PRELIMINARY REPORT: RP/SERQ/190701

Mechanical characterization of Cryptomeria wood

Promotion of Cryptomeria wood – development of innovative construction products

July 2019

serQ
centro de inovação e competências da floresta

Co-financed by:

GOVERNO DOS AÇORES

UNIÃO EUROPEIA

Fundo Europeu de Desenvolvimento Regional

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.

For this purpose, wood from Cryptomeria with different cross-sections and lengths, were divided into three lots for organization and planning according to the cross-section:

- Batch A: 50mm x 120mm x 3600mm – 508 elements
- Batch B: 80mm x 160mm x 4800mm – 312 elements
- Batch C: 100mm x 200mm x 6000mm – 250 elements

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1. SAMPLE CHARACTERIZATION

The sample consists of Cryptomeria wood, whose geometrical properties and quantities are indicated in Table 1 and Table 2, respectively.

Table 1. Dimensions of the wood elements

Batch	b - Width [mm]	h - Height [mm]	L - Length [mm]
A	50	120	3600
B	80	160	4800
C	100	200	6000

Table 2. Amount of wood received

Batch	Amount received [un]
A	508
B	312
C	250

Upon the reception of the wood, a preliminary control of the water content (contact humidity moisture device) of the elements was carried out, where high values (> 20%) were observed in most of the elements (Figure 1). It was necessary to dry it by wrapping it in an air-conditioned room with adequate temperature and humidity conditions in order to achieve adequate values and allowed by the test standards. It should be noted that Lot C was dried by an external entity, since SerQ did not have the physical conditions to dry it.

For a proper drying, the elements with water contents higher than 15% were separated, properly conditioned and placed in an air-conditioned room until reaching a balance water content of approximately 12%.

Figure 1. Water content recorded by a contact humidity moisture device. Source: SERQ

After drying, and in accordance with the requirements defined in EN 14081-2 [2], for the derivation of definitions for a mechanical classification system, a minimum of 450 elements, representative of the cross-sections normally used, the sampling indicated in Table 3 was defined.

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Table 3. Sampling considered for classification purposes

Batch	Nº elements [un]
A	250
B	200
C	50

In the selected elements, the dimensions (length, thickness and width) were measured. The cross-sectional dimensions of the section were measured at three points to consider the variations that occur due to sawing.

At this stage, the water content of the elements was also measured using a needle humidifier. The average values obtained for each batch are presented in Table 4.

Table 4. Sample dimensions

Batch	Length [mm]	Width – b [mm]	Height – h [mm]	Moisture Content, W (%)
A	3598	50.5	120.8	10
B	4800	79.3	158.4	15.1
C	6000	99.4	197.4	13.

2. WORK DESCRIPTION

The tests for the development of the mechanical classification system have been carried out on the indicated elements, and comprise the following:

i) dynamic tests: performed using the equipment *Machine Timber grader* (MTG) and accelerometer;
ii) static tests: carried out in accordance with the procedures of the European standard EN 408 [4].

Table 5 shows the number of tests performed up to the date of this report.

Table 5. Number of tests performed

Batch	Selection of visual elements (total) [un]	Dynamic tests (total) [un]	Static tests (total) [un]
A	261 (261)	261 (261)	261 (261)
B	205 (205)	205 (205)	205 (205)
C	54 (54)	54 (54)	54 (54)

2.1. Elements Selection

The selection of the elements for the dynamic and static tests was performed through a visual evaluation based on the indicated requirements and procedures in the European standard NP 4544:2015 [3] intended for the visual classification of sawn wood of cryptomeria (Cryptomeria japónica (L.f.) D. Don).

This standard defines the two quality classes and respective characteristic values of mechanical resistance: CYS I (cryptomeria for structures I) e CYS II (cryptomeria for structures II).

For the assignment of one of the quality classes to the elements the defects and characteristics of each element are evaluated and measured, which must meet the limits established in table 1 of the standard NP 4544:2015 [3] (Table 5).

Table 5. Characteristics of quality classes

<table>
<tr><th colspan="2">Singularities</th><th>Class CYS I</th><th>Class CYS II</th></tr>
<tr><td rowspan="2">Knots</td><td>Face</td><td>Ø ≤ 60mm; ≤ 1/2L</td><td>Ø ≤ 100mm; ≤ 3/4L</td></tr>
<tr><td>Edge</td><td colspan="2">Ø ≤ 50mm; ≤ 3/4E</td></tr>
<tr><td colspan="2">Growth rate</td><td colspan="2">≤ 6mm/year</td></tr>
<tr><td colspan="2">Density *)</td><td>≥ 310 kg/m³</td><td>≥ 290 kg/m³</td></tr>
<tr><td rowspan="4">Fissures ***)</td><td rowspan="2">Not going through the thickness</td><td colspan="2">Cracks whose depth does not exceed half of the piece can be ignored.</td></tr>
<tr><td colspan="2">≤ 1.5m or 0.5 × piece length **)</td></tr>
<tr><td rowspan="2">Going through the thickness</td><td colspan="2">On tops: ≤ 2 × piece width</td></tr>
<tr><td colspan="2">Not occurring on tops: ≤ 1.0m or ≤ 0.25 × length **)</td></tr>
<tr><td colspan="2">Slope of grain</td><td colspan="2">≤ 1/6</td></tr>
<tr><td rowspan="4">Warp***)</td><td>bow (in 2m)</td><td colspan="2">< 20mm</td></tr>
<tr><td>spring (in 2m)</td><td colspan="2">< 12mm</td></tr>
<tr><td>twist (in 2m)</td><td colspan="2">< 2mm per each 25mm width of the piece</td></tr>
<tr><td>cup</td><td colspan="2">no restrictions</td></tr>
</table>

Wane	Length, Width and Thickness	< 1/3 of the piece length or < 0.1m of length **) <1/3 of the thickness and width of the piece
Included Bark	Not going through the thickness	No restrictions if they are shorter than the width of the piece. If not, crack limits will be applied.
	Going through the thickness	Unlimited if its length is <½ of the width of the piece. If not, crack limits will be applied.
Biological degradation		No evidence of deterioration by rot fungi or insects. Deterioration by chromogenic fungi is permitted provided that their presence is incipient.
Compression wood		Accepted in one quarter of the W or of the T and until a length of 1m. Timber pieces presented compression wood in two opposite faces (going through the thickness) must be excluded.

*) value reported to a water content of 12%
**) the more restrictive condition applies
***) defects that may arise or change its dimensions due to changes in the water content of the parts. In this way, the classification of these singularities refers only to the state of the part at the time of classification. It is recommended that whenever changes of + -4% of water content occur the piece is reclassified to this singularity.
L- Piece width; E – Piece thickness

2.2. Mechanical Classification

Dynamic and static tests were performed to assess the mechanical classification of the sample. With the accomplishment of the mechanical classification it is intended to obtain the dynamic elastic modulus (MOEdin) and static (MOE) as well as the flexural tensile strength (fm). The MOEdin was determined using two devices: Machine Timber Grader (MTG) and accelerometer.

2.2.1. Dynamic tests

For the determination of the dynamic properties of the sample elements, non-destructive tests were carried out. These tests allow the dynamic modulus of elasticity to be obtained. For this, the technique of longitudinal vibration was used using a portable commercial equipment - Machine Timber Grade (MTG) and the accelerometer.

i) Machine Timber Grader (MTG)

The MTG is a portable equipment used for conducting the non-destructive test and determining the dynamic modulus of elasticity for most wood species. For certain species (most commercially used for structural purposes) this equipment allows classification of the element, according to the EN 338 Resistance Classes [5] (Figure 2). The equipment uses as a non-destructive method, the longitudinal vibration test, consisting of the introduction of a vibration in the element through an impact on one of the tops of the element and measurement at the same top of the vibration frequency resulting from that impact. This frequency of vibration 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 resistant 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 tensile strength.

Figure 2. Machine Timber Grader. Source: SERQ

To do this, as input to the equipment, the cross-section dimensions of the element, the length, the water content at the time of the test and the mass are entered. As a relevant output, the equipment provides information regarding its dynamic modulus of elasticity.

To take into account the water content of each element, a measurement with a needle humidifier was done - Figure 3. The needle humidifier is a device to measures wood water content. The measurement of this characteristic is based on the electrical conductivity between the two needles in the measuring material. The measurement is carried out at three points (approximately 60cm from the tops and half span) of the element, considering the average value of the three measurements.

Figure 3. Measurement of water content with the needle humidifier. Source: SERQ

ii) Accelerometer

The accelerometer is a device that allows the dynamic test to be performed since it is based on the measurement of the dynamic response of the element to an induced disturbance (vibrations).

The test consists of placing the accelerometer at one end of the beam element and causing a vibration at the opposing end of the member induced by a hammer. This test is sensitive and must be performed in the most controlled environment as it is intended that the vibrations absorbed by the accelerometers are exclusively due to the disturbance caused by the hammer, thus avoiding the interference of external factors that may distort the quality of the results.

It should be noted that the main objective of this test is to act as a basis for comparison with MTG results and with static tests.

Figure 4. Dynamic test with the accelerometer. Source: SERQ

2.2.2. Static testing

For the determination of the mechanical properties of the elements of the sample, static tests were performed, following the indications of standard EN 408: 2010 + A1 [4]. The static elastic modulus (MOE) and the tensile strength (fm) of the elements were determined with the static tests.

i) Static test for determination of static modulus of elasticity (MOE)

The test scheme used is shown in Figure 5 and Equation 1. In this test, the applied load shall not exceed 40% of the estimated maximum breaking force ($F_{max,\ est}$) and shall be applied in displacement control at a speed of 0.003h mm / s (h - nominal cross-sectional height).

In this test, the applied load shall not exceed 40% of the estimated maximum breaking force ($F_{max,\ est}$) and shall be applied in displacement control at a speed of 0.003h mm / s (h - nominal cross-sectional height). The vertical displacement of the mid-span elements, as indicated in Figure 5, was measured by displacement transducers.

The test span used for the sample elements was 18 h (h - nominal cross-sectional height). The choice of the test position was made in accordance with the applicable standards, i.e. in such a way that the cross-section or section of the element where rupture was expected to occur was between the two test loading points (zone in pure bending).

The static modulus of elasticity was determined by Equation 1:

$$MOE = \frac{3al^2 - 4a^3}{2bh^3\left(2\frac{w_2 - w_1}{F_2 - F_1}\right)} \quad (1)$$

where,

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

l – span (mm) – 18h;

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

h – cross sectional height of the element (mm);

$F_2 - F_1$ – load increase (in newtons) on the regression curve with a correlation coefficient of 0.99 or greater;

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

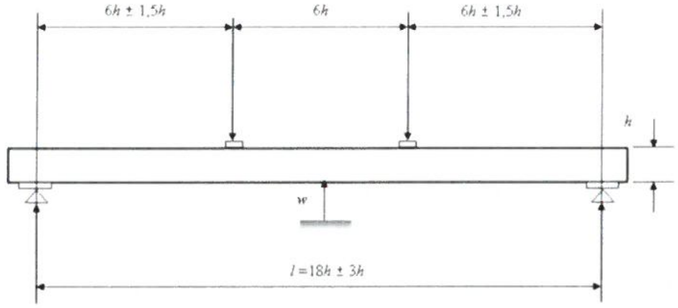

Figure 5. Test scheme in accordance with standard EN 408:2010+A1 [4]

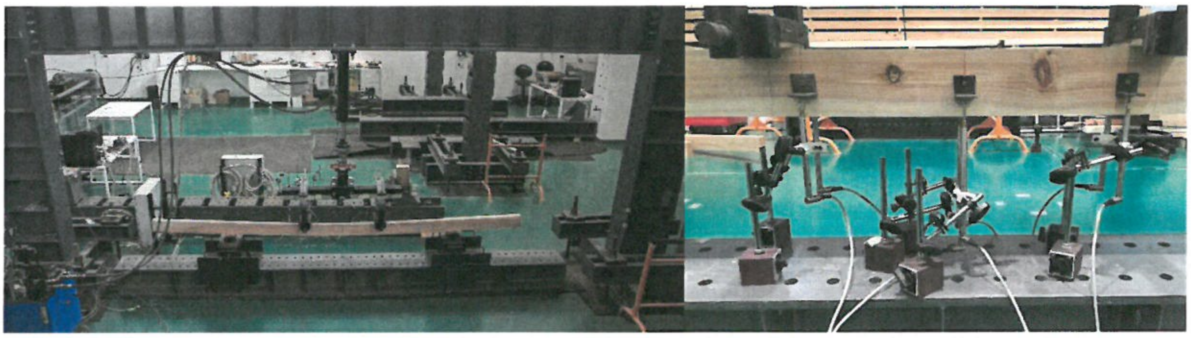

Figure 6. Test scheme and displacement transducers used. Source: SERQ

ii) Static test for determination of bending tensile strength (f_m)

In order to determine the flexural strength (f_m) of the elements, the test scheme used was the same as that of the static test for determination of the static modulus, with the exception that the vertical displacements were not measured in the middle. In this test, only the applied force was measured, in order to record the maximum force at breakage of the element (Fmax).

In this test the load application was done in displacement control (mm / s) so that the flexural rupture of the elements happened in 300 ± 120s. However, due to the variability found in the elements tested, the breakage did not always occur within this time interval.

The test position of the elements was the same as that determined and used in the static test to determine the modulus of elasticity.

The flexural strength was determined by Equation 2:

$$f_m = \frac{3Fa}{bh^2} \qquad (2)$$

where,

F – force (in newtons);

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

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

h – cross-sectional height of the element (mm).

iii) Determination of water content (W) and density (ρ)

After all the tests were carried out, the water content (W) and the density (ρ) of all the elements tested were determined. For this purpose, small "slices" of complete cross-section approximately 50 mm thick, as close as possible to the area where the fracture occurred, were cut after the breaking test and without defects.

The present indications of standard EN 13183-1 [6] were followed. The "slices" were immediately weighed, measured and placed in an oven at 103 ° ± 2 °. Subsequently, successive weighings were made until the mass variation was less than 0.1%. The water content (W) was obtained through Equation 3:

$$W = \frac{m_1 - m_0}{m_0} \times 100 \qquad (3)$$

where,

m_1 – mass of the slice before drying (in grams);

m_0 – mass of the slice after drying in kiln dryer (in grams).

In Figure 7 it is possible to observe the weighing procedure of the "slices" for determining the water content and density of each element.

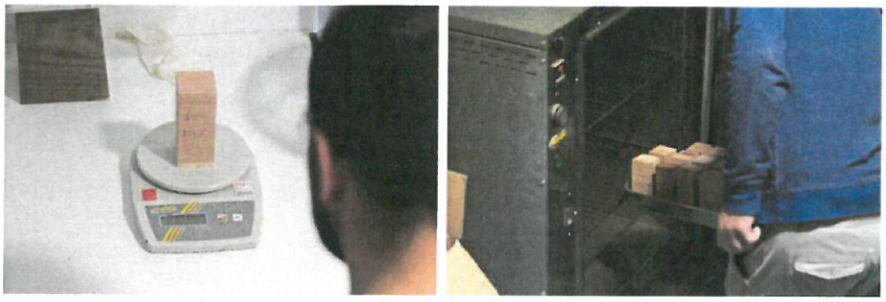

Figure 7. Determination of water content and density (weighing and drying in kiln). Source: SERQ

3. RESULTS

In this section we present the results obtained in the dynamic and static tests performed.

The mean, minimum and maximum values of the dynamic modulus of elasticity (MOE_{MTG}) and (MOE_{Acel}) and static modulus of elasticity (MOE) and flexural tensile strength (f_m) are shown in Table 7, 9 and 10.

Also, the values obtained for the water content (W) and density adjusted to 12% water content (ρ12%), according to the indications given in EN 384 [7], are presented.

Table 6. Results of dynamic and static tests, density (12%) and water content (average values of the respective lot)

Batch	MOE_{MTG} [N/mm²]	MOE_{Acel} [N/mm²]	MOE_{Global} [N/mm²]	f_m [MPa]	$\rho_{12\%}$ [kg/m³]	W [%]
A	7005.1	7136.0	7604.1	30.3	301.9	12.1
B	6048.4	6056.7	5914.1	23.7	295.6	14.8
C	5928.1	5921.3	5918.0	20.7	283.6	13.1

Table 7. Minimum values obtained from dynamic and static tests, density (12%) and water content

	Minimum value obtained					
Batch	MOE_{MTG} [N/mm²]	MOE_{Acel} [N/mm²]	MOE_{Global} [N/mm²]	f_m [MPa]	$\rho_{12\%}$ [kg/m³]	W [%]
A	3711.0	3808.9	4197.5	12.7	211.8	10.5
B	3154.0	3009.9	2599.8	11.6	212.0	12.9
C	4689.0	4844.3	4498.1	12.4	223.4	10.1

Table 8. Maximum values obtained from dynamic and static tests, density (12%) and water content

	Maximum value obtained					
Batch	MOE_{MTG} [N/mm²]	MOE_{Acel} [N/mm²]	MOE_{Global} [N/mm²]	f_m [MPa]	$\rho_{12\%}$ [kg/m³]	W [%]
A	12518.0	12600.3	13678.7	63.2	478.0	25.4
B	9826.0	9762.3	10193.7	50.2	387.9	23.4
C	8219.0	8237.7	8302.7	32.8	387.6	17.5

Throughout the tests the correlation between the elastic modulus obtained in the dynamic and static tests was calculated, as well as the correlation between the elastic modulus and the tensile strength obtained. Table 10, 11 and 12 presents the final correlations obtained.

Table 9. Final correlations – batch A

	MOE_{MTG}	MOE_{Acel}	f_m
MOE_{Global}	0,94	0,95	0,76
MOE_{MTG}	-	0,99	0,74
MOE_{Acel}	-	-	0,74

Tabela 10. Final correlations – batch B

	MOE_{MTG}	MOE_{Acel}	f_m
MOE_{Global}	0.95	0.96	0.73
MOE_{MTG}	-	1.00	0.70
MOE_{Acel}	-	-	0.70

Tabela 11. Final correlations – batch C

	MOE_{MTG}	MOE_{Acel}	f_m
MOE_{Global}	0.87	0.87	0.56
MOE_{MTG}	-	0.98	0.49
MOE_{Acel}	-	-	0.47

In Figures 8 to 16 the cloud graphs of the relevant results are presented with their linear regression curves. Figure 17 shows the force-time curve obtained in the static tests of Lot A, where the maximum, minimum and average values are presented. Figure 18 displays three different types of rupture patterns.

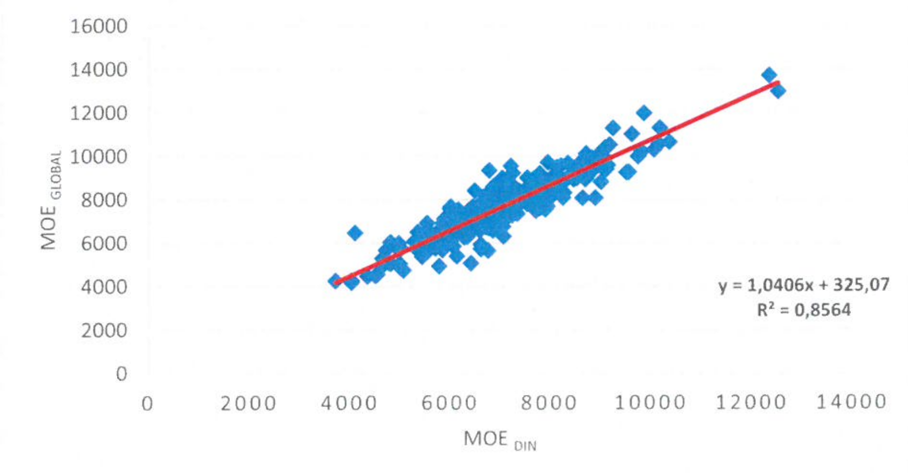

Figure 8. MOE_{MTG} *vs* MOE_{Global} – batch A

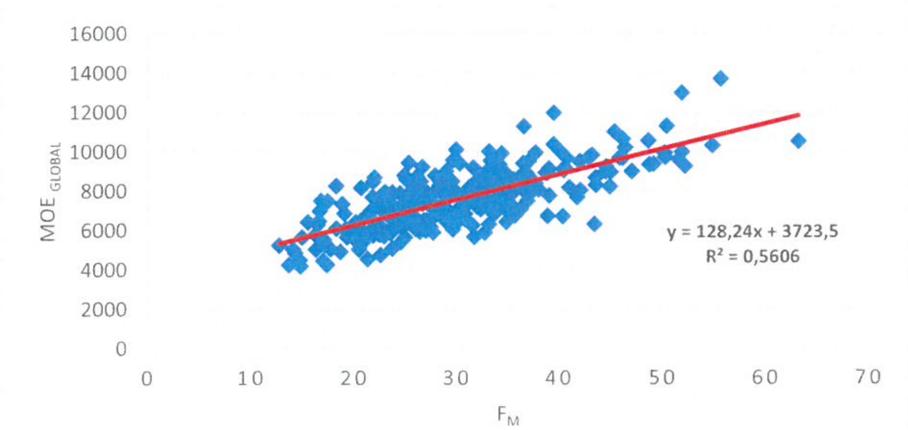

Figure 9. MOE_{Global} *vs* f_m – batch A

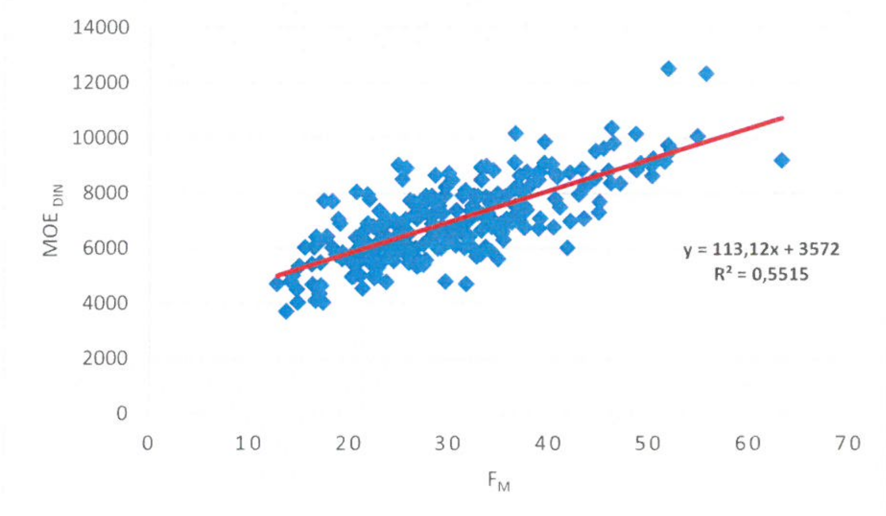

Figure 10. MOE_{MTG} *vs* f_m – batch A

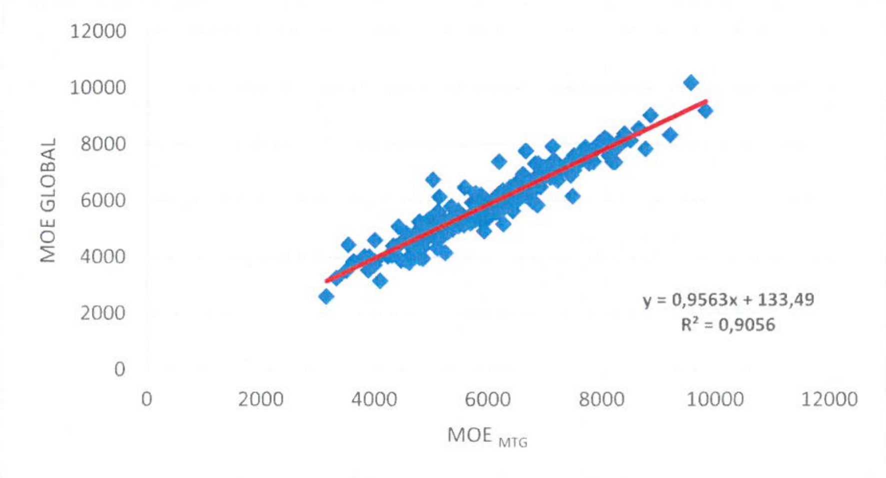

Figura 11. MOE_{MTG} *vs* MOE_{Global} – batch B

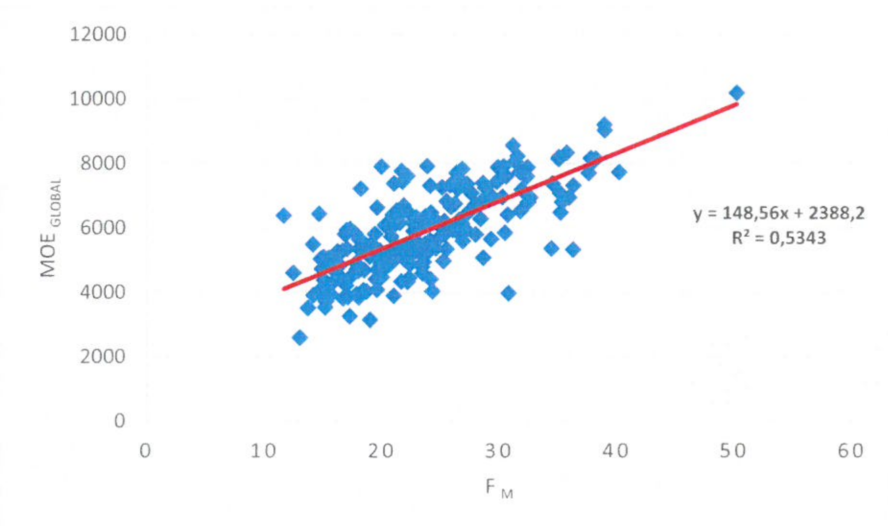

Figura 12. MOE_{Global} *vs* f_m – batch B

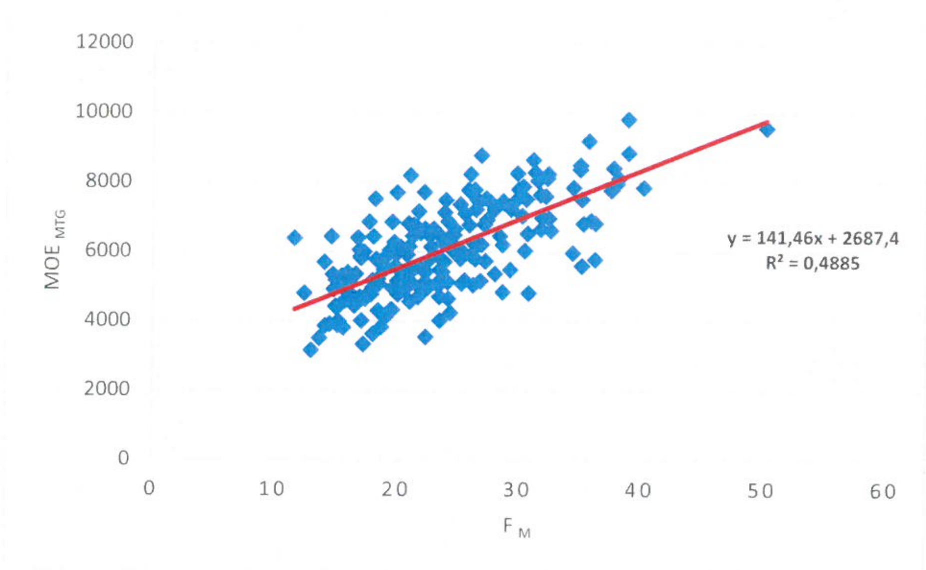

Figura 13. MOE$_{MTG}$ *vs* f$_m$ – batch B

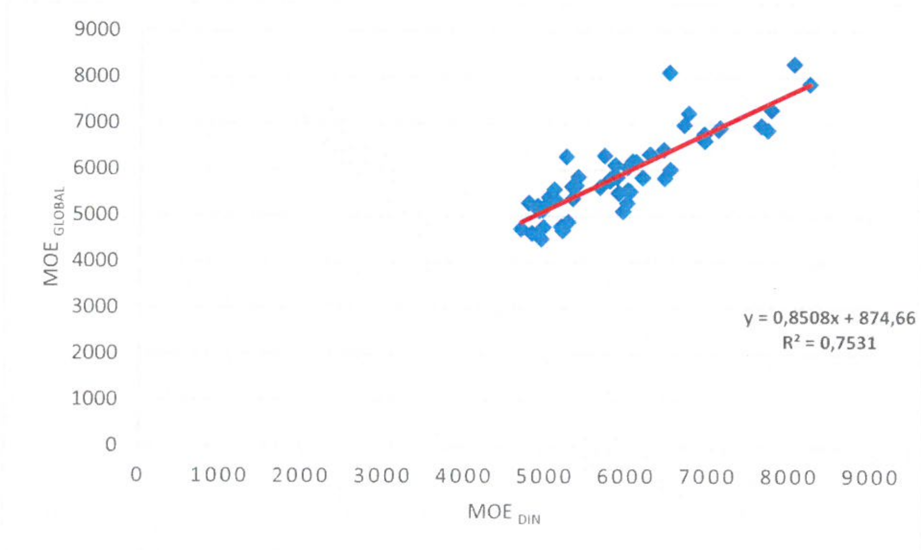

Figura 14. MOE$_{MTG}$ *vs* MOE$_{Global}$ – batch C

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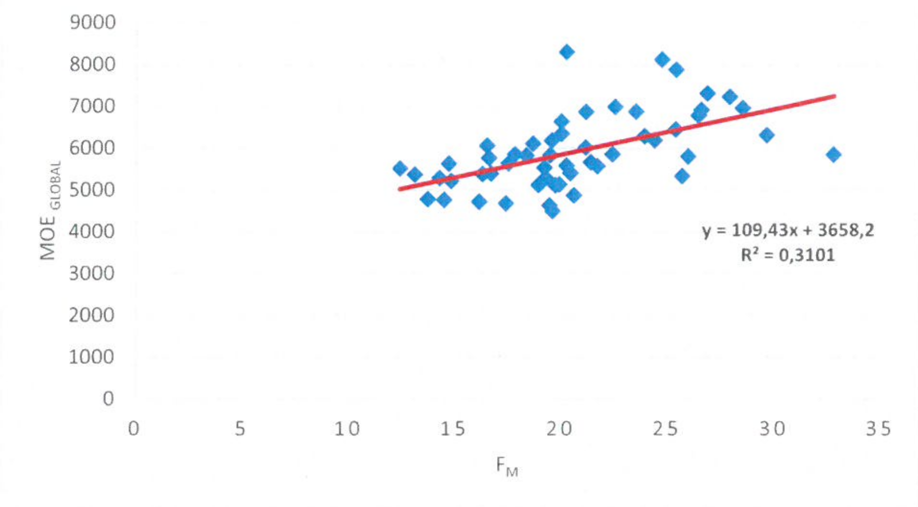

Figura 15. Gráfico MOE_{Global} *vs* f_m – batch C

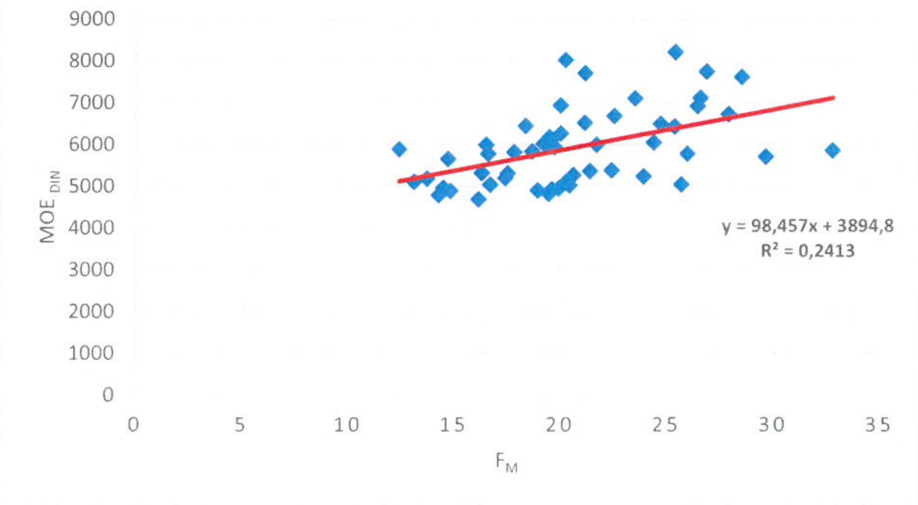

Figura 16. MOE_{MTG} *vs* f_m – batch C

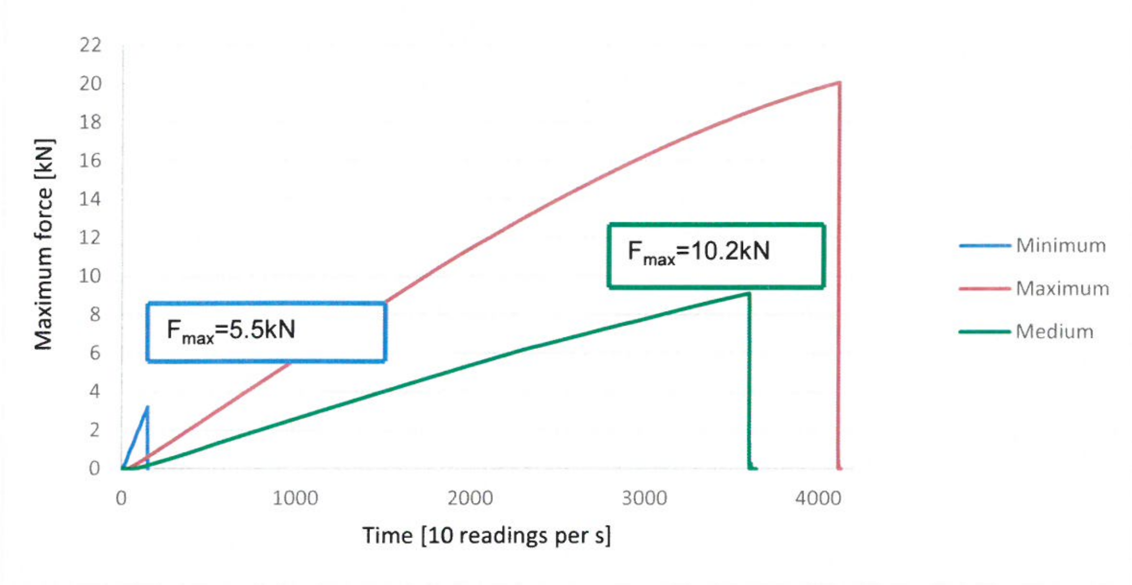

Figure 177. Correlation between maximum force and time

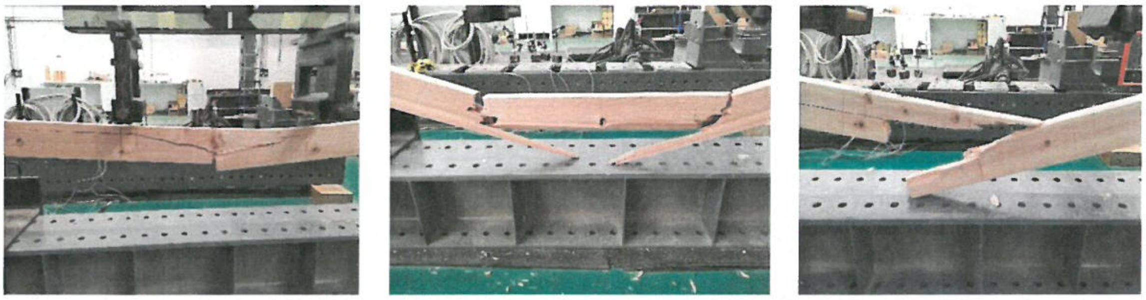

Figure 18. Three different types of ruptures

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

Sertã, 20 March 2019

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