Bending Strength and Stiffness of Portuguese Maritime Pine Utility Poles

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Abstract

The Civil Engineering Department of the University of Coimbra set up a project with the purpose of grading and characterizing Portuguese maritime pine utility poles. To achieve the aim of this project, 64 utility poles that met the requirements of Comité Européen de normalization EN14229 were collected in the central coastal region of Portugal. The utility poles were characterized according to various anatomic and geometric characteristics: the number of knots, the amount of taper, the nominal diameter, and the rate of growth. Each utility pole was also tested in bending. From these tests, the bending strength and modulus of elasticity were determined. The results obtained were in line with previously published results for utility poles from other species. In addition to this, wood samples were collected from each specimen to determine the moisture content and density. The correlation coefficients between the bending strength and modulus of elasticity were determined, as were the coefficients between the bending strength and the anatomic and geometric characteristics. From this analysis, it was concluded that the properties that had a closer correlation with bending strength were those of modulus of elasticity, density, and taper. The correlation coefficient between bending strength and the set of geometric and anatomic characteristics and density was determined by a multiple linear regression, and it was concluded that this set of parameters may be used for nondestructive evaluation of the utility poles.

Wood has been used in Portugal for the production of utility poles since the second half of the 19th century. In terms of species used, maritime pine (*Pinus pinaster* Ait.) was always the dominant type of wood with this application. The forest areas where the wood raw materials are obtained are the coastal central area of the country, namely, the National Forests (Fig. 1). Indeed, the represented area corresponds to the region from which most of the maritime pine poles are obtained in Portugal. In spite of its commercial importance, the information available about the mechanical properties of this wood product is very scarce, even though such properties are key factors in assessing the quality and safety of the products used to support overhead lines. Indeed, there are no studies concerning the use of maritime pine utility poles in supporting overhead lines. Recently a research project was undertaken to grade maritime pine roundwood specimens for structural applications (Morgado et al. 2009), which according to the regulations do not include the function of utility poles. In that study, a sample of 200 wood specimens with a mean nominal diameter of 103 mm was tested. The results obtained in that study provide useful information for utility poles. Nevertheless, the requirements for structural applications, particularly those regarding test setup and the levels of moisture present in the tests, significantly differ from the requirements for utility poles.

On the other hand, a number of studies have been undertaken to test utility poles from other species. Cerda and Wolfe (2003) presented a study performed with the purpose of assessing the mechanical properties of radiata pine (*Pinus radiata*) utility poles, planted in southern Chile. The sample tested consisted of 45 utility poles in green condition with a nominal length of 12 m.

A similar study was performed by Torrán et al. (2009) for *Eucalyptus grandis*. The utility poles, in green condition and untreated, were loaded until the failure point was reached. Two samples were tested: Sample 1 comprising 57 specimens obtained from trees with an age of 14 years and with a nominal length of 12 m, and Sample 2 comprising 48 specimens obtained from trees with an age of 11 years and a nominal length of 8 m. The tests were carried out following the procedures described in ASTM Standard D1036 (American Society for Testing and Materials 1998).

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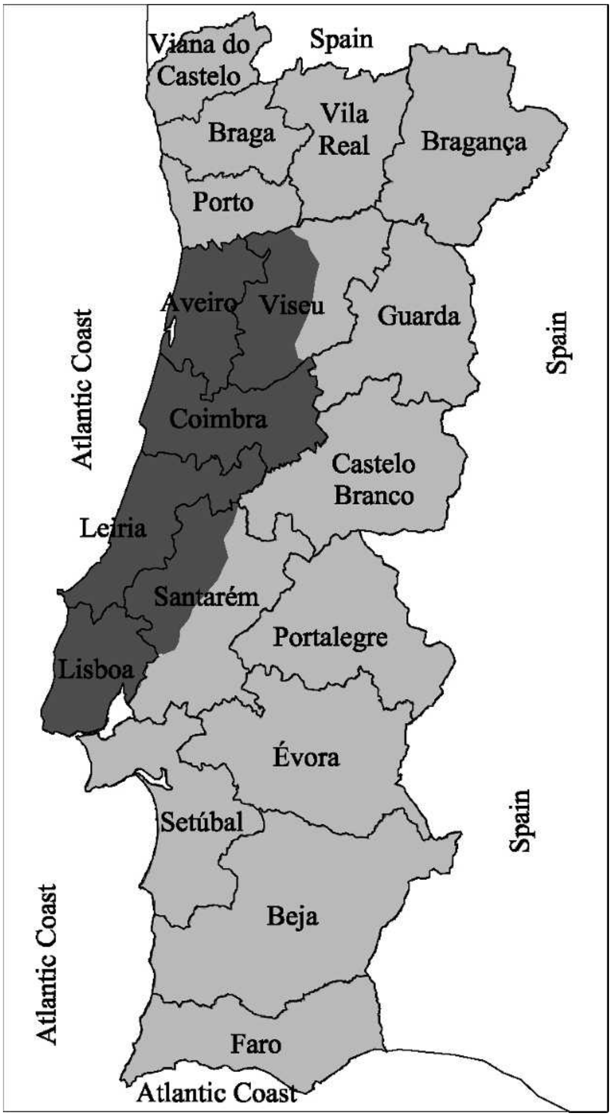

Figure 1.—Region in Portugal where the pole samples were collected.

Carradine and Gonzalez (2006) conducted a similar study with three Brazilian species (Abiurana ferro [*Pouteria caimito*], Acariquara [*Minquartia guianensis* Aubl.], and mata mata preto [*Eschweilera* sp.]). The utility poles were tested in green condition and had a nominal length of 13.7 m. The test procedure used was again the one specified by ASTM Standard D1036. These tests were complemented by destructive tests on small specimens of clear wood.

Horrigan et al. (2000) performed a study that was composed of two samples of utility poles of spotted gum (*Corymbia maculate*). The utility poles were tested in a four-point testing method for both new utility poles and utility poles that have been in service. Authors found a significant variation of strength between both samples.

There are also studies that have been made to assess the influence of the exposure to high temperatures during drying on the mechanical properties of specific conditions (Chui et al. 2001).

The grading techniques have also been studied, namely through the use of nondestructive methods (ultrasonic and transverse vibration) that have been tried by Miná et al. (2004) and Chui et al. (1999), respectively. The purpose of these studies was the evaluation of the correlation between dynamic modulus of elasticity and static modulus of elasticity. Chui et al. (1999) also studied the correlation between dynamic modulus of elasticity and bending strength.

The objectives of this study were (1) to determine the modulus of elasticity and bending strength of utility poles manufactured of Portuguese maritime pine, through destructive bending tests on untreated poles, and (2) to determine the correlations between these mechanical properties and the physical and anatomic characteristics as well as pole geometry for potential nondestructive evaluation. The characteristics considered in this study were diameter, ovality, taper, knots, slope of grain, and growth rate.

Despite the various test configurations found in other standards for testing utility poles, we decided to use the cantilever test setup as described in Standard EN14229 (Comité Européen de normalization [CEN] 2007) and usually used in Europe.

Materials

Visual characterization

The sample was composed of a total of 64 specimens obtained by selection of material held in a production unit. The selection was performed following the established procedures of that production unit and the requirements of EN14229 (CEN 2007). The wood specimens were debarked and cut to the intended nominal length of about 8 m, and they were subject to no other processing.

The visual assessment of the sample included the analysis of several characteristics that are likely to influence mechanical response of the utility poles, namely, diameter, ovality, taper, knots, slope of grain, and growth rate.

The tests were performed in accordance with the guidelines given in EN14229 (CEN 2007). In order to fulfill its requirements, the utility poles' nominal length had to be between 7.92 and 8.16 m, while its nominal diameter at the ground line had to be between 180 and 220 mm. The mean value of nominal length was 8.03 m.

First, the determination of ovality was made by calculating the difference between the maximum and minimum diameters of the cross section, expressed as a percentage of the minimum diameter.

Next, the taper was determined by the ratio between the difference of the nominal diameters of the ground-line section and of the load-bearing section and the distance measured between these two sections.

Third, a key visual parameter is the presence of knots because of the disruption they cause in the longitudinal fibers (US Department of Agriculture [USDA] 1999). For this reason, special attention was paid to this feature. This was accomplished by measuring the diameter of single and multiple knots, together with their perimeter and location relative to the butt end of the corresponding cross section. From these measurements two parameters were determined: Case 1, the maximum diameter of a knot or knot cluster expressed as a factor of the circumference of the wood utility pole at the point where the knot occurs; and Case 2, the maximum sum of all the knot diameters in any 300-mm segment of the wood utility pole, expressed as a factor of the

Table 1.—Anatomic, geometric, and mechanical characteristics measured on the utility poles and their correlation coefficients with bending strength and anatomic and geometric characteristics obtained by Morgado et al. (2009).[a]

	This study, mean (SD)	Morgado et al. (2009), mean (SD)	Correlation coeficient, r (with f_m)[b]
Nominal length (m)	8.0 (0.04)		—
$d_{nom,g}$ (mm)	196.1 (10.2)	103.0 (22.7)	−0.33
$d_{nom,q}$ (mm)	152.1 (11.5)		0.33
Ovality, ground-line (%)	3.9 (2.2)	5.5 (2.8)	0.13
Ovality, load point (%)	4.7 (2.8)		0.03
Taper (mm/m)	6.9 (5.0)	6.3 (3.4)	−0.64
Knots			
Medium (mm)	23.2 (9.7)		−0.44
Maximum (mm)	44.2 (9.7)		−0.35
Case 1 (mm/mm)[c]	0.083 (0.018)		−0.36
Case 2 (mm/mm)[d]	0.321 (0.111)		−0.42
Slope of grain (cm/m)	4.8 (2.6)	6.5 (3.6)	−0.13
Heartwood (%)	17.0 (9.6)		—
Growth rate (rings/25 mm)	13.0 (3.6)		0.19
Density (kg/m^3)[e]	573 (57)		0.66
Modulus of elasticity (GPa)	10.9 (1.5)		0.83

[a] f_m = bending strength; $d_{nom,g}$ = nominal diameter of the ground-line section; $d_{nom,q}$ = nominal diameter of the load-bearing section.

[b] The negative sign means that f_m decreases with the increase of the other correlated property.

[c] Case 1 corresponds to maximum diameter of the knot by circumference of the cross section.

[d] Case 2 corresponds to maximum sum of all diameters in 300-mm length by circumference of the cross section.

[e] The presented values of density correspond to a moisture content of 12 percent.

circumference of the wood utility pole at the midpoint of the segment.

The determination of the slope of the grain was made using the deviation of the fibers in a length of 10 cm and subsequently extrapolated to a length of 1 m. In practice, the measurements were calculated from the slope of the cracks.

Last, the growth rate was determined by measuring the number of rings in 25 mm on the largest radius of the cross section, starting the measurement at a distance of 50 mm from the center. The mean values and the standard deviation of the results obtained are presented in Table 1.

These values can be compared with those obtained by Morgado et al. (2009) for the same species. The ovality, obtained here at the ground line and at the loading point, is slightly lower than the value presented by Morgado et al. (2009). The taper values determined are similar in both studies, while the slope of the grain is lower in this sample. From this analysis, it is possible to conclude that the visual parameters of the two samples did not show significant differences despite the use of material from different areas, and despite the use of wood specimens with different diameters: 103 mm (mean value) in the study presented by Morgado et al. (2009) and 196 mm (mean value at the ground line) in this study.

Mechanical tests

Bending tests were performed to determine the utility poles' bending strength and modulus of elasticity. In these tests, Standard EN14229 (CEN 2007) was followed. According to the specifications of this standard, the utility poles must be placed in such a way that the underside of the test utility pole, in its ''natural rest'' position, should be in tension. The natural rest position should be determined in advance by rolling the utility pole on supports.

Figure 2 shows a schematic representation of the bending test setup. The utility pole is rigidly clamped for the first 1.5 m from the butt or alternatively from the butt section to the ground-line section (Fig. 3). The load is applied 150 mm from the top of the utility pole perpendicular to its undeformed axis. All the forces (applied loads and supports) are applied to the utility pole through timber shoes. Two pairs were used in the support area with a length of 500 mm each, and one pair in the load application area with a length of 300 mm.

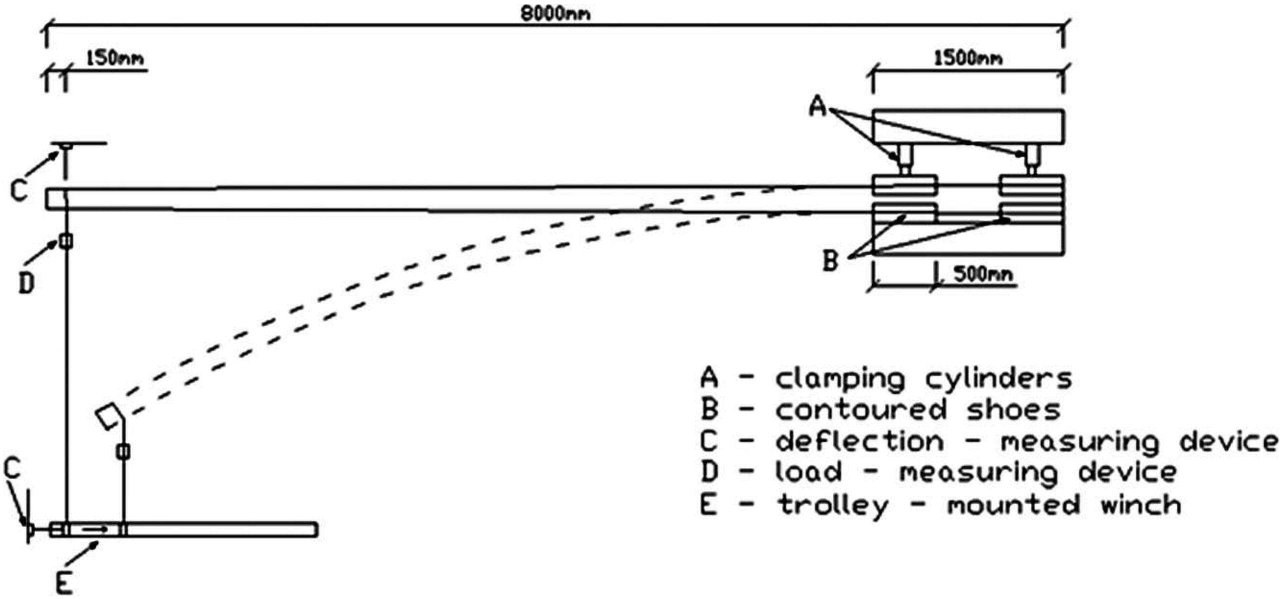

Figure 2.—Bending test setup.

Figure 3.—An example of a pole rigidly clamped.

The modulus of elasticity of the pole is a key property not only because it provides good correlation with the flexural strength, but mainly because it is the basis for the determination of the pole's deformations. In accordance with the guidelines in EN14229 (CEN 2007), the determination of the modulus of elasticity of the utility pole must be based on 30 pairs of load-deflection measurements. These measurements should be made for loads lower than 40 percent of the estimated load-carrying capacity of the utility pole. Furthermore, these measurements should be obtained within 90 seconds with a tolerance of ±30 seconds.

The bending strength of the utility poles was determined using the same test setup described above. The loading procedure was different in this case because the load had to be applied at such a rate that failure would occur in 300 seconds with a tolerance of ±120 seconds. In each test, the failure location was identified and registered. The values of bending strength (Fig. 4) were calculated in accordance with the indications from Annex C from EN14229 (CEN 2007).

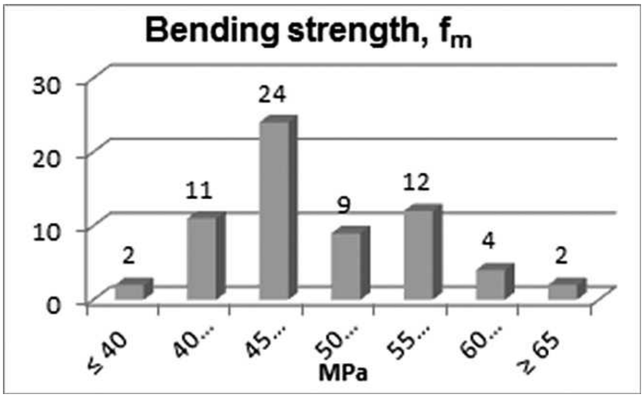

Figure 4.—Distribution of frequencies of values of bending strength.

A 50-mm-thick disk was collected near the failure zone for each of the specimens. This wood piece was used to determine the moisture content and the density at the time of testing. The values obtained for the density were adjusted to 12 percent moisture content, following the guidelines given in EN384 (CEN 2004). According to this standard, for a moisture content above 12 percent the density should be decreased by 0.5 percent for every 1 percent difference in moisture content. Table 2 presents the results of bending strength, modulus of elasticity, moisture content, and density obtained in this sample.

Results and Discussion

From the analysis of the utility poles after destructive tests, the failures occurred as a result of tension (Fig. 5) or compression (Fig. 6) or a combination of both. In 81 percent of the cases, it occurred in sections with knots, and in the remaining 19 percent of the cases no knots were visible. Of the utility pole failures, 62 percent occurred within a distance of 2 m from the butt of the pole, and the mean value of that length for the entire sample was 2.01 m.

Table 2.—Mechanical properties of the sample in green condition (except density).[a]

	f_m (MPa)	E (GPa)	W (%)	ρ (kg/m^3)[b]
Mean value	50.2	10.9	65	573
Characteristic value	37.0	—	—	479
Minimum value	39.3	8.1	28	454
Maximum value	68.4	15.8	118	692
SD	6.6	1.5	24	57
No. of specimens	64	64	64	64

[a] f_m = bending strength; E = modulus of elasticity; W = moisture content; ρ = wood density.

[b] The presented values of density correspond to moisture content of 12 percent.

Figure 5.—Failure by tension.

Table 3 presents the results obtained in this study and in another similar study made by Morgado et al. (2009; both with Portuguese maritime pine roundwood), regarding the most important mechanical characteristics for wood utility poles and logs, namely, bending strength (mean and characteristic values), modulus of elasticity (mean value), and density (mean value). The tests were realized at different moisture contents (65% in the present study and 13.2% in the study by Morgado et al. 2009). In order to have comparable data, the values presented in Table 3 are adjusted to a moisture content of 12 percent.

Figure 6.—Failure by compression.

Table 3.—Comparison between roundwood (poles and small diameter) of Portuguese maritime pine with a moisture content adjusted to 12 percent (Morgado et al. 2009).[a]

Roundwood	f_m (MPa)	$f_{m,k}$ (MPa)	E (GPa)	ρ (kg/m^3)
Poles[b]	74.3	54.8	12.9	573
Small diameter[c]	86.8	57.1	14.9	536

[a] f_m = bending strength; $f_{m,k}$ = characteristic value of bending strength; E = modulus of elasticity; ρ = wood density.

[b] This study.

[c] Morgado et al. (2009).

According to information provided by Hoffmeyer (1995), the values of mechanical properties can be adjusted in order to take the moisture content into account. The adjustment recommended is 4 percent per percentage point of moisture difference below the fiber saturation point for the bending strength and 1.5 percent for modulus of elasticity. These guidelines were followed in the adjustments made here.

A comparison between the mean values of bending strength obtained here and those obtained by Morgado et al. (2009) for samples of smaller diameter shows that the smaller-diameter values are 16.8 percent higher than those obtained in this study. The mean values of the global modulus of elasticity of smaller-diameter specimens are 15.5 percent higher than those obtained here for utility poles.

Table 4 presents the mean values of the mechanical properties obtained for utility poles from other species: radiata pine *P. radiata* (Cerda and Wolfe 2003); *E. grandis* (Torrán et al. 2009); abiurana ferro *P. caimito*, acariquara *M. guianensis* Aubl., and mata mata preto *Eschweilera* sp. (Carradine and Gonzalez 2006); southern pine (*P. palustris, P. taeda, P. echinata,* and *P. elliottii*), Douglas-fir *Pseudotsuga menziesii,* and western redcedar *Thuja plicata* (Tang et al. 2006).

From the results presented in Table 4, it becomes clear that the Portuguese maritime pine shows a bending strength similar to that of other species, such as Douglas-fir, radiata pine, and acariquara. On the other hand, when the bending strength of maritime pine is compared with western redcedar, the former is 39.9 percent higher. The bending strength of maritime pine presents a coefficient of variation (COV) of 13 percent, equal to that of *E. grandis* and similar to that of radiata pine and Douglas-fir. The same analysis for the modulus of elasticity shows that the values obtained for maritime pine are similar to those obtained for other species, except for southern pine and Douglas-fir, which have, respectively, values 58.4 and 66.5 percent higher than the maritime pine. For this property, the COV of maritime pine is 14 percent. The same value was obtained for *E. grandis*.

From this analysis, it is possible to conclude that utility poles from maritime pine roundwood have good mechanical properties when compared with other species. Nevertheless, in order to take full advantage of these properties, it is important to improve the grading rules. To that end, it is essential to know the correlation between the bending strength and other properties suitable for use in the grading process. For this reason, correlations between bending strength and mechanical properties, and between geometric and anatomic characteristics were calculated, with the

Table 4.—Comparison of roundwood Portuguese maritime pine with other species (mean values).[a]

	f_m (MPa)	COV (%)	E (GPa)	COV (%)	ρ (kg/m^3)	W (%)
Maritime pine: Portugal[b]	50.2	13	10.9	14	795[c]	65.0
Radiata pine: Chile[d]	52.0	14	10.5	—	440	Green condition
Eucalyptus grandis (12 m): Argentina[e]	62.9	13	10.9	14	707	45.0
Eucalyptus grandis (8 m): Argentina[e]	56.3	13	9.5	14	682	47.0
Abiurana ferro: Brazil[f]	108.5	17.8	—	—	900	30.5
Acariquara: Brazil[f]	53.3	24.2	—	—	810	30.4
Mata mata preto: Brazil[f]	87.4	23.9	—	—	820	40.3
Southern pine: United States[g]	58.1	20.6	17.3	18.4	—	Green condition
Douglas-fir: United States[g]	54.2	14.4	18.2	18.2	—	Green condition
Western redcedar: United States[g]	35.9	19.2	11.0	22.9	—	Green condition

[a] f_m = bending strength; COV = coefficient of variation; E = modulus of elasticity; ρ = wood density; W = moisture content.

[b] This study.

[c] The presented values of density correspond to each specimen in green condition.

[d] Cerda and Wolfe (2003).

[e] Torrán et al. (2009).

[f] Carradine and Gonzalez (2006).

[g] Tang et al. (2006).

results presented in Table 1. With regard to the correlations between geometric characteristics and bending strength, the highest coefficient (absolute value) was obtained for taper ($r = -0.64$). The best correlation between bending strength and other mechanical properties was obtained for modulus of elasticity ($r = 0.83$). Regarding the anatomic properties, the best correlation was obtained between density and bending strength ($r = 0.66$). The study of small-diameter samples of maritime pine by Morgado et al. (2009) also presented similar correlations ($r = 0.7$ for density and $r = 0.75$ for global modulus of elasticity). In addition to this, Torrán et al. (2009) determined a coefficient of correlation between modulus of elasticity and bending strength, but the results obtained were significantly lower (0.52 for Sample 1 and 0.37 for Sample 2) than the values presented here for maritime pine. Indeed, a strong correlation between modulus of elasticity and bending strength has been demonstrated in other studies, such as the study conducted by Green et al. (2006), which evaluated the bending properties of round timber specimens with a diameter of 230 mm. In this study, a correlation of 0.78 was obtained between the modulus of elasticity and the bending strength.

A multiple linear regression between the mechanical properties, geometric and anatomic characteristics yielded higher coefficients of correlation with bending strength (described below) than the coefficients of correlation obtained by simple linear regression analysis (presented in Table 1). The strongest correlation for bending strength involving two parameters was obtained with modulus of elasticity and a nominal diameter at the load point ($r = 0.90$), followed by the correlation involving modulus of elasticity and taper ($r = 0.89$), and the third best correlation was found with modulus of elasticity and density ($r = 0.86$). The correlation that involves all of the visual parameters and properties determined yielded a coefficient of correlation equal to $r = 0.94$. However, because the determination of the modulus of elasticity is expensive and difficult, the density and all of the visual parameters might be considered as alternatives for grading purposes; the coefficient of correlation obtained between these properties and the bending strength was $r = 0.88$. Globally, these correlations are higher than the highest obtained by Morgado et al. (2009) for maritime pine small-diameter roundwood, which was $r = 0.85$ involving all of the visual parameters and global modulus of elasticity.

Conclusions

In this study, the bending properties of Portuguese maritime pine roundwood utility poles were determined. The results obtained here are similar to those obtained for other species available in similar studies. The sample of 64 utility poles yielded a bending strength mean value of 50.21 MPa with a COV of 13 percent and a modulus of elasticity mean value of 10.93 GPa with a COV of 14 percent at green condition. These values clearly show the potential of maritime pine wood for application in utility poles. These properties met the standard requirements specified for the application. Furthermore, the results obtained are significantly higher than those given for informative purposes in EN14229. The potential estimation of bending strength without destructive tests was evaluated through the determination of correlations between bending strength on the one hand and geometric and anatomic characteristics and modulus of elasticity on the other. It was concluded that the modulus of elasticity shows a strong correlation with bending strength ($r = 0.83$), and density also shows a good correlation with bending strength ($r = 0.66$). A multiple linear regression between all of the visual parameters and other properties showed a coefficient of correlation equal to 0.94. A similar analysis, which excludes the modulus of elasticity but includes all visual parameters and density (which are ultimately more suitable for grading purposes), also showed a good coefficient of correlation, 0.88. These results clearly show that it is possible to significantly improve the existing grading methods. New grading methods may help in better use of utility poles with better grades.

Acknowledgments

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