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EFFECT OF ACCELERATED AGING ON THE FIRE REACTION PERFORMANCE OF TWO TYPES OF MODIFIED WOOD

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ABSTRACT: This study aims to evaluate the effects of degradation caused by exposure to atmospheric agents over time (weathering) simulated in an accelerated aging chamber, as well as the fire behaviour of two types of modified wood: thermo-treated and acetylated. The samples were exposed to accelerated aging cycles, which combined condensation, UV radiation, and spraying, for four weeks, following the protocols based on the UNE-EN 927-6:2019 standard. After the aging process, the colour variation was analysed, and the appearance of deformations and splitting was also observed. Flammability tests were also carried out to investigate the fire reaction behaviour of the samples as a function of exposure time in the accelerated aging chamber. The results showed progressive lightening and colour loss intensity in both types of modified wood after aging. However, the cracks appeared more noticeable in the thermotreated wood. Acetylated wood samples exhibited worse fire behaviour than thermotreated wood, especially before the aging procedure. The aging process improved the reaction to fire of all samples, especially its self-extinguishing ability.

KEYWORDS: Acetylated wood, thermo-treated wood, modified wood, accelerated weathering, fire performance of wood.

1 – INTRODUCTION

One of the most relevant challenges of using wood as a construction material is its interaction with water, particularly in outdoor applications such as facade cladding, which is classified as use classes 3.1 and 3.2, under UNE-EN 335:2013.

As a natural composite, wood primarily consists of cell wall polymers -cellulose, hemicelluloses, and lignin- that exhibit a strong affinity for water (hygroscopicity). This intrinsic property allows wood to absorb and retain water molecules, leading to swelling and, upon drying, to desorption and shrinking [1], which can result in splits and checks affecting its durability. Furthermore, exposure to temperature fluctuation and sunlight accelerates surface aesthetic degradation over time. In addition to these physical changes, wood is vulnerable to biological degradation under varying environmental conditions, making it susceptible to attack by decay organisms such as rotting fungi, insects, bacteria, and marine borers. Wood modification, which is a procedure to alter wood properties through the application of heat (thermal modification) or chemicals (chemical modification), is becoming a common way to enhance the performance of wood to make it more dimensionally stable and durable.

This study focuses on the long-term capacity of two types of modified wood (thermo-treated and acetylated wood) and how their fire performance is affected after an accelerated aging test carried out over four weeks. For this purpose, accelerated ageing and reaction to fire tests were carried out following the protocols described in the UNE-EN 927-6:2019 and UNE 23727-90 standards, respectively.

Over the last 10 years, modified wood has been the subject of much research [2], but the relationship between these two aspects requires further investigation.

1.1 THERMO-TREATED WOOD

The thermal modification of wood is a well-established process that has been extensively studied over several decades, offering multiple advantages, among them, its

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recyclability, as it is a treatment free of toxic substances. Thermal treatment improves resistance to decay and insect attacks [3], reduces the equilibrium moisture content (EMC) of wood, i.e., the ability to exchange water with the surrounding environment [4], and enhances dimensional stability.

The thermal procedure consists of wood torrefaction at temperatures ranging from 180 °C to 250 °C, performed in a poor oxygen atmosphere to avoid wood combustion, and involving either steam, nitrogen, or oil [5]. Heat treatment modifies the structure of wood cell wall polymers through different chemical reactions, conferring the material's new properties [6]. As a negative aspect, some authors reported that heat-treated wood generally exhibited lower mechanical properties than untreated wood, confirming a trend observed in various species [7].

The chemical composition of wood changes because of heat treatment due to the varying thermal stability of its constituent compounds. In general, heat-treated wood exhibits an increase in extractives, apparent lignin, and cellulose, while hemicellulose content decreases [8]. This fact may account for the reduced intensity of heat transfer observed in heat-treated timber [9].

Kačík et al. [5], in their experiments with spruce wood, observed that thermal treatment caused a substantial reduction in hemicellulose content, reaching up to 72.39% at 210 °C. This degradation led to a relative increase in the proportion of more thermally stable components, such as cellulose and lignin. Furthermore, an ageing treatment of 600 hours resulted in an additional 5% decrease in hemicellulose content. These findings are consistent with previous studies, confirming that the thermal modification of spruce wood primarily reduces polysaccharide content through the degradation of hemicelluloses [10]. This also highlights the critical role of temperature in the thermal treatment process, as its intensity directly influences the extent of chemical changes in the wood structure.

1.2 ACETYLATED WOOD

Acetylation of wood is a chemical process that consists of the esterification of the hydroxyl groups of the cell walls by acetic anhydride. This process leads to the substitution of hydrophylic hydroxyl groups from hemicellulose, cellulose, and lignin by hydrophobic acetoxy groups [11-12]. The acetylation process involves a process of vacuum and pressure immersion of solid wood in an acetic anhydre solution followed by an increase of the temperature above 100ºC to improve the yield of the acetylation reaction. The rate and success of acetylation are usually measured with the weight percentage gain (WPG) that is calculated from the dried mass of wood before and after the treatment. [13]. Commercial acetylated wood products exhibit a WPG of around 20% [14]. Acetylation decreases the equilibrium moisture content of wood and improves its dimensional stability, fungal decay, and termite resistance, as well as weathering performance [15].

2 – MATERIALS

Two types of modified wood were studied: thermo-treated maritime pine wood (*Pinus pinaster*) **TMP** and acetylated radiata pine wood (*Pinus radiata*) **ARP**. Pinus radiata and Pinus pinaster are the species commonly used in each type of modified wood at a local level. The degradation phenomena and the fire reaction were studied and evaluated on the tangential surface of the specimens (Fig.1).

Table 1*: Tested specimens caracteristics*

Code	Wood species	Treatment	Density average g/cm³
ARP	Pinus radiata	Acetilated radiatae pine	0,607
TMP	Pinus Pinaster	Thermotreated maritime pine	0,521

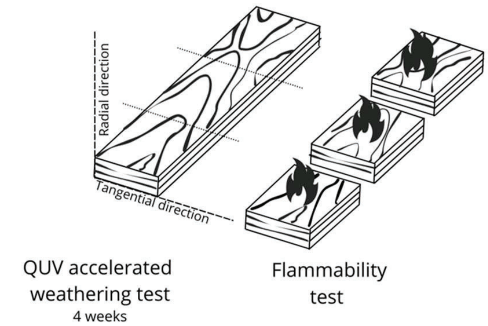

Figure 1*. Full pieces of each specimen were used for QUV testing and later divided into three parts for flammability testing. The dimensions are provided in the following sections. All samples were analysed on the tangential surface.*

3 – METHODS

To carry out the accelerated aging processes on the wood samples and the subsequent analysis of the colour degradation and the fire behaviour analysis, the tests described below were performed.

Acelerating aging test

The accelerated aging of wood specimens was performed according to the protocol of the standard UNE-EN 927-6:2019. In this process, a one-week exposure cycle begins with 24 hours of condensation, followed by 48 cycles of

3 hours, which combine a 2.5-hour UV-A 340 radiation period and a water spray period of 0.5 h. Table 2 shows the total time for each period.

Table 2*: Protocol followed for accelerated aging process*

Standard	Exposure periods throughout the trial (h)			
	Condensation	UV-A	Water spray	Total test time
UNE-EN 927-6:2019	96	480	96	672

Colour measurements

A PCE-TCR 200 colourimeter has been used to measure the CIELAB colour coordinates L^*, a^* and b^*. L^* is the lightness, going from 0 (black) to 100 (white), whereas a^* and b^* are the colour coordinates, from green (negative) to red (positive) and from blue (negative) to yellow (positive), respectively. The total colour differences ΔE_{ab}^* can be calculated as:

$$\Delta E_{ab}^* = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}$$

where L^*, a^* and b^* are the measured values after aging and L_0^*, a_0^* and b_0^* are the corresponding reference values from non-aged samples. Each colour data corresponds to the average of measurements taken from the different points depicted in figure 2, 8 for acetylated wood and 4 for thermo-treated wood.

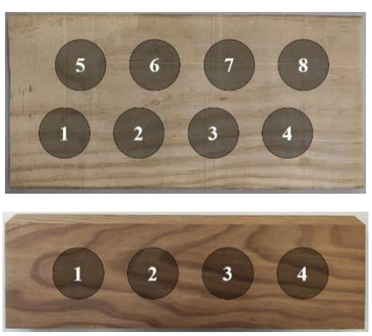

Figure 2. *Points on the samples for colour analysis. (top) acetylated wood (Bottom) thermo-treated wood.*

Epiradiator test

Wood samples of 100 x 100 x 15 mm were tested with the device described in the Spanish standard UNE 23727-90. The samples were placed on a metallic grid 3 cm below a heat source of 500 W. The heating source was removed and put back after each ignition and extinction. The parameters determined were the time to ignition, the number of ignitions, and the average time of flame persistence during the first 5 minutes of testing. The results obtained are detailed in section 4.3.

4 – RESULTS AND DISCUSSION

Visual observations

Visual observation reveals that acetylated wood samples (ARP) do not exhibit defects after four weeks of exposure in the aging chamber, whereas thermo-treated wood samples (TMP) tend to present remarkable signs of degradation, including cracks and splittings on the exposed surface, even from W1. However, no moisture-related curvature deformation (cupping) was observed in any of the ARP or TMP samples.

Figure 4 shows a series of photographs comparing the unaged samples with those subjected to accelerated aging. Aged samples experience a progressive lightness, and the colours lose intensity. Especially in TMP samples in which the grain is more and more visible as well.

Colourimetry results

The visual observations discussed in the previous section are in good agreement with the colour measurements obtained with the colourimeter, where the coordinate L* related to the evolution of lightness increases with aging for both types of treated woods. Figure 3 shows the evolution of lightness in which ARP varies from 66.9 in the case without aging (W0) to 81.5 for the sample aged for four weeks (W4). TMP exhibits a L* value of 42.4 for the sample without aging and 63.5 for the sample after four weeks of aging. Figure 5 plots the difference in lightness (ΔL^*) (top) and the total colour difference (ΔE_{ab}^*) (bottom) for the aged wood samples from W1 to W4. The ΔL^* figure shows that the increase in lightness for ARP samples is most significant during the first three weeks, and after that, it tends to stabilize. However, in TMP saples, the increase continues throughout the four weeks.

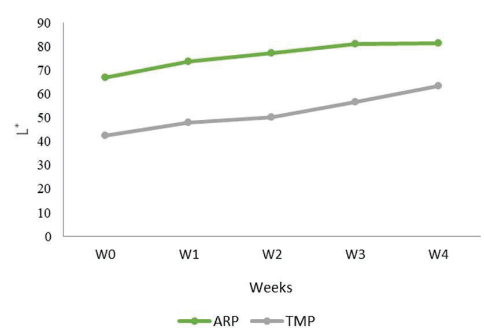

Figure 3. *Lightness L*, as a function of the aging weeks, for the two types of treated wood analysed.*

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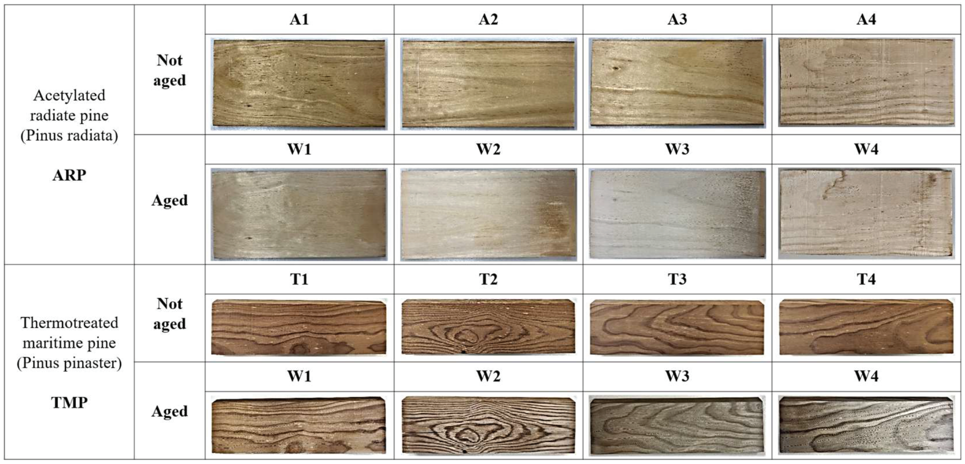

Figure 4*. Samples before and after each week of the four-week aging test. (top) acetylated wood (Bottom) thermos-treated wood.*

Finally, as an indicator of the total colour differences, Figure 5 (bottom) shows the ΔEab* parameter. ARP samples exhibit a remarkable change in colour after one week of aging, but ΔEab* remains stable during the following weeks. Regarding the TMP samples, the colour changes occur during the four weeks and are more pronounced than in the case of ARP.

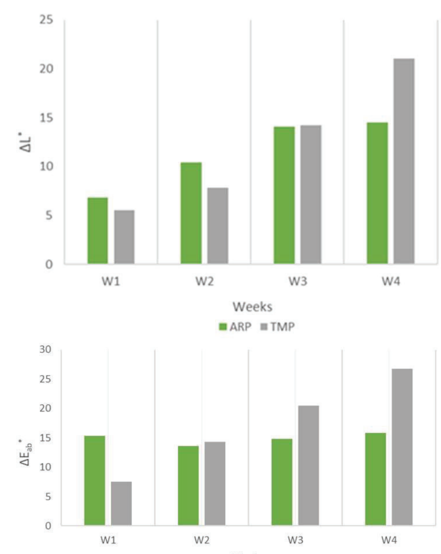

Figure 5*. lightness (top) and total colour differences (bottom) after 4 weeks of exposure comparative for the two types of treated wood.*

Fire behaviour

Overall, the TMP samples demonstrated superior fire performance compared to the ARP samples, as indicated by the test parameters presented in Tables 3 and 4 and Figure 6.

Tables 3 and 4*: Data from the flammability tests using the epiradiator. Three replicates were performed for each sample and week. The results are the average of them. (Top) Acetilated wood samples, (Bottom) Thermo treated wood samples.*

		Average			Standard deviation
Ref. material	Aging time	Number of ignitions	First ignition time (s)	Duration (s)	Duration (s)
Acetylated wood	W0	3	14	117	39
	W1	6	16	39	11
	W2	6	12	36	9
	W3	9	16	18	7
	W4	6	12	43	13

		Average			Standard deviation
Ref. material	Aging time	Number of ignitions	First ignition time (s)	Duration (s)	Duration (s)
Thermotreated wood	W0	5	26	52	23
	W1	8	23	27	7
	W2	7	23	13	6
	W3	11	29	12	1
	W4	9	26	20	1

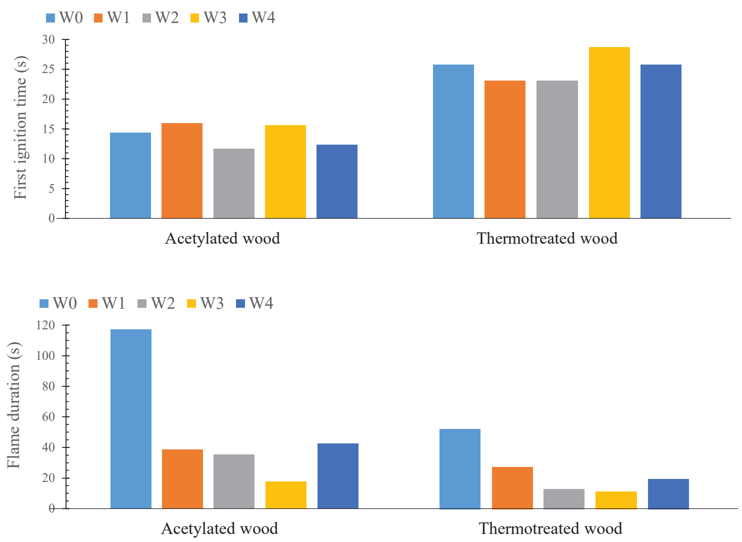

Figure 6. *Effect of aging on the average of first ignition time and flame duration for both types of modified woods.*

This favourable performance can be attributed to the substantial degradation of hemicellulose induced by the heat treatment, which consequently increases the relative proportion of more thermally stable components such as cellulose and lignin [9-16]. In all cases, from W0 (non-aged) to W4, the TMP samples exhibited longer times for first ignition and shorter flame durations. It is also noticeable that the difference observed in the W0 samples of both types of modified woods shows a marked contrast in flame duration (Fig. 6, bottom). The W0 ARP sample has an overage duration of 117 seconds, while the W0 TMP sample has an overage duration of 52 seconds. The acetylation process increases the amount of combustible organic groups on wood. Therefore, the fire reaction worsens, as can be observed in the shorter time needed for the first ignition and the longer average combustion duration. Mohebby et al. and Papadopoulos et al. observed an increase in the duration of combustions on acetylated beech plywood and OSB and particle boards [17-18]. Rabe et al. carried out a study on the fire behaviour of different modified woods and observed that thermotreated beech had a lower amount of organic volatiles and a higher char yield, which reduced the fire load and improved to some extent the fire performance. On the other hand, the acetyl groups of acetylated wood increased the effective heat of combustion [19]. Aged acetylated wood samples experienced a significant improvement in fire performance with a remarkable reduction in the average combustion duration. This phenomenon needs further investigation, but it could be related to an initial leaching of the rest of the acetic anhydride that could accelerate the combustion reaction in the case of non-aged acetylated wood.

The cracks developed in TMP samples during the ageing period —some of them quite pronounced—do not appear to influence the fire performance. This is noteworthy, as such defects often contribute to increased flame persistence.

Both types of modified wood exhibited an improvement in their fire reaction after the aging process. The self-extinguish ability increases in both TMP and ARP after aging, as evidenced by the increase in the number of ignitions in each week shown in Tables 3 and 4 and the reduction in average flame duration shown in Figure 6 (bottom). This tendency can be attributed to the leaching of wood components with low thermal stability, such as extractives and low-molecular-weight polysaccharides derived from hemicellulose [20 -21].

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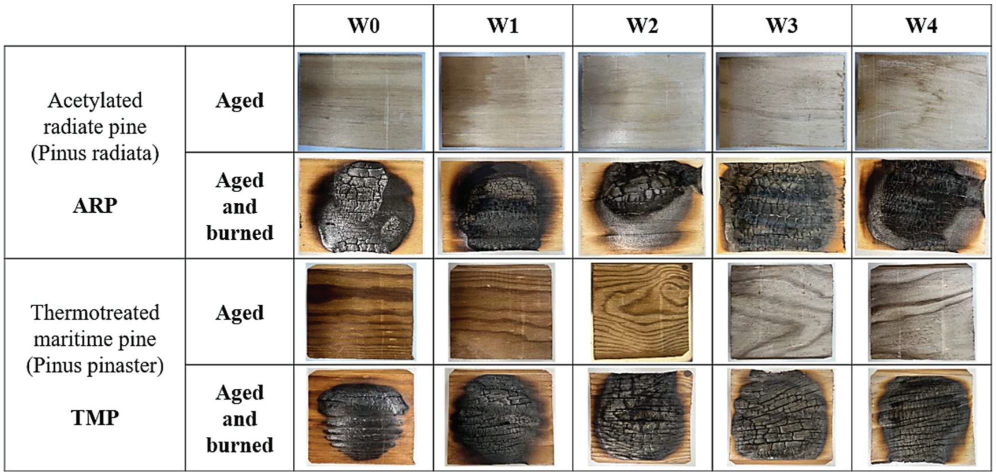

Figure 7. *Samples before and after the flammability test for each week of the aging test*

5 – CONCLUSIONS

The modified wood evaluated, thermo-treated, and acetylated exhibited an increase in lightness with accelerated aging. In acetylated wood, no significant changes in lightness occur after the third week of aging. Thermo-treated wood shows a progressive increase in the lightness value during the four weeks of aging. Regarding the total colour difference, acetylated wood presents a stable behavior after the first week of aging, while thermo-treated wood has more pronounced changes in colour for the whole aging cycle.

The acetylation process worsens the fire performance of non-aged acetylated wood, especially regarding the average duration of combustions. The acetyl groups contribute to the release of flammable volatiles in acetylated wood.

Both types of modified wood analyzed in this study exhibited improved fire performance following the aging test, with noticeable enhancement observed as early as the first week, especially in acetylated woods.

6 – ACKNOWLEDGMENTS

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