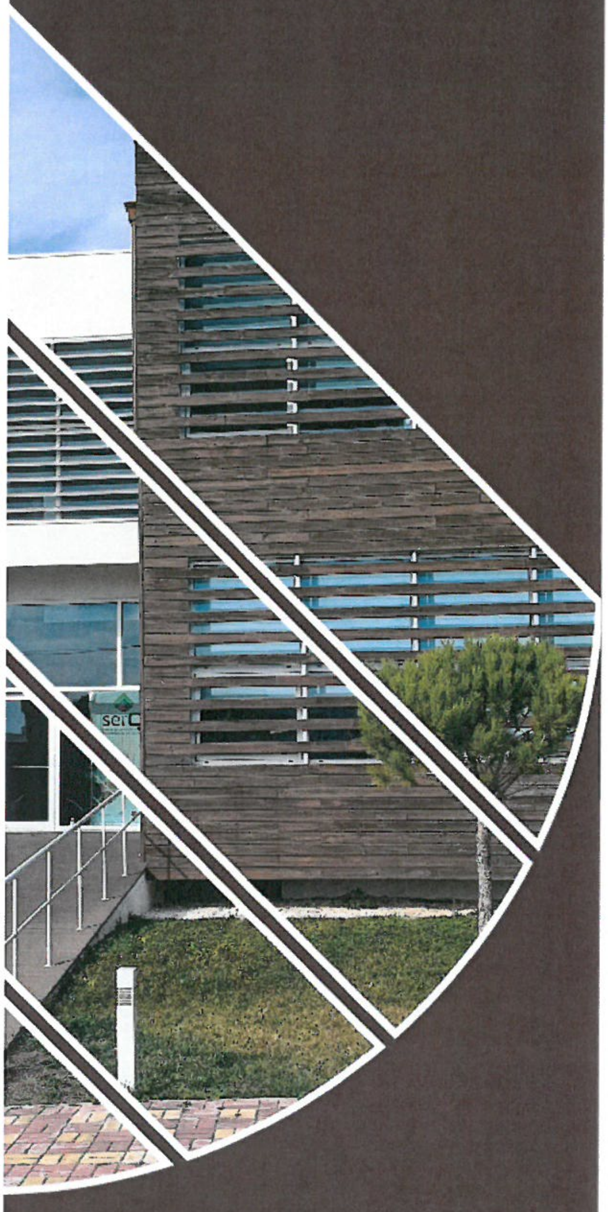

PRELIMINARY REPORT: RP/SERQ/190702

Mechanical characterization of Blackwood species

Project: Promotion of Cryptomeria wood – development of innovative construction products

July 2019

serQ
centro de inovação e competências da floresta

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FRAMEWORK

This report was prepared within the framework of the project "Promotion of Cryptomeria wood in construction. New products, opportunities and markets", in which the work is carried out by the Innovation and Competence Forest Centre (SerQ). The main objective of this report is to present the work done so far.

Having as main objective the investigation and development of innovative products for construction, based on the use of the wood of Cryptomeria from Azores, the present project includes the following tasks:

- Development of a Mechanical Classification system, according to the EN 14081 [1, 2]:
  - Selection of test elements based on visual classification according to the procedures referred in the Standard NP 4544 [3];
  - Conducting non-destructive dynamic tests with MTG and accelerometer;
  - Static tests according to the procedures defined in the Standard EN 408 [4];
- Product Development.

Considering the development of products, it was defined as research goal the study of the combination of Cryptomeria (*Cryptomeria japonica*) and Blackwood (*Acacia melanoxylon*). The knowledge of the mechanical properties of the raw-material is a key aspect for the development of new products, reason why it was considered to perform an experimental campaign for their determination, namely its modulus of elasticity and bending strength.

A total of 80 specimens were obtained from two different samples delivered at SerQ facilities with two different proveniences (Azores Islands and Continental Portugal). The cross section dimensions were similar, although with different lengths, being all the timber of Blackwood divided in two samples according to the provenience:

- Sample D (Azores Islands): 50mm x 120mm x 2200mm
- Sample E (Continental Portugal): 50mm x 120mm x 2900mm

Within the scope of the present report the results from experimental tests are displayed in order to proceed with the mechanical characterization of Blackwood species (both proveniences) and for further development of products.

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1. SAMPLE CHARACTERIZATION

The Blackwood timber (*Acacia melanoxylon*) was divided in two samples according to their provenience and characteristics, listed in Table 1.

Table 1. Characteristics of both samples of Blackwood timber (provenience, dimensions and number of specimens).

Sample	Provenience	Number of specimens	b - Width [mm]	h - Height [mm]	L - Length [mm]
D	Açores	40	50	120	2200
E	Continente	40	50	120	2900

At the reception of the timber at SerQ facilities it was observed through moisture meter that some specimens had moisture content above 20%. It was decided to improve the natural reduction of moisture content by spacing the specimens with 2cm slats, providing air circulation between the timber boards.

Later and having the objective of determining the most relevant mechanical properties in bending for design purposes of timber products/structures, two samples (one from each provenience) of 40 boards were selected, as recommended by EN 384 [7].

Selected specimens were measured in their respective cross sections, namely: i) length, ii) thickness and iii) width. To have in consideration the variations which occurs during the sawing process, the cross sectional dimensions were measured in three different locations (both ends and at mid-length).

At this stage, the moisture content was measured through an electronic wood moisture meter (Figure 1). The average values are presented in Table 2.

Figure 1. Moisture content measurement with an electronic wood moisture meter. Source: SerQ

Table 2. Average dimensions of both samples

Sample	Length – L [mm]	Width – b [mm]	Height – h [mm]	Moisture content, W (%)
D	2201	49.3	118.3	14.0
E	2898	49.9	121.5	12.9

2. WORK DESCRIPTION

The experimental work is described below comprising non-destructive tests (dynamic tests - longitudinal vibration method) and static tests. Finally, clear wood samples for moisture content (oven-dry method) and density determination were collected.

2.1. Mechanical characterization

Both dynamic and static tests were performed during the mechanical characterization of Blackwood samples. The mechanical characterization intends to obtain the dynamic modulus of elasticity (MOE_{din}) and static modulus of elasticity (local – MOE_{local} and global – MOE_{global}) as well as the bending strength (f_m). MOE_{din} was obtained through the use of a portable device – Machine Timber Grader (MTG).

2.1.1. Dynamic tests

The MTG is a portable device used for conducting the non-destructive test and determining the dynamic modulus of elasticity for several wood species. For certain species (most commercially used for structural purposes) this equipment allows classification of the specimen, according to the EN 338 Resistance Classes [5] (Figure 2). The equipment considers as a non-destructive method, the longitudinal vibration test, consisting of the introduction of a vibration in the element through an impact on one end of the element and measurement at the same end of the natural frequency of vibration resulting from that impact. This frequency is related to the geometric properties and density of the element for the determination of the dynamic modulus of elasticity. This is the indicator property for the assignment of a strength class since it presents good correlations with the static modulus of elasticity which, in turn, combined with the density, is usually the property that best correlation presents with the bending strength.

Figure 2. Machine Timber Grader. Source: SerQ

The MTG device is connected with a software which requires as input data the following information: i) cross-section dimensions; ii) length; iii) moisture content and iv) weight. As output, the device provides information regarding the dynamic modulus of elasticity of each specimen tested, being also possible to record the natural frequency.

To measure the moisture content, an electronic wood moisture meter was considered (Figure 1). The measurement of this property is based on the electrical conductivity between the two needles spiked to the specimen. Three different locations were adopted (approximately 60 cm from both ends and mid length), being considered the average of the three measurements.

2.1.2. Static tests

The static tests were performed to determine the mechanical properties of all specimens from both samples, following the EN 408:2010+A1 [4]. Both static modulus of elasticity (MOE) and bending strength (f_m) were determined.

i) Static modulus of elasticity (MOE)

Figure 3 and Figure 4 presents the test scheme and layout used for static tests. The maximum applied load should not exceed 40% of the predicted failure load ($F_{max,est}$) and shall be applied in displacement control with a constant rate of 0.003h mm/s (h – nominal height of cross-section). As shown in Figure 3, the deflections were measured by displacement transducers of 20 mm and 50 mm of maximum capacity.

The standard test span is 18h (h – nominal height of cross-section). However, in case of Sample D, it was not possible to consider that relation due to the maximum length of the specimens. Having into consideration the admissible variations for the distances between the loading points and the nearest support, the adopted span was 17h. For Sample E a span of 18h was adopted. Considering the adopted span and the available length of the specimens the test position was chosen by simplification the mid length being centred with the two loading points, especially for Sample D.

The local modulus of elasticity (MOE_{local}) was determined through Equation 1 whereas Equation 2 was considered for global modulus of elasticity (MOE_{global}) determination:

$$MOE_{local} = \frac{a l_1^2 (F_2 - F_1)}{16 I (w_2 - w_1)} \qquad (1)$$

$$MOE_{global} = \frac{3al^2 - 4a^3}{2bh^3\left(2\frac{w_2 - w_1}{F_2 - F_1}\right)} \qquad (2)$$

where,

a – distance between a loading point and the nearest support – 6h (mm);

l – span – 18h (mm);

l_1 – distance between measurement positions – 5h (mm);

b – width of the specimen cross-section (mm);

h – height of the specimen cross-section (mm);

I – second moment of area (mm^4)

$F_2 - F_1$ – increment of load (in N) on the regression line with a correlation coefficient of 0.99 or better;

$w_2 - w_1$ – increment of deformation/ vertical displacement (in mm) corresponding to $F_2 - F_1$.

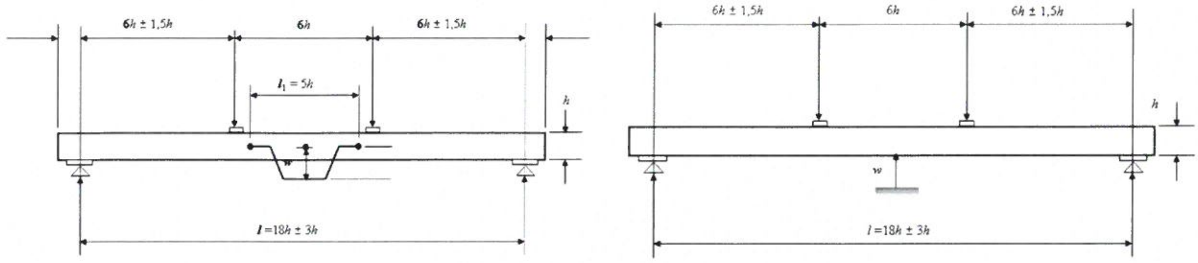

Figure 3. Test scheme adopted for MOE_{local} (left) and MOE_{global} (right), according to EN 408:2010+A1 [4]

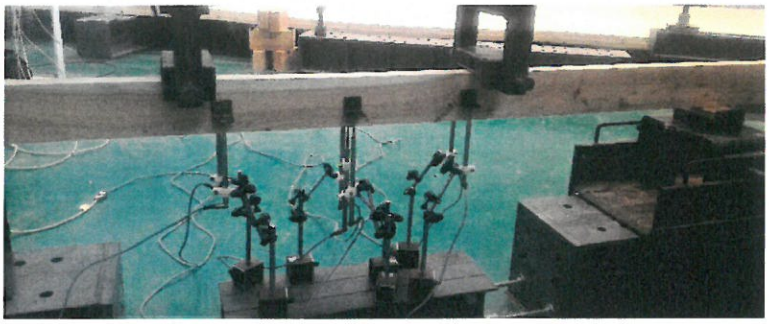

Figure 4. Test layout and displacement transducers used. Source: SerQ

ii) Bending strength (f_m)

In order to determine the bending strength (f_m), the same test layout for static modulus of elasticity was used. However, the deflections were not measured considering only the measurement of the maximum load (F_{max}) during the test.

In the bending strength test the load protocol was in displacement control at a constant rate such as the maximum load is reached with 300 ± 120s.

The test position as well as the span were the same as used for static modulus of elasticity tests.

The bending strength was determined through Equation 3:

$$f_m = \frac{3Fa}{bh^2} \tag{3}$$

where,

F – maximum load (N);

a – distance between loading point and the nearest support – 6h (mm);

b – width of the specimen cross-section (mm);

h – height of the specimen cross-section (mm).

2.1.3. Determination of moisture content and density

After bending strength tests, the moisture content (W) and the density (ρ) of each specimen tested were determined. For this purpose, from each specimen a small "slice" of full cross section was obtained with approximately 50 mm length. Each "slice" was obtained as closest as possible of failure location clear of failure signs and other defects (e.g. knots, wane, etc...).

The procedure described in EN 13183-1 [6] was followed. The weight and dimensions (length, width and height) of each "slice" were measured and placed in an oven at 103±2ºC. Successive weighings were made until the mass variation was less than 0.1%. The moisture content (W) was determined through Equation 4:

$$W = \frac{m_1 - m_0}{m_0} \times 100 \quad (4)$$

where,

m_1 – weight before drying (g);

m_0 – weight after drying process in oven (g).

3. RESULTS

In this section the obtained results from non-destructive tests and static tests are described.

The results of the dynamic modulus of elasticity (MOE_{din}), static modulus of elasticity (local – MOE_{local} and global – MOE_{global}), bending strength (f_m), density (ρ) and moisture content (W) are presented in Table 3 and Table 4, for Sample D and Sample E, respectively. According to EN 384 [7], some physical and mechanical properties should be adjusted to 12% moisture content. The referred Tables also include the adjusted values of density ($\rho_{12\%}$) and global static modulus of elasticity ($MOE_{12\%}$). Also the bending strength values were adjusted to a reference depth of 150 mm and to a span of 18h (f_{m_adj}).

Table 3. Summary of results from non-destructive and static tests, density and moisture content – Sample D

	MOE_{din} [MPa]	MOE_{local} [MPa]	MOE_{global} [MPa]	f_m [MPa]	ρ [kg/m³]	W [%]	$\rho_{12\%}$ [kg/m³]	$MOE_{12\%}$ [MPa]	f_{m_adj} [MPa]
Average	13451	15462	13648	65.0	590	11.0	593	13499	61.0
Minimum	10726	10388	9954	27.7	492	9.1	493	9786	25.9
Maximum	20054	23017	20520	130.1	772	15.4	779	20036	121.9
COV (%)	16.4	20.8	17.6	28.1	11.0	15.1	11.0	17.3	28.0
Number of tests	40								

Table 4. Summary of results from non-destructive and static tests, density and moisture content – – Sample E

	MOE_{din} [MPa]	MOE_{local} [MPa]	MOE_{global} [MPa]	f_m [MPa]	ρ [kg/m³]	W [%]	$\rho_{12\%}$ [kg/m³]	$MOE_{12\%}$ [MPa]	f_{m_adj} [MPa]
Average	14757	15328	14429	72.3	702	12.1	701	14447	69.3
Minimum	9420	9129	8399	26.8	535	9.2	538	8508	25.7
Maximum	18137	19299	17660	129.1	803	16.8	808	17587	123.8
COV (%)	13.5	15.8	14.4	31.2	10.3	12.2	10.3	14.5	31.2
Number of tests	40								

Figures 5 and 6 presents the load vs deformation curves obtained from the tests performed on specimens from Sample D and Sample E, respectively.

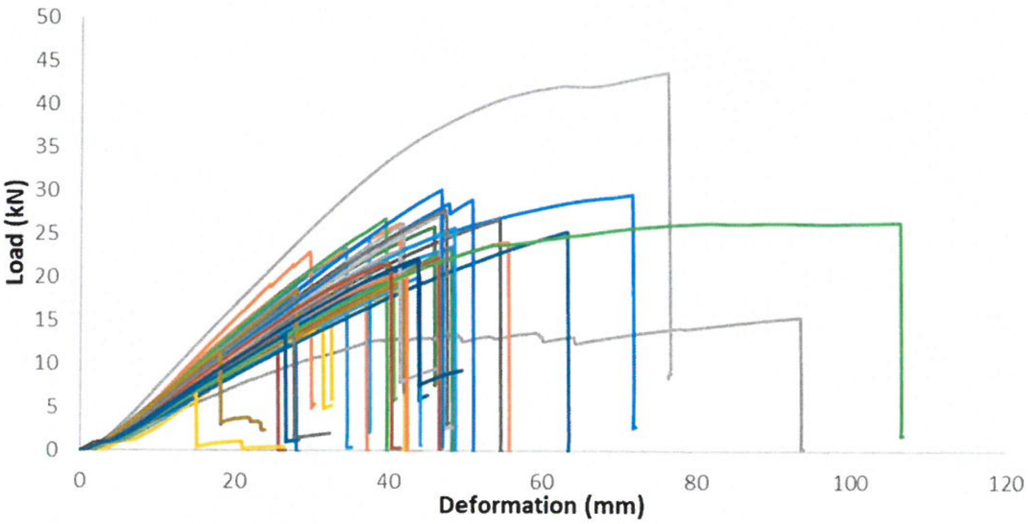

Figure 5. Load vs deformation curves obtained from bending strength tests – Sample D

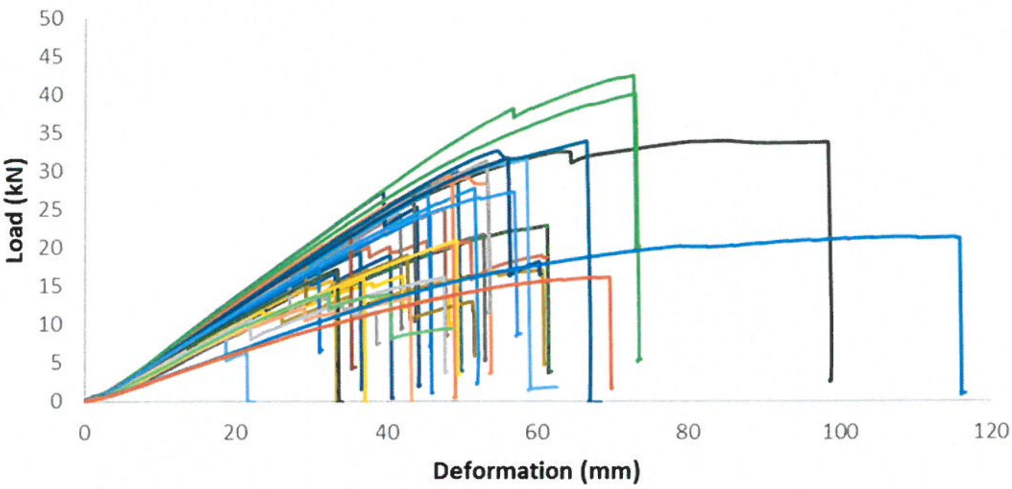

Figure 6. Load vs deformation curves obtained from bending strength tests – Sample E

Different load vs deformation behavior was observed which reflects the higher COV values not only for bending strength values but also for static modulus of elasticity.

In general, the failure mode was governed by the failure of fibres located in tension at the central span (between two loading points), without and with the presence of knots (Figure 7). It was also observed that 12.5% of the specimens showed ductile behaviour visible through the occurrence of compression folds on the upper part of the specimens (Figure 8).

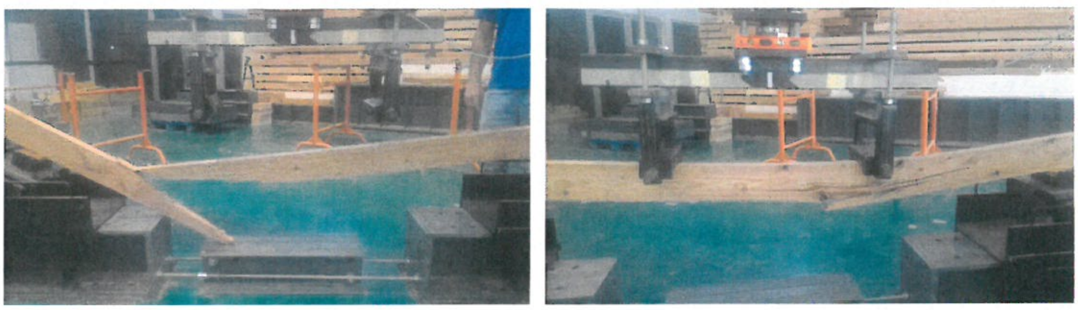

Figure 7. Different types of failure: failure on clear wood (left); failure with presence of knots (right)

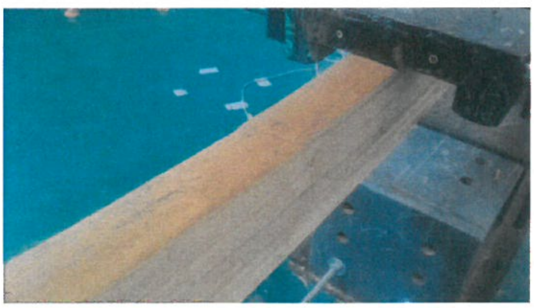

Figure 8. Different types of failure: failure with compression signs

The prediction of the mechanical properties of Blackwood is extremely important due to the higher costs associated with performing static tests. Currently it is possible to predict them namely through the non-destructive tests which did not influence the condition of the specimens. From the results previously presented there were established single linear correlations between the most important mechanical properties in bending ($MOE_{12\%}$ and f_{m_adj}). The correlation coefficient values obtained are listed by sample in Table 5. Figures 9 to 11 presents graphically the correlations obtained by sample and for the entire sample.

Table 5. Correlation coefficients between properties experimentally determined

	Sample D			**Sample E**		
	MOE_{din}	**$MOE_{12\%}$**	**f_m**	**MOE_{din}**	**$MOE_{12\%}$**	**f_m**
ρ	0.64	0.63	0.28	0.68	0.71	0.49
MOE_{din}	-	0.97	0.44	-	0.96	0.52
$MOE_{12\%}$	0.97	-	0.41	0.96	-	0.57

Figures 9, 10 and 11 presents graphically the correlations established between non-destructive tests and static tests.

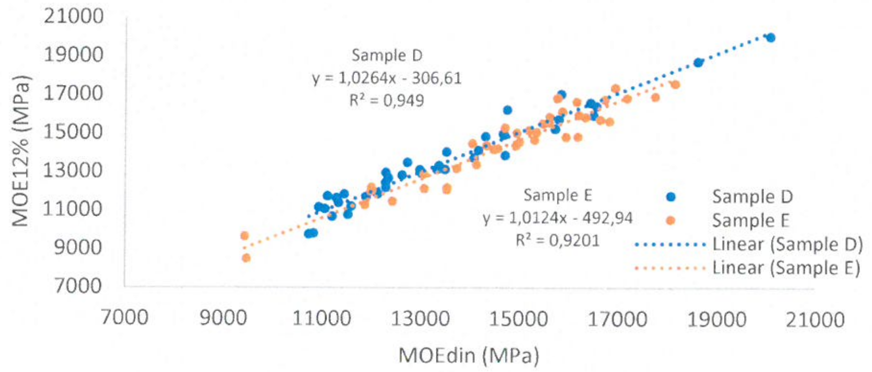

Figure 9. Simple linear correlation between MOE_{din} and $MOE_{12\%}$

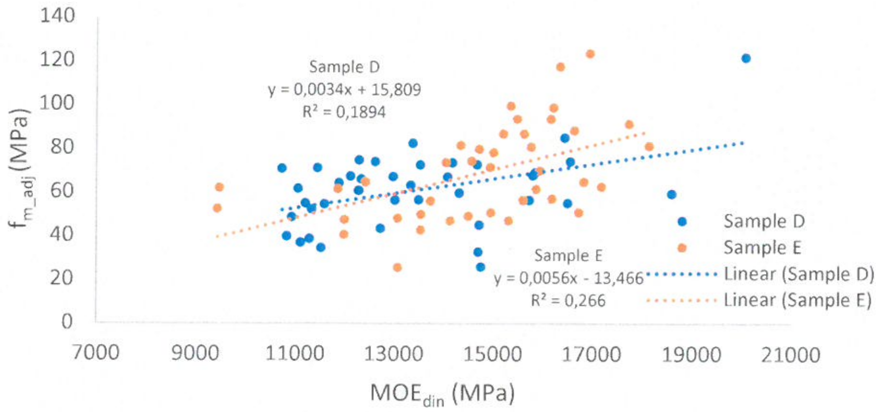

Figure 10. Simple linear correlation between MOE_{din} and f_{m_adj}

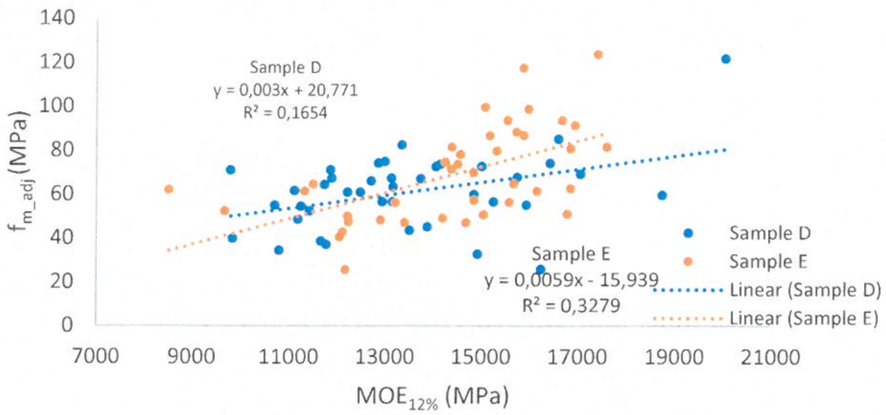

Figure 11. Simple linear correlation between $MOE_{12\%}$ and f_{m_adj}

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REFERENCES

1. CEN, *EN 14081-1: Timber Structures - Strength graded structural timber with rectangular cross section*, in *Part 1: General requirements*. 2016, Comité Européen de Normalisation: Brussels, Belgium.

2. CEN, *EN 14081-2: Timber Structures - Strength graded structural timber with rectangular cross section*, in *Part 2: Machine grading; additional requirements for initial type testing*. 2018, Comité Européen de Normalisation: Brussels, Belgium.

3. IPQ, *NP 4544: Madeira serrada de criptoméria para estruturas - Classificação visual para fins estruturais*. 2015, Instituto Portugês da Qualidade, I.P.: Lisboa.

4. CEN, *EN 408:2010+A1: Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties*. 2012, Comité Européen de Normalisation: Brussels, Belgium.

5. CEN, *EN 338: Structural timber - Strength classes*. 2016, Comité Européen de Normalisation: Brussels, Belgium.

6. CEN, *EN 13183-1: Moisture content of a piece of sawn timber*, in *Part 1: Determination by oven dry method*. 2002, Comité Européen de Normalisation: Brussels, Belgium.

7. CEN, *EN 384:2016+A1: Structural timber - Determination of characteristic values of mechanical properties and density*. 2018, Comité Européen de Normalisation: Brussels, Belgium.

The content of this report has been verified and validated, which is why it is signed by those responsible for the work.

Sertã, 05 july de 2019

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(Sofia Knapic)

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