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DURABILITY OF REACTION TO FIRE PERFORMANCE OF WOOD BASED PANELS THROUGH ACCELERATED AGING CYCLES

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1. INTRODUCTION

Wood is being used by humans since the early civilizations, and was one of the most important materials used the building construction. In recent years, due to ecological and environmental policies and restrictions in Europe, wood, wood products and wood structural elements have being positioned as a green raw material, Ecologically Sustainable and renewable material with a positive impact in the buildings carbon dioxide emissions in comparison to other construction materials, such as steel, concrete and bricks. The EUs driving policies for a competitive economy with low carbon emissions, [1], boost its architectural and engineering application in the building industry, but actually subjected to an higher demand in terms of its life cycle performance basic requirements, such as the sustainable use of natural resources, mechanical resistance and stability and Safety in case of fire, among others, [2].

The disseminated use of wood and wood products in the building construction have led to a need of wood based product development (Engineered wood products), namely wood-based panels, such as particle board (PB), medium density fibreboard (MDF), plywood, hardboards and wood flooring, [3], and wood structural members from large wood panel construction using cross-laminated timber (CLT), and others [4].

Being a hygroscopic material, wood thermal and mechanical properties, and aesthetic appearance, are affected by its surrounding environment, regarding temperature, humidity and

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direct or indirect solar radiation in outdoor and indoor appliances. Furthermore, when the moisture content is above 20%, wood is susceptible to attack by fungi and bacteria. Structural wood products when exposed to excessive moisture variations can lead to swelling or shrinkage causing warping and cracking of the element reducing its mechanical properties, stability and durability. Additionally, wood structural elements with superficial cracks will have their reaction and resistance to fire reduced as the fire will propagate through them leading to a faster cross section charring rate and heat release rate (HRR). For these reasons different wood treatment methods, physical or chemical treatments, are used to increase wood stability and durability, and improving the resistance to biological degradation, fire resistance, UV resistance and mechanical properties, [4, 5]. Currently applied superficial chemical treatments include coating moisture-, bio-, fire- or UV-resistant agents on the surface of wood.

Wood is considered a flammable material, and although it has an intrinsic/natural fire protection, charring to decrease the heating rate, from the European standard fire classification of construction products and building elements, EN13501-1 [6], untreated wood is usually classified as being of class D, with lower density products in class E. This classification system considers the reaction to fire performance, smoke production and flaming droplets/particles. When fire retardant treatments are applied wood products can reach C and B class levels. Table 1 shows how the classification of construction products is made based on fire reaction levels [7].

Table 1 - Classification of the reaction to fire of wood products.

Euro class	**Smoke Class**	**Burning droplets class**	**Typical products**
A1	-	-	Stone, concrete
A2	s1 s2, or s3	d0 d1 or d2	Gypsum boards (thin paper), mineral wool
B	s1 s2, or s3	d0 d1 or d2	Gypsum boards (thick paper), fire retardant wood products
C	s1 s2, or s3	d0 d1 or d2	Coverings on gypsum boards
D	s1 s2, or s3	d0 d1 or d2	Wood, wood-based panels
E	-	- or d2	Some synthetic polymers
F	-	-	No performance determined

Additionally, when wood products are protected with non-fire retardant coatings their ignition properties and flame spread are influenced by the coating chemical composition and film thickness, [8, 9]. Wood treatment with fire retardant coatings (FRC) or intumescent fire retardant coatings (IFRC), [10], can overcome these weaknesses when wood products are exposed to fire and, for wood structural elements, assure the required fire resistance and load bearing capacity to be used in the building construction, meeting the requirements of the Eurocode 5, [11].

Fire retardants applied in the products surface or by pressure impregnation may considerably improve the fire properties of wood and wood products, but the long term durability of this protection is not fully known. It is expected that, mainly in exterior applications but also in interior humid conditions, the fire retardant efficiency may reduce due to its hygroscopicity [12] and water solubility of the chemicals used.

The recent standard EN16755, [13], specifies a new classification testing for Durability of Reaction to Fire performance (DRF) based mainly on the Nordtest standard NT Fire 054 [14]. This classification is based on the intended use, considering interior dry and humid applications and exterior applications, as shown in Table 2. For exterior applications, the reaction to fire performance after weather exposure can be classified using natural or accelerated weathering.

Table 2 - Requirements for DRF Classes of fire-retardant wood products in interior and exterior end use applications, [13].

DRF class		***Existing fire requirements***	***Additional performance requirements at different end use of fire retardant wood-based products***	
	Intended use	*Reaction to fire class, initial*	*Hygroscopic properties*	*Reaction to fire performance after weather exposure*
INT1	Interior dry applications	Relevant fire class	**-**	**-**
INT2	Interior humid applications	Relevant fire class	- Moisture content < 28 % - No exudation of liquid - Minimum visible salt with no increase at surface	-
EXT	Exterior applications	Relevant fire class	- Moisture content < 28 % - No exudation of liquid - Minimum visible salt with no increase at surface	Maintained reaction to fire performance (*) after - Accelerated weathering or - Natural weathering Application of specified maintenance may be included.

*Criteria for small scale fire testing after weather exposure: - Class B products (according to EN 13501–1): Heat Release Rate, HRR30s ave ≤ 150 kW/m2 during 600 s after ignition and Total Heat Release THR600s increase < 20 % compared to fire testing before the weather exposure. - Class C products (according to EN 13501–1): HRR 30s ave ≤ 220 kW/m2 during 600 s after ignition and THR600s increase < 20 % compared to fire testing before the weather exposure.

To evaluate the performance and durability of fire treated wood based panels on the thermal and mechanical properties, including reaction to fire, a study is being done considering the long term behaviour of wood products with and without fire retardant products after being submitted to accelerated aging and compared to non-aged wood products.

A set of experimental tests are performed towards the mechanical characterization and fire reaction of different wood based panels with and without fire retardant products, according to the EN 310 standard [15] to determine bending strength (MOR) and modulus of elasticity (MOE), and in the cone calorimeter to evaluate mass loss and heat release rate.

2. MATERIALS AND METHODS

2.1 Mechanical characterization

The mechanical characterization was done in five different wood based panels, with and without fire retardant: standard Medium Density Fiberboard without fire retardant (MDF-ST-NFR), Medium Density Fiberboard with fire retardant (MDF-FR), Particle Board type P2 without fire retardant (PB-P2-NFR), Particle Board type P2 with fire retardant (PB-P2-FR) and Oriented Strand Board type 4 without fire retardant (OSB3-NFR). The panels were all supplied by the company Sonae Arauco, [16].

The mechanical properties of the panels provided by the manufacturer and its fire reaction classes are shown in Table 3.

The mechanical strength was determined by the standard EN310 [15], using the three-point bending test to determine bending strength (MOR) and Modulus of elasticity (MOE).

Table 3 - Mechanical properties of the manufacturer.

Ref. panel	**Thickness ranges [mm]**	**Class of Reaction to fire**	**Bending Strength [MPa]**		**Modulus of Elasticity [MPa]**	
			0º	90º	0º	90º
MDF-FR	13 - 19	B-s2, d0	20	-	2200	-
MDF-ST-NFR	13 - 19	D-s2, d0	20	-	2200	-
PB-P2-FR	14 - 20	B-s1, d0	11	-	1600	-
PB-P2-NFR	14 - 20	D-s2, d0	11	-	1600	-
OSB3-NFR	18 -25	D-s2, d0	26	14	4800	1900

There were a total of 20 tested specimens for each MDF, PB and OSB panel, following the cutting plan of EN310. Each panel cut in two groups of ten specimens, for each orientation 0º and 90º, with half of the samples tested with the upper side on the top and other half with the lower side on the top.

The test specimens were rectangular with length between supports based on the panel thickness. Since the width is b (50 ± 1) mm and the length between the supports is 20 times the nominal thickness (t), the total length is l1 mm (length between the supports), plus 50 mm. Table 4 represents the specimens size for each panel type used in the tests.

Table 4 - Dimensions of test pieces used in the test.

Types of panels	Nº of test pieces	Width (b)[mm]	Thickness (t)[mm]	Length between the supports (l1) [mm]	Total length (l2) [mm]
MDF-FR-0º	10	50	16	320	370
MDF-FR-90º	10	50	16	320	370
MDF-NFR-0º	10	50	16	320	370
MDF-NFR-0º	10	50	16	320	370
PB-FR-0º	10	50	15	300	350
PB-FR-90º	10	50	15	300	350
PB-NFR-0º	10	50	15	300	350
PB-NFR-0º	10	50	15	300	350
OSB3-NFR-0º	10	50	18	360	410
OSB3-NFR-90º	10	50	18	360	410

The test specimens were conditioned in a climatic chamber (ACS DM600) to a constant mass, for all the samples to enter in a hygroscopic equilibrium in an atmosphere with relative humidity of (65 ± 5) % and a temperature of (20 ± 2) ºC, according to Figure 1. It was considered that a constant mass was reached when the results of two consecutive measurements of the test piece mass, carried out at 24 hours of distance, are not differing of more than 0,1%, which means that the test piece mass cannot differ more than 0.10g. Eight days of conditioning were necessary so that the constant mass be reached.

Figure 1- Conditioning of test specimens.

The three point bending test was done using an Universal testing machine suitable for bending tests up to 100 [kN], INSTRON 3382. The setup consists of a cylindrical load head with 30 [mm] diameter placed parallel to the supports at the specimen mid span, as in Figure 2. The supports

are adjustable to allow the different length specimens support on a cylindrical clamp with 15 [mm] diameter, as shown in Figure 2.
The load was applied at a rate determined to achieve the maximum load within 60±30 seconds throughout the test. The mid span vertical displacement was also measured during the tests.

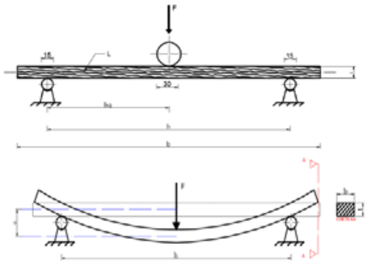


Figure 2- Schematic representation of the test and measurement of deflection, [15].

The bending strength calculation (MOR) was calculated from the following Equation 1.

$$\mathrm{MOR} = \frac{3\mathrm{F}_{\mathrm{máx}}\mathrm{l}_1}{2\mathrm{bt}^2} \quad (1)$$

Where $F_{máx}$ represents the maximum load (N), l_1 is is the distance between the centers of the two supports (mm), t is the thickness of the test specimens (mm) and b is the width of the test specimens.

For the modulus of elasticity (MOE) calculation, it was necessary to use equation 2, having a direct relationship between MOE and the maximum strength obtained in the bending test. The way in which the MOE should be calculated in the sample elastic regime, as proposed by the EN 310 standard [15], uses F_1 corresponding to 10% of the max break strength and F_2 corresponding to 40% of the α_1 and α_2 deformations.

$$\mathrm{MOE} = \left[\frac{\mathrm{l}_1^3(\mathrm{F}_2 - \mathrm{F}_1)}{4\mathrm{bt}^3(\alpha_2 - \alpha_1)}\right] \quad (2)$$

2.2 Reaction to fire performance of wood based panels

The wood panels were aged artificially using a cycle of humidity and temperature for indoor environments. Although ETAG 028:2012, [9], is specifically applied to construction products protected by paints, varnishes and surface-impregnated products, it was used as a reference for the definition of the aging cycle, depending on the product category of use. The categories of use are referred as type X, used in internal and external applications and exposed to rain and ultraviolet radiation, type Y, intended for indoor and outdoor environments not exposed to rain or UV, Z1 used in indoor environments exposed to high humidity and Z2 used for internal use only.

The cycle used in this paper reproduces the category of use of type Z1, in which the panels are exposed to 27 ± 2ºC and 90 ± 5% relative humidity during 8 hours, following of 16 hours at 23 ±

2ºC and 50 ± 3% relative humidity, resulting in a 24-hour cycle, carried out for 10 days without interruption for an expected life of 5 years, [10]. Figure 3 shows the exposure of the panels on a single panel face.

a) b) c) d)

Figure 3 - a) Samples at the climate chamber. b) Cone calorimeter test. c) Samples before fire reaction test. d) Samples after fire reaction test.

For the evaluation of the reaction to fire, a mass loss calorimeter was used according to ISO 5660, [13]. The samples were exposed in horizontal orientation to a radiant heat flux of 50 [kW/m^2] positioned at a distance of 25 [mm] from the cone base. During the tests, the following parameters were obtained: heat release rate (HRR), ignition time (IT), total heat release (THR) and residual mass (m/m0). The dimensions used were 100 [mm] x100 [mm] x thickness, indicated in Table 5.

Table 5 - Number of specimens tested in the cone calorimeter.

Panel type	Fire reaction class	Nº of samples		thickness [mm]
		NAGED	AGED	
MDF-FR	B-s2, d0	4	4	16
MDF-ST-NFR	D-s2, d0	4	5	16
PB-P2-FR	B-s1, d0	4	5	15
PB-P2-NFR	D-s2, d0	5	4	15
OSB3-NFR	D-s2, d0	4	5	18

Before the tests, the samples were also submitted to the atmospheric conditioning to reach the hygroscopic equilibrium at temperature of (23 ± 2) [ºC] and relative humidity (RH) of (50 ± 5) [%].

Table 6 - Requirements for DRF Classes of fire-retardant wood products in interior and exterior end use applications, [8].

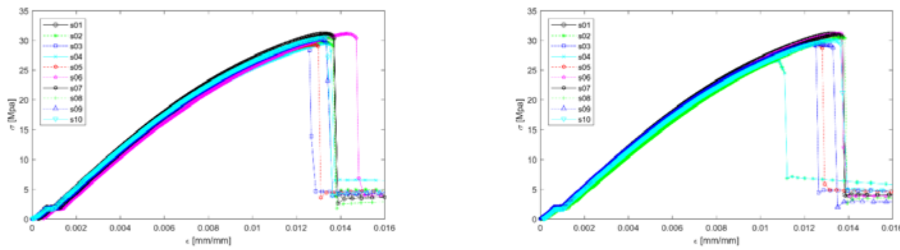
	Building products excluding floorings
Heat flux	50 kW/m²
Criteria for small scale fire testing after weather exposure	Class B products (according to EN 13501–1): Heat Release Rate, HRR30s ave ≤ 150 kW/m2 during 600 s after ignition and Total Heat Release THR600s increase < 20 % compared to fire testing before the weather exposure. Class C products (according to EN 13501–1): HRR 30s ave ≤ 220 kW/m2 during 600 s after ignition and THR600s increase < 20 % compared to fire testing before the weather exposure.

The results of the heat release rate and the total heat released measured by the tests carried out in the calorimeter allows to evaluate the durability, through the accelerated aging cycles, on the fire reaction of the samples, and thus to reclassify the fire reaction of the samples. This performance is analysed with reference to EN 16755 [8], which considers the criteria presented in Table 6 for the definition of the reaction to fire after climatic exposure.

3. RESULTS AND DISCUSSIONS

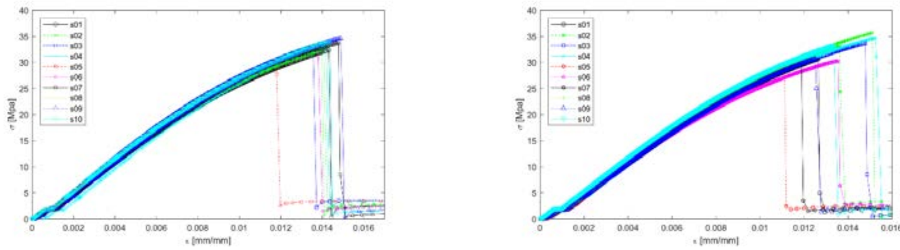
The most distinctive property of the MDF panels is its homogeneous composition, due to their reduced particles size. Thus, the mechanical properties between the test specimens do not vary much, regardless the orientation of the panel cut. An MDF panel feature is that outer layers have a higher density compared to inner layers, it follows that the outer layers have a higher compaction, occasionally causing greater mechanical resistance compared to other panel types, [17].

The experimental results from the MDF wood based panels are shown in the Figure 4 and Figure 5 for the fire retardant and non-fire retardant panels, respectively.



a) b)

Figure 4 - Bending strength MDF-FR: a) Direction 0º b) Direction 90º



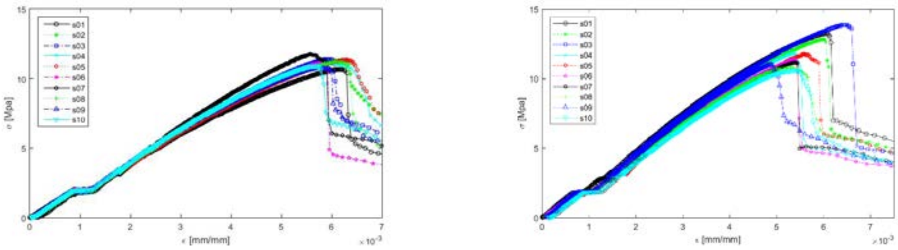
a) b)

Figure 5 - Bending strength MDF-ST-NFR: a) Direction 0º b) Direction 90º

The average values for the 0º orientation test specimens were of 30.214 [MPa] for MOR and 3233 [MPa] for the MOE. For the 90º orientation those values were of 29.584 [MPa] and 3259 [MPa]. For panels without fire retardant the mean values of MOR and MOE were 32.913 [MPa] and 3128

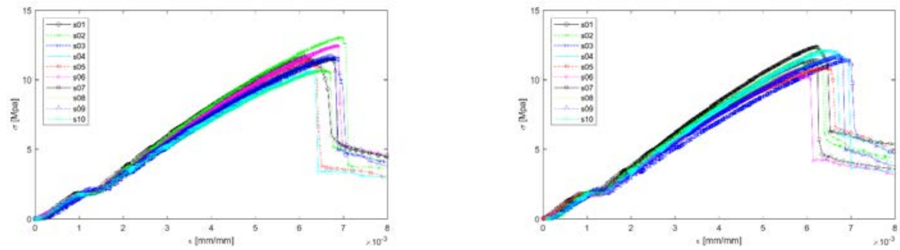
[MPa] for the test specimens at 0º, and for the values at 90º the MOR and MOE was 32.0 and 3154 [MPa].

The Particle boards panels have the most consistent values among those provided due to the reduced size of their particles and their high degree of homogeneity. The test results are represented in the next figures.



a) b)

Figure 6 - Bending strength PB-P2-FR: a) Direction 0º; b) Direction 90º.



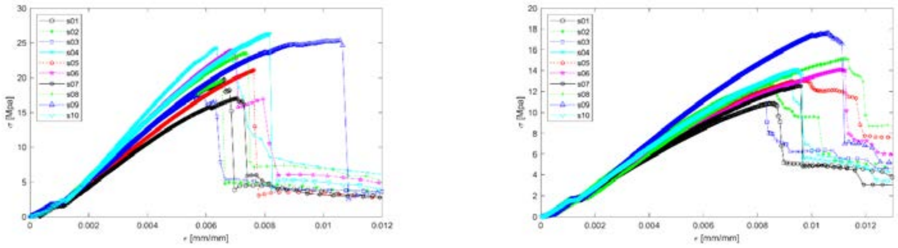
a) b)

Figure 7 - Bending strength PB-P2-NFR: a) Direction 0º; b) Direction 90º.

There was apparently no significant variation of MOR and MOE in both directions, but fire-retardant panels had a higher modulus of elasticity and a small variation compared to MOR values. The mean values of MOR and MOE for PB-P2-FR were of 11.095 [MPa] and 1980 [MPa] respectively for the 0° direction. The mean values for the specimens tested at 90 ° were of 11.845 [MPa] and 2191 [MPa] respectively.

For the PB-P2-NFR panels, the mean values were of 11.591 [MPa] and 1862 [MPa] at 0º for the MOR and MOE values, respectively, and for the 90º tests, were of 11.529 [MPa] and 1874 [MPa]. The OSB panels presented more dissimilar flexural strength values between the specimens. This behaviour is due to the lack of a uniform panel density inside the plate, this implies that specimens have a higher surface density, and consequently, higher values of static bending [18]. However, the higher density in the lower part of the board implies smaller values of bending strength, as shown in Figure 8.

The behaviour of the OSB panels has shown a remarkable difference between the two orientations. This difference is so significant because the wood fibres in the parallel orientation are better organized and oriented to counter the pressure and therefore resist to higher values of tension.



a) b)

Figure 8 - Bending strength OSB-NFR: a) Direction 0º; b) Direction 90º.

A significant difference was observed in the test specimens values having the same orientation. The average value found for the panels tested at an orientation of 0° was 21.796 [MPa] for MOR and 3859 [MPa] for MOE. In the panels tested at 90° the values of the analysed mechanical properties are significantly reduced, resulting in MOR and MOE values of 13.558 [MPa] and 1677 [MPa], respectively.

Table 7 - Three Point bending test results.

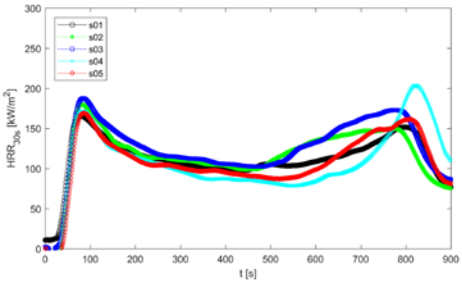
Wood Based	MOR, [MPa]						MOE, [MPa]	
Type	0º			90º			0º	90º
	Min	Max	Averag.	Min	Max	Averag.	-	-
MDF-FR	29.191	31.154	30.214	26.611	31.187	29.584	3233	3255
MDF-ST-NFR	30.241	34.600	32.913	28.714	35.666	32.000	3128	3154
PB-P2-FR	10.646	11.384	11.095	10.585	13.845	11.845	1980	2191
PB-P2-NFR	10.580	13.053	11.591	10.658	12.355	11.529	1862	1874
OSB3-NFR	16.963	26.300	21.796	10.861	17.622	13.558	3850	1677

The complete experimental three point bending test results performed to all wood based panels are presented in Table 7. The table shows the minimum, maximum and the average values of the Bending strength (MOR) and the Modulus of elasticity (MOE) for both directions (0º and 90º).

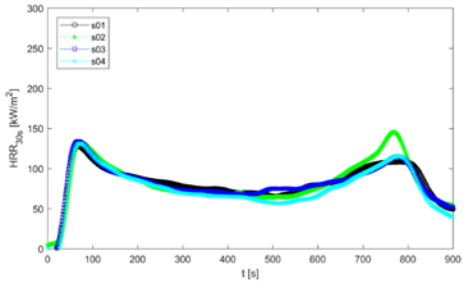
Figure 9 shows the heat release rate variation from particleboard panels, with a moving average of 30 seconds (HRR_30s), before and after the aging cycle. During the tests there was no significant difference in the residual mass of the samples, so their variation is not shown here. The average values of all the samples tested are shown in Table 7 for the different types of panels.

The aging cycle applied to the PB-NFR panels significantly influenced the total heat released (THR) up to 600 seconds of exposure, resulting in average values of 45.71 [MJ/m²] for aged panels and 63.36 [MJ/m²] for the non-aged. There was a decrease in THR between non aged and aged panels of 27.8% and 16.5% for products without flame retardant and flame retardant, respectively.

Exposure to temperature and humidity cycles causes changes in the behaviour of urea-formaldehyde resin by releasing volatile compounds, reducing their contribution to the combustion of the panel. The ignition time of PB-NFR-NAGED was 32.2 [s] and the PB-NFR-AGED was 41.75 [s].



a)



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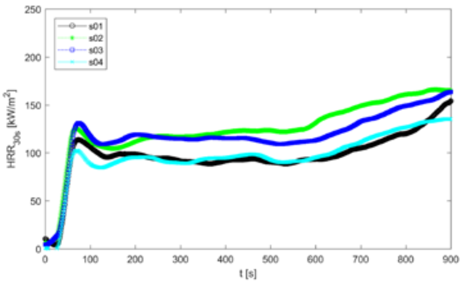

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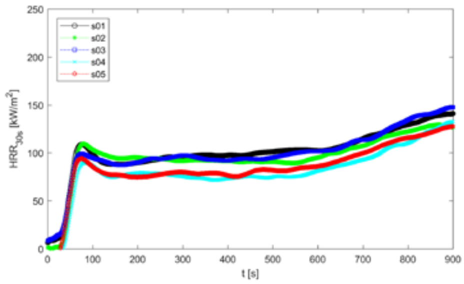

d)

Figure 9- HRR results. a) PB-NFR and NAGED. b) PB-NFR and AGED. c) PB-FR and NAGED. d) PB-FR and AGED.

With the exception of MDF panels without flame retardant, exposure to accelerated aging leads to a reduction in the rate of heat release as shown in Table 8. In the MDF-NFR samples the THR increased from 56.87 to 67.75 [MJ / m²] after aging, while the ignition time decreases from 38.5 to 33.5 [s] in aged panels. In the case of MDF panels with fire retardant, there was no ignition and THR was lower in aged samples, similar to PB panels, changing from 11.35 to 11.03 [MJ / m²].

Table 8 – Results and comparison between aged and non-aged wood based panels.

Panel Type	HRR_{30s} [KW/m²]		THR_{600s} [MJ/m²]		TI [s]	
	NAGED	AGED	NAGED	AGED	NAGED	AGED
PB-P2-FR	108.183	93.228	58.706	49.024	38.0	42.2
PB-P2-NFR	111.555	75.038	63.360	45.711	32.2	41.75
MDF-FR	28.456	21.902	11.356	11.033	-	-
MDF-ST-NFR	94.094	120.916	56.875	67.754	38.5	33.5
OSB4-NFR	184.401	122.820	103.83	65.377	32.0	29.4

The behaviour observed in the OSB-NFR panels was similar to PB-NFR, in which the THR decrease after the aging of the samples, releasing less heat. The ignition time also decreased in relation to the non-aged samples, from 32 to 29.4 [s].

The reaction to fire performance after weather exposure of wood based panels with fire retardants (PB-P2-FR and MDF-FR), considering the rate of heat release and the total heat released, according to Table 6 , allows to classify them in class B of reaction to fire after the exposure to accelerated aging.

4. CONCLUSIONS

Wood based panels is being used in building construction as a construction product. To overcome the lack of fire resistance it is frequent that wood based panel's producers to offer panels with fire retardants. It is not fully known how this panel behave in the long term, or if they are able to maintain their fire reaction classification when exposed to weather conditions (humidity and temperature variations). The main goal of this study is to give some clarification about the durability of fire reaction performance of wood based panels with and without fire retardants.

This work presented a set of experimental tests to determine mechanical properties of MDF, PB and OSB wood based panels. The Bending strength (MOR) and Modulus of elasticity (MOE) determined agree with the boards manufacture, except for the case of MDF panels where a difference of about 10 [MPa] was verified.

Also the MDF panels tests performed at 0° and 90° do not showed significant variation, due to panel homogeneity. However the behaviour of OSB4 at 0º and at 90º is very different, presenting MOR and MOE values about 40% and 55% smaller, respectively.

With the exception of MDF-NFR panels, there was a decrease in the total heat released in the tests performed on the samples after exposure to accelerated aging. The aging of OSB panel without flame retardants resulted in a 37% decrease in THR compared to the non-aged. The durability performance analysis allows to maintain the analysed flame retardant panels in class B of fire reaction.

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