of drying, several visual characteristics of the poles were measured and recorded, namely: spiral grain, ovality, taper, rate of growth, sweep, fissures and knots. The measurement rules for features given in EN1310 (CEN 1997) were followed. The results obtained are presented in Table 1 together with the results obtained in Dutch project with 68 logs of Larch.

The spiral grain was assessed by measuring the inclination of the fissure relatively to the longitudinal axis of the log. A significant number of logs (98%) showed a spiral grain equal or inferior to 16,7 cm/m, the limit value established for lower visual strength grade of Maritime pine sawn timber according to NP4305 (IPQ 1995).

The ovality, when significant, can compromise the application of the log (both because of the shape and of the amount of compression wood present). This feature was assessed by measuring the maximum and minimum diameters in a section located at least 1m away from the larger end. The ovality is given by the ratio involving the difference between the two diameters and the maximum diameter. All the specimens presented an ovality equal or inferior to 20% usually considered as the limit value for upper round timber grades (Ranta-Maunus 1999).

The taper was assessed based on the mean diameter (mean of maximum and minimum diameters) measured in sections at least 5 cm from the ends, and the distance between those sections. The taper was then considered as the difference between the two mean diameters divided by the distance between the measuring points. The limit for structural application suggested by Ranta-Maunus (1999) is 10 mm/m, this requisite is fulfilled by 86,5 % of the specimens.
The rate of growth is a very important parameter for Softwoods, since it reflects, in an indirect way, the density of the wood, which has a significant influence in the strength and stiffness of timber members. In practice this property was determined for each end as the ratio between the largest diameter and the number of growth rings, expressed in millimeters. In the lower visual strength grade of Maritime pine sawn timber the limit for rate of growth is 10 mm (IPQ 1995). The results obtained in this project for roundwood show that all the specimens fulfill this requirement.
Sweep was assessed by measuring the maximum distance between the rounded concave longitudinal surface and a straight line joining the innermost points of the surfaces. For multiple sweep the biggest value was recorded. The value of the sweep was obtained by the ratio D/L (Fig. 5). The results obtained are higher than the limits indicated in other studies for other species, (Ranta-Maunus 1999). However, the fact that the specimens were extracted from natural regeneration forests or stands where an initial thinning should have taken place but was not carried out, could explain these weak results.

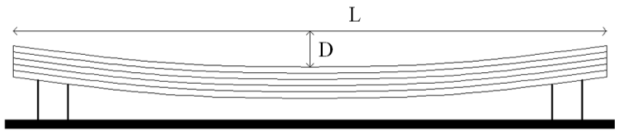

Figure 5: Simple sweep measurements

The fissures were assessed by measuring the length (l) and thickness (e) of each one, the biggest ratio e/l was recorded.
The diameter of each isolated knot was measured. In cases of knot clusters, the sum of individual knots diameters and the overall width of the knot cluster were measured, the lower value was recorded.

Table 1: Visual properties of the sample (mean values)

Study	**Diameter [mm]**	**Initial curvature [cm/m]**	**Growth rings [mm]**	**Knots–d_{max} [mm]**	**Fissures (e/l) [mm/m]**
Maritime Pine	103	1,18	3,8	20,4	0,83
Larch	136	0,21	4,5	21,2	0,75
	Density [kg/m^3]	**Grain angle [cm/m]**	**Moisture content [%]**	**Taper [cm/m]**	**Ovality [%]**
Maritime Pine	536	6,5	13,2	0,63	5,54
Larch	514	5,4	10,9	-	-

MECHANICAL TESTING

The indications from standard EN14251 (CEN 2003) were followed for the determination of all mechanical properties. The bending strength parallel to the grain ($f_{m,0}$), compression strength parallel to the grain ($f_{c,0}$) and modulus of the elasticity of roundwood specimens were assessed by testing. In the determination of modulus of elasticity, independent measurements were performed to assess the local (E_{local}) and the global (E_{global}) modulus. The E_{global} was determined using the indications and formulations given in EN408 (CEN 2003), with the necessary adaptations for round sections. The differences between E_{local} and E_{global} relies on the test arrangement (E_{local} measured in the central part of the span – without shear stresses – and E_{global} over the entire span – including bending and shear stresses).

Bending tests

The bending tests were performed on a loading frame with a capacity of 200kN, the test arrangement is presented in Fig. 6 according to the schematic set up presented in Fig. 7. To implement this test arrangement, the loading frame had two I-beams where the two end supports were attached in such a manner that various specimen lengths could be tested. The design of the end supports enabled both rotation and translation of the specimen end sections. The design of the loading heads enabled both rotation and translation of the loaded sections of the test specimen surface during the test. To distribute the loads on the surface of the test specimen and to prevent rolling during the experiment, hardwood blocks (length 100 mm, curvature machined to the appropriate diameter) were used at both end supports and in the loading heads.

Figure 6: Bending test

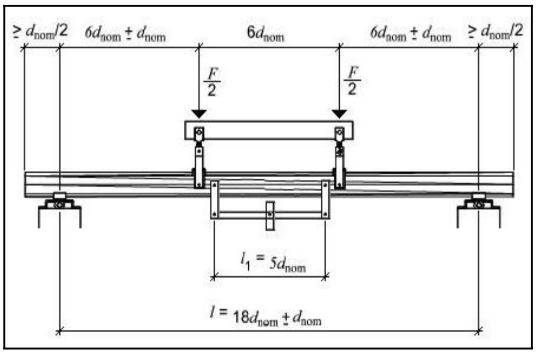

Figure 7: Schematic representation of the bending test

The d_{nom} of each log was determined by measuring the maximum and minimum diameters in both ends. If the ovality was higher than 5%, the d_{nom} was considered as the largest of the minimum diameters. If the ovality was lower or equal to 5% the d_{nom} was considered as the diameter corresponding to the perimeter of the major end, according to EN14251 (CEN 2003).

All the distances necessary to perform the test were determined as a function of the nominal diameter (d_{nom}). The specimens were then placed on the test machine with the supports and loading heads adjusted to fulfill the lengths $18d_{nom}$ and $6d_{nom}$ respectively with the sweep, if any, in the direction of the load. The length $5d_{nom}$ was adjusted in the two aluminum braces (in both sides of the test specimen) and attached (screwed) to the specimen.

To determine E_{local} three reference points were marked in the test specimen in order to carry out the measurements of the displacements according to EN 14251(CEN 2003). The determination of E_{local} was done with the mean of the measurements performed in each one of the aluminum braces located in both sides of the round members. Extra displacements were measured, in the supports and at the centre of the specimen to determine the E_{global}. The specimens were loaded up

to a force of 40% of the estimated rupture load, with a loading speed that would guarantee the failure in 300 seconds with a tolerance of 120 seconds. The procedure to determine bending strength ($f_{m,0}$) was similar to the one described for the elasticity modulus but without measurement of deformations. The failure was typically caused in tension at mid span by the rupture near a knot or under the loading head, in the lower diameter side of the specimen.
Shortly after the testing of each specimen, a full disk was cut from the failure zone in order to assess the density and moisture content of the specimen at the time of testing.

Compression tests
The compression tests (Fig. 8) were performed to assess the compression strength parallel to the grain ($f_{c,0}$). The testing machine had rotated loading-heads, which permitted the application of a compressive load without inducing bending. The specimens had a length of $6d_{nom}$ and presented the end surfaces plans, parallel to each other and perpendicular to the longitudinal axis of the specimen. They were loaded concentrically, with a loading speed that ensured the failure in 300 seconds with a tolerance of 120 seconds, following the recommendations of the standard. Failure occurred typically near a knot.

Figure 8: Compression test

Dynamic modulus of elasticity
Most of the machine-graded timber available today is graded from bending stiffness. The timber is centrally loaded between supports to cause a deformation from which the stiffness of the cross-section is calculated and used as a grading parameter. An alternative way to determine the stiffness is based on the relationship between the frequency of a freely vibrating piece of timber and its modulus of elasticity. Since this method is independent of a specific geometry problems such as curvature and taper it may prove to be a suitable method for the grading of small-diameter roundwood (Vries and Gard 1998).
A relatively cheap and quick way of measuring the stiffness of timber is based on the relationship between the eigenfrequency for free-free condition of a log and its elasticity. This method is based on the Euler beam theory for free flexural vibrations of prismatic beams. The eigenfrequency of a material is the basis vibration of the whole log at normal mode. The vibration can be initiated by a longitudinal or a transverse impact. Due to the geometry and mass of the samples and test arrangement considered, the longitudinal vibration method was applied. The equipment used in this work was the Timber Grader – MTG (Fig. 9).

Figure 9: Non-destructive test with MTG

DISCUSSION OF RESULTS

In order to evaluate the influence of the visual characteristics on mechanical properties, especially on the $f_{m,0}$, correlations between those parameters were determined. The results obtained in this study and in the Dutch study are presented in Tabel 2.

The best correlation between $f_{m,0}$ and visual parameters was obtained for the rate of growth (r=0,55) and for the maximum diameter of knots diameter (expressed as percentage of the specimen minimum diameter) (r=0,36). The correlation between $f_{m,0}$ and other mechanical properties was also determined and the results obtained were better than the ones obtained with the visual parameters. E_{dyn} and density are the parameters with the best correlation with $f_{m,0}$ (r=0,77 and r=0,70, respectively). Due to this strong correlation, these parameters can be the base for Machine strength grading, similar proposals were made in other studies, as for example, Mackes et al. (2005). When multiple regression analyses were done, the correlations increased slightly. The best correlation to $f_{m,0}$ involving two parameters was obtained with E_{global} and density (R=0,83). A multiple regression analysis involving all visual parameters and the E_{global} had also been done. In this case, the coefficient of correlation has improve (R=0,85), but the improvement does not worth for the time spend on the determination of all properties.

Table 2: Coefficients of correlation between fm,0 and others parameters

Study	E_{local}	E_{global}	E_{dyn}	Density	Rate of growth	d_{nom}
Maritime Pine	0,76	0,75	0,77	0,70	-0,55	-0,11
Larch	0,85	0,87	0,90	0,79	-0,67	-
	Spiral grain	**Taper**	**Ovality**	**Sweep**	**Fissures (e/l)**	**Knots–d_{max}**
Maritime Pine	-0,33	-0,32	0,12	0,1	-0,09	-0,36
Larch	-0,23	-	-	-	-	-0,52

The mechanical properties obtained in the two studies for the bending strength ($f_{m,0}$), compression strength ($f_{c,0}$), modulus of elasticity and density, for the reference moisture content (12%), according to EN384 (CEN 1997), are given in Table 3.

Table 3: Mechanical properties of the sample

Value	Study	$f_{m,0}$ [N/mm²]	$f_{c,0}$ [N/mm²]	E_{local} [GPa]	Density [kg/m³]
Mean	Maritime Pine	82,7	40,9	14,6	535
	Larch	50,1	33,6	10,4	514
Charact.	Maritime Pine	53,8	27,3	12,5	435
	Larch	28,7	26,6	6,1	397
Std.	Maritime Pine	16,7	7,4	14,1	60
	Larch	13,3	4,4	2,6	71
Minimum	Maritime Pine	48,5	19,5	5,1	376
	Larch	31,7	25,0	6,5	395
Maximum	Maritime Pine	133,5	68,8	14,6	768
	Larch	87,2	45,1	17,6	712
N	Maritime Pine	180	197	180	200
	Larch	68	68	65	68

The mean bending strength obtained was 82,7 N/mm^2 with a coefficient of variation of 19,0%, which led in a 5^{th} percentile of 53,8 N/mm^2. For the $f_{c,0}$ was obtained a mean value of 40,9 N/mm^2 with a coefficient of variation of 18,1%, which led in a 5^{th} percentile of 27,3 N/mm^2. The mean value of E_{local} was 14621 N/mm^2.

Table 4 are presented the mean values of the mechanical strength, together with the results of studies for other species: Ponderosa pine (Larson et al. 2004); Radiata pine (Cerda and Wolfe 2003); Douglas fir, White fir and Radiata pine (Wolfe and Moseley 2000); Scots pine, Norway spruce, Sitka spruce, Larch and Douglas (Ranta - Maunus 1999). The comparison shows that strength values obtained for Maritime pine and Larch (Ranta – Maunus study) are significantly higher than for other species. For the modulus of elasticity the situation is similar, but in this case Sitka spruce yields higher values.

Table 4: Comparison of roundwood Portuguese Maritime pine with other species (mean values)

Specie	$f_{m,0}$ [N/mm²]	$f_{c,0}$ [N/mm²]	E_{local} [GPa]	Density [kg/m³]
Maritime pine[1] – Portugal	82,7	40,9	14,1	536
Larch[2] – Netherlands	50,1	33,6	10,4	514
Larch[3] – Netherlands	85,0	45,0	14,3	580
Scots pine[3] – Finland	50,0	28,0	11,9	470
Scots pine[3] – United kingdom	54,0	32,8	14,9	529
Norway spruce[3] – Austria	61,0	-	12,9	451
Norway spruce[3] – Finland	60,0	30,7	12,9	434
Silka spruce[3] – UK	58,0	28,6	16,1	478
Douglas[3] – France	52,0	33,0	11,1	442
Ponderosa Pine[4] – USA	56,0	-	10,7	410
Radiata Pine[5] – Chile	52,0	-	10,5	440
Douglas fir[6] – USA	61,0	37,0	9,7	488
White fir[6] – USA	46,0	28,0	8,3	395
Radiata Pine[6] – USA	39,0	18,0	5,6	400

[1]This study, 2008 [2]Dutch study, 2007 [3]Ranta-Maunus, 1999 [4]Larson et al. 2004
[5]Cerda and Wolfe, 2003 [6]Wolfe and Moseley, 2000

VISUAL GRADING

Considering the coefficients of correlation obtained an attempted was made to generate visual strength grades based on wood's features taper, spiral grain, knots diameter (related with the smallest diameter of the log) and rate of growth. While setting the limits to each feature in each grade (two grades were considered at this stage) two main concerns were to assure the representativeness of each grade (to ensure that represents at least 15% of the logs population) and that the efficiency of the grading process (possibility to restrain the variability of roundwood, assessed by the ratio between the average of the coefficients of variation of both grades and the coefficient of variation of the total sample, expressed in percentage) is lower than 80%.
The limits were adjusted to obtain two grades, A (upper grade) and B (lower grade), similar to Portuguese standard for sawn timber of maritime pine (IPQ 1995). The option for two visual grades had into consideration that more grades could lead to a better yield of the material but it would turn slower and costly the grading process, while the consideration of only one grade would turn fastest the process but would lead to a lower yield.
The limits allowed for each grade are presented in Table 5. It was accepted for the two visual grades the same limit values for taper and spiral grain. This decision had in mind that although the most important features as regards strength differentiation between visual grades are rate of growth and knots diameter, taper and slope of grain could affect the structural application of a particular log due to geometric imperfections (taper) or dimensional instability (spiral grain).
To ensure that the logs had geometrical characteristics appropriate to structural applications, were defined limits of 10% and 20% in terms of ovality for grades A and B, respectively. For the curvature, the limits of 2,5mm/m for grade A and 5mm/m for grade B are recommended (Ranta-Maunus 1999).

Table 5: Limits and classes for the visual grading

Limits - Grade A			Limits - Grade B	
Spiral grain [m/m]	0,20		Spiral grain [m/m]	0,20
Knots [%]	0,20		Knots [%]	0,50
Rate of growth	3,00		T Rate of growth	5,00
Taper [mm/m]	15,00		Taper [mm/m]	15,00

Proprieties		Efficiency	Proprieties	
$f_{m,0}$ [MPa]	96,37	82,89%	$f_{m,0}$ [MPa]	81,61
$f_{m,k}$ [MPa]	64,92		$f_{m,k}$ [MPa]	52,38
$f_{c,0}$ [MPa]	45,79	87,62%	$f_{c,0}$ [MPa]	40,94
$f_{c,0,k}$ [MPa]	31,14		$f_{c,0,k}$ [MPa]	27,85
$E_{local,mean}$ [MPa]	16850,50	77,27%	$E_{local,mean}$ [MPa]	14013,57
$E_{local,0,05}$ [MPa]	11289,83		$E_{local,0,05}$ [MPa]	9389,09
$E_{global\ mean}$ [MPa]	17472,08	70,42%	$E_{global\ mean}$ [MPa]	14503,74
$E_{global\ 0,05}$ [MPa]	11706,29		$E_{global\ 0,05}$ [MPa]	9717,51
ρ_{mean} [Kg/m^3)	587,69	85,83%	ρ_{mean} [Kg/m^3]	530,86
ρ_k [Kg/m^3]	512,11		ρ_k [Kg/m^3]	428,34
$E_{local\ 90,\ mean}$ [Mpa]	561,68		$E_{local\ 90,\ mean}$ [Mpa]	467,12
$E_{global\ 90,\ mean}$ [Mpa]	582,40		$E_{global\ 90,\ mean}$ [Mpa]	483,46
$G_{local\ mean}$ [MPa]	1053,16		$G_{local\ mean}$ [MPa]	875,85
$G_{global\ mean}$ [MPa]	1092,00		$G_{global\ mean}$ [MPa]	906,48
$f_{t,0,k}$	38,95		$f_{t,0,k}$	31,43
$f_{t,90,k}$	0,60		$f_{t,90,k}$	0,60
$f_{v,k}$	3,80		$f_{v,k}$	3,80
$f_{c,90,k}$	3,61		$f_{c,90,k}$	3,00
Representativeness	15,56%		Representativeness	66,67%

The properties for grade A are considerably higher than those of grade B, allowing better yield of the material. With these limits was achieved a great differentiation between the two grades. The minimum representativeness of 15% has been fulfilled, in terms of efficiency was not possible to achieve values significantly lower than 80% in all properties. However this value is considered good since the coefficient of variation (around 20% for bending strength) associated with the total sample is low.

CONCLUSIONS

Two hundred dry and debarked roundwood specimens, of nominal diameter between 70 and 190 mm, were subjected to bending and compression tests.
The mean bending strength obtained was 82,7 N/mm^2,while the mean compression strength was 40,9 N/mm^2. The mean values of E_{local} were 14621 N/mm^2.
The results obtained in this study for the mechanical properties are higher than most of the ones obtained in similar condition for other American and European wood species. For the modulus of elasticity the situation is similar, but the differences are small.

The possibility to foresee the bending strength without performing destructive tests was also studied. Correlations were done between bending strength and various visual characteristics and mechanical properties. It was concluded that the bending strength presents good correlation with the density and with E_{local}. This correlation could be improved if these two parameters were considered together. The values of correlations between the density, together with the modulus of elasticity and the bending strength clearly indicate that machine strength grading can be used, with success for Maritime roundwood timber.

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