

Thermal Aging Effect on Various Characteristics of Alder and Spruce Coated with Fire-Retardant Paints

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Abstract

Aim of study: This study aimed to determine the effect of thermal aging at 70 and 150 °C for 624 h on the color, surface roughness, fire performance, and weight loss of alder and spruce wood coated with commercial fire-retardant paint containing antimony trioxide (Sb₂O₃) or titanium dioxide (TiO₂).

Material and method: Alder (*Alnus glutinosa* subsp. *barbata*) and spruce (*Picea orientalis*) specimens were coated with fire-retardant paint containing 1% and 2% Sb₂O₃ or TiO₂ and thermally aged at 70 and 150 °C for 624 h. The color change, surface roughness (R_z), limiting oxygen index (LOI), and weight loss of the specimens were determined using the CIE Lab* system, ISO 4287, and ASTM D2863, respectively.

Main results: Aging at 150 °C caused greater total color change than at 70 °C, while painted samples showed less noticeable color change than uncoated controls. Spruce showed greater fire-performance stability than alder. The highest LOI retention was obtained with 2% TiO₂ at 70 °C and 2% Sb₂O₃ at 150 °C. The weight loss of samples at 150 °C ranged from 7% to 11%.

Research highlights: Thermal aging temperature strongly affected color stability and fire performance. Sb₂O₃ and TiO₂ improved fire-performance retention, with the effect varying according to wood species and additive type.

Keywords: Thermal Aging, Wood Surface, Color Change, Fire Retardant Paint, Fire Retardancy

Yangın Geciktirici Boyalarla Kaplanmış Kızılağaç ve Ladinin

Çeşitli Özellikleri Üzerinde Termal Yaşlandırmanın Etkisi

Öz

Çalışmanın Amacı: Bu çalışmada, %1 veya %2 Sb₂O₃ ve TiO₂ içeren yangın geciktirici boya ile kaplanmış kızılağaç ve ladin odununun renk, yüzey pürüzlülüğü, yanma performansı ve ağırlık kaybı üzerine 70 ve 150 °C'de 624 saat uygulanan termal yaşlandırmanın etkisinin belirlenmesi amaçlanmıştır.

Materyal ve yöntem: Kızılağaç (*Alnus glutinosa* subsp. *barbata*) ve ladin (*Picea orientalis*) örnekleri %1 ve %2 Sb₂O₃ ya da TiO₂ içeren yangın geciktirici boya ile kaplanmış ve 70 ile 150 °C'de 624 saat yaşlandırılmıştır. Tüm örneklerin renk, yüzey pürüzlülüğü (R_z), sınırlı oksijen indeksi (LOI) ve ağırlık kaybı; sırasıyla CIE L*a*b* sistemi ile ISO 4287 ve ASTM D2863 standardına göre belirlenmiştir.

Temel sonuçlar: 150 °C'deki yaşlandırma, 70 °C'ye göre daha yüksek toplam renk değişimine neden olmuş; boyalı örneklerde kontrol örneklerine göre daha düşük renk değişimi görülmüştür. Ladin, yanma performansı bakımından kızılağağaçtan daha kararlı bulunmuştur. En yüksek LOI korunumu 70 °C'de %2 TiO₂, 150 °C'de %2 Sb₂O₃ içeren ladin örneklerinde elde edilmiştir. 150 °C'deki ağırlık kaybı %7–11 arasında değişmiştir.

Araştırma vurguları: Termal yaşlandırma sıcaklığı renk kararlılığı ve yangın performansını belirgin şekilde etkilemiştir. Sb₂O₃ ve TiO₂ ilavesi yangın performansının korunmasını artırmış, etkiler odun türüne ve katkı maddesine göre değişmiştir.

Anahtar Kelimeler: Termal Yaşlandırma, Ahşap Yüzey, Renk Değişimi, Yangın Geciktirici Boya, Yangın Geciktirici



Introduction

Wood, one of the oldest known building materials, still attracts great attention in human life. Wooden materials can deteriorate due to aging, weathering, and biodegradation (Matsuo et al., 2011). These are appropriate for applications in a wide range of goods for indoor and outdoor applications because of their anatomical structure, physical and mechanical capabilities, and chemical structures. A protective coating for the wood material is required to ensure adequate protection against dimensional change under changeable atmospheric circumstances. Drying, impregnation, and covering with a protective layer of varnish or paint can help to mitigate these vulnerabilities caused by the unique composition of wood (Cavdar et al., 2010; Sönmez et al., 2011). Painted wood is affected by changes in relative humidity and temperature. It is necessary to investigate how changes in outdoor weather and climatic conditions affect painted wood, especially in historical buildings and museums (Bratasz, 2013; Barbera et al., 2022).

Aging reveals irreversible changes in the properties of wood over time under the influence of various factors such as temperature, air humidity, water, wettability for adhesives or coatings, ultraviolet (UV) light, or chemical solutions. The ambient temperature affected almost every aging process in the manufacture and application of wood. Heat is frequently utilized to accelerate aging processes for polymeric materials, such as using time-temperature superposition (Li and Kasal, 2022). Temperature is the most important factor in accelerating the aging process (Andrady et al., 1998; Demirci et al., 2013). The influence of temperature is insufficient to destroy the chemical bonds within commercial polymers. The energy required to break these bonds ranges between 70 and 90 kcal/mol. Furthermore, the presence of humidity in the environment increased its impact on temperature (Demirci et al., 2013; Feller, 1995).

Thermal treatment on wood is essential for two reasons. The first is that heat alteration increases wood durability, dimensional stability, fungus resistance, and other qualities. The second is to investigate changes in the qualities of wood when exposed to fire,

particularly mechanical properties, as it is widely used as a building material (Kačíková et al., 2013; Jimenez et al., 2013). Fire retardant intumescent paints can be applied to the surface of wood and such materials provide a protective coating with fire-retardant properties. Fire retardant additives that have a protective barrier effect on the wooden surface include phosphates, carbamides, borates, antimony, bromides, and chlorides. Antimony trioxide and titanium dioxide are often used as synergistic reinforcements to improve fire retardancy. Titanium dioxide is also widely used as a coating material in interior flooring materials and exterior building materials (Torun et al., 2020).

Thermal treatment decreases the density, and mechanical characteristics of wood while increasing dimensional stability and hydrophobicity and causing both positive and negative color changes. Some heat-treated wood qualities may cause inevitable color changes (Wikberg, 2004; Johansson, 2005; Enjily and Jones, 2006). However, since the values of mechanical properties may decrease after thermal treatment, necessary precautions must be taken if wood is to be used as a structural element (Aytin et al., 2016). Heat treatment, which does not require the usage of chemicals, is accomplished by simply increasing the temperature of the wood. Temperatures below 140°C have minimal impact on the qualities of wood, however, higher temperatures cause severe damage to the wood's structure, resulting in changes to its physical, chemical, and mechanical properties (Bekhta and Niemz, 2003; Yildiz et al., 2006a; Brischke et al., 2007; Matsuo et al., 2011; Aytin et al., 2016).

Previously, UV accelerated aging, natural weathering, and short-term heat treatment of wood/ modified wood/ coated wood were studied intensively (Wikberg, 2004; Enjily and Jones, 2006; Yildiz et al., 2006a; Candelier et al., 2013). But there was a limited study on the long-term heat aging (at high temperatures) effect on the properties of wood or coated wood. The application of fire retardant paint for wood is widely used in places exposed to intense heat. However, there has been limited research on the heat aging effect of wood surface coated with fire retardant paint in the literature. This study

examined the effect of heat aging on the properties of the coated wood surface with antimony trioxide (Sb_2O_3) and titanium dioxide (TiO_2) combined with commercial fire retardant paint. The fire performance-Limited Oxygen Index (LOI), surface roughness, color properties, and weight loss of wood samples after heat treatment were investigated.

Material and Methods

Raw Materials for the Coating Procedure

This study used two conditioned wood species as spruce (*Picea orientalis* L. Link; density: 0.405 g/cm^3) and alder (*Alnus glutinosa* subsp. *barbata* Yalt.; density: 0.454 g/cm^3). The commercial fire retardant paint was supplied by TeknoPaint in Turkey, and antimony trioxide (Sb_2O_3) and titanium dioxide (TiO_2) were purchased from Sigma Aldrich in Turkey.

Wood samples made of alder and spruce were sized as 150 mm by 15 mm by 5 mm and were painted on all their surfaces, each of their corners, with pure commercial fire retardant mixed with 1% and 2% titanium dioxide and antimony trioxide. Wood samples were prepared on tangent surfaces. The conditioned wood samples were sanded before painting to obtain a smooth surface. In the sanding process, first sandpaper number 180 was used on the machine, and then the surfaces were smoothed with sandpaper number 120 using a hand sanding machine. The initial moisture content of the wood samples varied between 16 and 18%. The wood samples were conditioned in a climate room at 20°C and 65% relative humidity until they reached an equilibrium moisture content of 12%. The wood surfaces were first painted with fire retardant paint at a rate of 233 g/m^2 , followed by a 12-hour drying period. Second, the fire retardant paint was combined separately with the titanium dioxide and antimony trioxide and mixed for 5 minutes. This mixture was applied to solid wood surfaces with a brush. Forty-two wood specimens were used in total for spruce and alder. After painting, all coated samples were conditioned at room temperature and 65% humidity for 12 hours. Three samples each of alder and spruce were subjected to aging.

Thermal Aging Process

The thermal aging process temperatures were selected based on the literature review (Yang et al., 2015; Nemeth et al., 2016; Li and Kasal, 2022; Krystofiak et al., 2022). Heat treatment and hygro-thermal treatment for wood were applied mostly using mild temperatures. Above 150°C , it is not recommended due to the fact that different chemical reactions may occur depending on cell wall composition in wood species. Li and Kasal reported that the extractives could migrate in the direction of the wood surface at 70°C during thermal aging. This study examined the extractives' migration effect on the coated wood samples' surface properties at 70°C (Table 1).

The painted wood samples were thermally aged in a heating chamber (Binder-Model ED115) with natural convection at two temperatures, 70°C and 150°C for 624 hours. The different samples were used for 70°C and 150°C .

After the thermal aging process, the aged samples were kept in the desiccator for one hour before being weighed. The three replicates were thermally aged for each group. Weight loss was calculated with the following equation (Eq.1).

$$\text{Weight Loss (\%)} = \frac{(W_{\text{after}} - W_{\text{before}})}{W_{\text{before}}} \times 100 \quad (1)$$

Since the moisture content was a crucial factor affecting the quality of the wood surface, wood samples were oven dried at 70°C for 4 days until they attained a constant weight. This prevented moisture content variations between the treatments.

Table 1. The experimental codes of the thermal aging of the painted samples

Paint formulation	Spruce	Alder
Fire retardant paint (FR)	LC	KC
FR+1%antimony trioxide	LA1	KA1
FR+2%antimony trioxide	LA2	KA2
FR+1%titanium dioxide	LT1	KT1
FR+2%titanium dioxide	LT2	KT2
Un-coated samples	Spruce	Alder

Color Changes

The color measurements were made following the thermal aging test at 70°C and 150°C , respectively, to determine potential

color changes and surface deformations on the samples exposed to thermal degradation. The parameters of the color measurement were PCE-TCD 100 (CM10P Color Meter) at a 10° observer angle; an 8 mm test aperture and a C light source (Illuminant). Measurements were taken from three different points on each sample according to CIE L*a*b* method by parameters L*a*b* and ΔE*. The color coordinates and total color change were calculated with the following formulas according to ASTM D 2244-14. The CIE L*a*b* color system is represented by a three-dimensional model. It expresses lightness (L*) and the four colors as green (-a*), red (+a*), blue (-b*), and yellow (+b*). ΔE is defined as the difference between two colors in a L*a*b* color space. ΔL* indicates a light color difference (Eq. 2-5).

$$\Delta L^* = [L^*_{\text{thermal aged wood sample}} - a^*_{\text{un-thermal aged wood sample}}] \quad (2)$$

$$\Delta a^* = [a^*_{\text{thermal aged wood sample}} - a^*_{\text{un-thermal aged wood sample}}] \quad (3)$$

$$\Delta b^* = [b^*_{\text{thermal aged wood sample}} - b^*_{\text{un-thermal aged wood sample}}] \quad (4)$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (5)$$

Surface Roughness and Fire Performance

The surface roughness of the samples was determined using a Mitutoyo SJ-210 instrument according to ISO 4287. The measurement parameters were set as follows: a stylus with a tip radius of 0.5 μm and a 90° contact angle was used, traversing the surface at a speed of 0.5 mm/s. A total of 25 random measurements were acquired, each spanning a length of 15 mm. The roughness parameter, Rz (μm): mean peak-to-valley height, was measured on each coated three wood sample surfaces before and after thermal aging. The surface roughness measurements were made by taking wood surfaces from three different points.

The thermal aging effect on the fire performance of these chemicals (Sb₂O₃ and TiO₂) combined with the fire retardant paint was accomplished by the Limited Oxygen Index (LOI) test chamber (Dynisco Limiting

Oxygen Index Chamber), according to ASTM-D 2863. The LOI is a critical parameter for quantifying a material's flammability. A higher LOI value indicates that the material is less flammable and has better flame retardant properties (Wang et al., 2025). It defines the minimum concentration of oxygen, expressed as a percentage, that is required to sustain the combustion of a material in a controlled atmosphere. Three samples in each group were used for determining the LOI level (O₂ %) before and after the thermal aging process.

The retention ratios were calculated to detect the effect of the thermal aging on surface properties and fire performance using Equations (Eq.5) and (Eq.6).

Retention ratios of surface roughness:

$$Rz_{\text{retention}} = \frac{Rz_{\text{after}}}{Rz_{\text{before}}} \times 100 \quad (6)$$

Retention ratios of LOI level:

$$LOI_{\text{retention}} = \frac{LOI_{\text{after}}}{LOI_{\text{before}}} \times 100 \quad (7)$$

where the Rz_{retention} and LOI_{retention} refer to Rz and LOI mean values before and after thermal aging.

Results and Discussion

Color Changes

Figure 1 shows the Δa* and Δb* color change parameters of the samples after the thermal aging test. In Figure 1a, the green color coordinate (-Δa*) is observed at 70 °C and the red color coordinate (+Δa*) at 150 °C in the painted spruce and alder samples. When looking at these values, the +a value represents green and the -a value represents red. The highest change in Δa* value was obtained from the LA2 sample (spruce), while the highest value for Δa* was attained from the KT2 sample (alder). When thermal aging was done at 150° C for spruce (L) and alder (K) samples, it was observed that all Δa values were positive. Also, Figure 1b shows lower Δb* of all painted samples at 70 °C. +b value indicates yellow direction, and -b direction indicates blue direction. Additionally, the

highest Δb^* values were obtained from the spruce wood (L) sample.

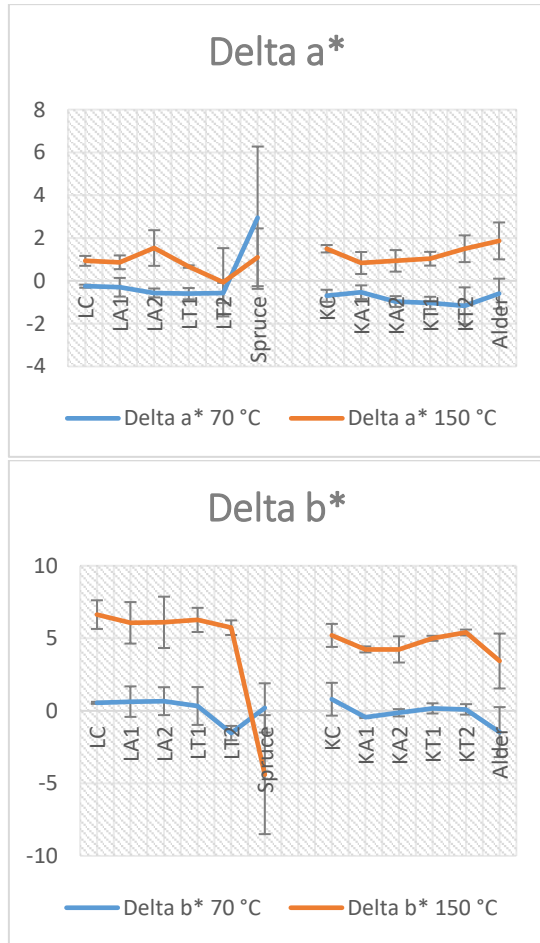


Figure 1. Change in color parameters Δa^* (a) and Δb^* (b) values of samples after thermal aging test for 624 h

The change in ΔL^* (the lightness difference) and ΔE^* (the color difference) values of samples after the thermal aging test for 624 h is given in Figure 2. As can be seen in Figure 2a, control uncoated spruce and alder wood samples showed continuous darkening ($-\Delta L^*$) and decreasing chromatic values (a^* , b^*). Gaff et al. reported that the thermal treatment decreased hemicellulose content and the darkening surface of the uncoated wood at high temperatures. On the other hand, the painted wood samples' color did not show a noticeable change. For both wood species, lower ΔE^* values were observed in the thermal aging treatment at 70° C compared to the thermal aging treatment at 150° C. ΔE^* is the determinant of the total

color change in the samples. ΔE^* is not significantly changed by the addition of 1-2 wt % of Sb_2O_3 and TiO_2 .

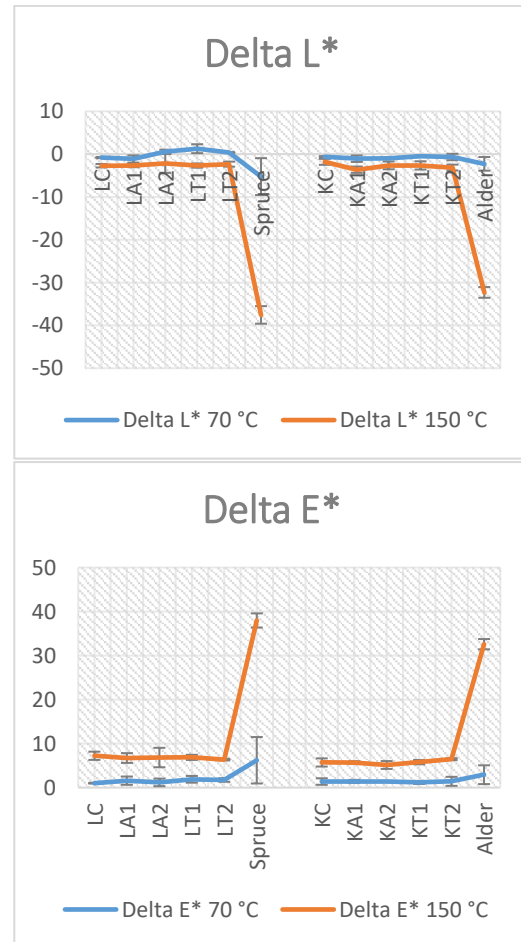


Figure 2. Change in ΔL^* (a) and ΔE^* (b) values of samples after thermal aging test for 624 h

Table 2 summarizes the total color change (ΔE^*) range and classification of groups. While all groups (except alder and spruce control uncoated wood) were in the range of $0.2 < \Delta E^* < 2$ at 70 °C, KC, KA1, KA2, and KT1 samples were in the range of $3 < \Delta E^* < 6$ for thermal aging at 150° C. LC, LA1, LA2, LT1, LT2, KT2 wood samples were in the range of $6 < \Delta E^* < 12$.

Figure 3 illustrates the samples' image after 70 °C and 150 °C of thermal aging process for 624 h. It was stated that there was no significant color change between each painted wood sample. However, the aging temperature and coating process played a significant role in the total color changes of

the wood samples, and the highest ΔE^* 's values of the samples were obtained at 150 °C (Figure 3). One of the primary changes in the chemical properties of wood following heat treatment is the degradation of hemicelluloses, as documented by numerous researchers (Tjeerdsma et al., 1998; Yildiz et al., 2006b; González-Peña et al., 2009; Niemz et al., 2010; Kránitz et al., 2016). This degradation is thought to be responsible for the color changes observed in the wood (Bourgois et al., 1991). Barčík et al. reported in their studies that total color changes on the wood surface increased dramatically within

the temperature range 160-180 °C. Kačík et al. investigated the effects of thermal treatment and accelerated aging on the characteristics of spruce wood. The researchers found that thermal treatment at various temperatures (160°C, 180°C, and 210°C) significantly altered the wood's chemical composition and properties. Both thermal treatment and accelerated aging caused significant color changes. As the treatment temperature increased, the wood's lightness (L^* value) decreased, and its color shifted towards a darker brown.

Table 2. Total color change (ΔE^*) range (Gaff et al., 2023; Tomak et al., 2023) and classification of groups

ΔE^*	Observation	70 °C	150 °C
0.2<	Invisible differences	-	-
0.2< ΔE^* <2	Small differences	LC,LA1,LA2,LT1,LT2 KC,KA1,KA2,KT1,KT2	-
2< ΔE^* <3	The color change can be seen with a high-quality filter	-	-
3< ΔE^* <6	The color change can be seen with a medium-quality filter	Alder	KC,KA1,KA2,KT1,
6< ΔE^* <12	Significant color changes	Spruce	LC,LA1,LA2,LT1,LT2,KT2
ΔE^* >12	Completely different color	-	Alder, Spruce



Figure 3. The samples' image after 70 °C and 150 °C of thermal aging process for 624 h (a) and at 20 °C (b)

The Retention rate of Surface Roughness

The surface roughness of coated and uncoated – spruce and alder wood samples

after thermal aging for 70 °C and 150 °C is given as retention ratios ($100 * (\text{before/after})$) in Figure 4. Retention ratios were calculated to compare the changes (%) in the surface roughness parameter (R_z) of samples due to thermal aging exposure. The retention ratios in surface roughness of the spruce samples with titanium dioxide in the fire retardant paint formulation (LT1 and LT2) after the thermal aging test for 624 h at 70 °C and 150 °C were higher than those of the spruce samples with antimony trioxide in the fire retardant paint formulation (LA1 and LA2). It is also seen that the retention rates of spruce wood samples (L) thermally treated at 70° C are lower than spruce wood samples thermal modified at 150°C. The retention rates of spruce wood samples at 150 °C increased with the increase in the usage of antimony trioxide and titanium dioxide in the fire retardant paint formulation (from 1% to 2%). For the alder wood sample (K), the retention rates increased as the use of antimony trioxide increased at 70°C, while the retention rates decreased at 150 °C. The retention rates of alder wood samples for 70°C and 150°C remained almost

the same when the ratio of the titanium dioxide increased from 1% to 2%.

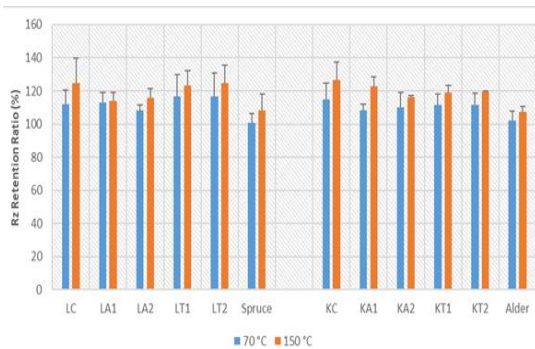


Figure 4. Retention ratios in surface roughness of samples after thermal aging test for 624 h

The Retention rate of Fire Performance

The LOI shows the minimum oxygen amount needed to fire for a material. Figure 5 indicates the effect of the thermal aging process on the fire performance of the fire retardant painted wood samples. When the retention rate is near the hundred, it means no change in the LOI level with the thermal aging.

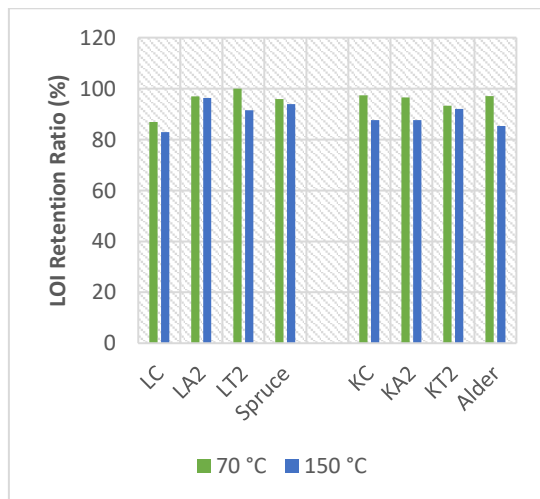


Figure 5. Retention ratios in fire performance – LOI levels of samples after thermal aging test for 624 h

The retention rate for the LOI level of the wood samples moderately decreased with an increment in thermal aging temperature. The maximum LOI retention value at 70 °C was obtained for the spruce sample with 2% titanium dioxide in the fire retardant paint formulation (LT2), whilst the maximum

retention rate was achieved for the spruce sample with 2% antimony trioxide in the fire retardant paint formulation (LA2) samples at 150 °C. Compared to the fire retardant painted samples without synergistic, the retention rate of the LOI level for the coated samples increased with the addition of chemicals to the fire retardant paint at both temperatures.

Contrary to alder samples (K), it was found that the thermal aging caused almost similar changes at both temperatures on the LOI level of the painted spruce samples (L) with the addition of antimony trioxide. The presence of 2% titanium dioxide in fire retardant paint formulation for spruce samples (LT2) at 70 °C kept the same fire performance, but it was seen a slight decrease at 150 °C in that group.

The spruce wood samples (L) were more stable against the thermal aging effect compared to alder wood samples (K). In addition, the fire performance of all coated spruce samples (L) was slightly higher even after thermal aging at 150 °C. However, the thermal aging at 150 °C deteriorated the painted alder surface (K) and lost the fire retardant effect except for the samples with the presence of titanium dioxide (KT). Despite the thermal aging at both temperatures, the loss of the fire retardant effect of the fire retardant paint with the synergistic effect of titanium dioxide and antimony trioxide on the wood surface was detected to be a maximum of 17 O₂%. It is thought that these small losses are due to the delamination of the paint layer from the wood surface after the aging during the LOI test. This can be clearly seen during the fire test (Figure 6) as the paint layer separates from the wood surface due to fire retardant paint and chemicals forming a barrier layer on the wood surface.



Figure 6. The LOI test sample on coated spruce (LT2)

Kačíková et al. studied the performance of thermally modified Norway spruce and indicated LOI level increased by 9% when the samples were heated at 158 °C for 90 minutes. In the actual study, there was no significant effect of thermal aging temperatures on the LOI level for the spruce samples (L). In another study, Qu et al. reported that hydrophobic coated fir wood samples with an increment aging temperature from 80°C to 100°C had a higher final residue (ash content) at 900°C in TGA analysis. They stated that high aging temperatures enhanced hydrolysis-polycondensation of the MTES/TEOS (methyltriethoxysilane/ tetraethylorthosilicate) -based coatings.

Weight Loss of Samples after Thermal Aging

The weight loss (%) of alder (K) and spruce wood (L) samples after thermal aging for 624 hours at 70°C and 150°C is shown in Table 3. Moisture of the wood was responsible for the weight loss in the samples at 70 °C. Considering the moisture content was the source of the weight loss of the samples, the average loss at 150 °C ranged from 7-11% depending on wood species and coating types.

The spruce sample with 1% antimony trioxide in the fire retardant paint formulation (LA1) had the lowest weight loss at 150°C. The minimum weight loss for alder wood samples at 150 °C was obtained from alder samples with 2% antimony trioxide in the fire retardant paint formulation (KA2) and 1%

(KA1) samples, respectively. The high density of wood resulted in higher weight loss when thermally treated (Froidevaux and Navi, 2013). The control spruce had higher density and weight loss compared to the control alder samples. This may also explain why the total color change of control alder samples at 70 °C was lower than that of spruce (Table 3). Li and Kasal investigated the mechanism of the thermal aging effect on wood cell walls. They stated that thermal aging detracted the substances of the top layer from the wood cell wall. This leads to weight loss in the wood material.

Table 3. Percentage of weight loss of the samples after thermal aging for 624 hours at 70 °C and 150 °C

Spruce	70 °C	150 °C
LC	8.221 ^{cd**} (0.044)*	18.406 ^{bc***} (0.419)
LA1	7.902 ^{abc} (0.149)	18.221 ^{bc} (0.663)
LA2	7.639 ^a (0.209)	17.274 ^{abc} (0.439)
LT1	7.795 ^{ab} (0.138)	17.848 ^{bc} (0.372)
LT2	7.775 ^{ab} (0.216)	18.015 ^{bc} (0.356)
Control spruce	8.989 ^e (0.487)	16.140 ^{abc} (1.349)
Alder	70 °C	150 °C
KC	8.065 ^{bcd} (0.451)	18.437 ^{bc} (0.108)
KA1	7.954 ^{abcd} (0.119)	18.401 ^{bc} (0.428)
KA2	7.642 ^a (0.134)	18.488 ^{bc} (0.362)
KT1	7.674 ^{ab} (0.138)	18.824 ^c (0.043)
KT2	7.815 ^{ab} (0.341)	18.466 ^{bc} (0.315)
Control alder	8.229 ^d (0.043)	15.153 ^a (2.381)

* It refers standard deviation

** : Duncan Homogeneity groups $p > 0.001$

*** Duncan Homogeneity groups $0.5 > p > 0.1$

Conclusions

This study concluded that the fire retardant paint and the synergistic chemicals antimony trioxide (Sb_2O_3) and titanium dioxide (TiO_2) would be used safely in areas where wood is exposed to long-term heat. The painted spruce and alder samples exhibit the green color coordinate (-a*) at 70°C and the red color coordinate (+a*) at 150°C. The maximum ΔE^* values of the samples were achieved at 150°C, although the aging temperature and coating procedure played a significant effect in the overall color changes of the wood samples. At 150 °C, the retention rates of spruce wood samples (L) increased with the addition (from 1% to 2%) of Sb_2O_3 and TiO_2 .

The retention rates of the alder wood sample (K) increased as the use of Sb_2O_3 increased (from 1% to 2%) at 70°C; however, the retention rates of the alder wood sample (K) reduced at 150 °C. The weight losses values were changed depending on heat temperature and uncoated/coated. All coated wood samples had lower weight loss rate than those of coated samples. When the thermal aging temperature was increased, it was increased. Based on the LOI test results; specifically, antimony trioxide for spruce (LA) and titanium dioxide for alder (KT) could be used as the best synergistic in the fire retardant paint against adverse effects of the thermal aging condition.

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Ethics Committee Approval

N/A

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Author Contributions

Conceptualization: A.D.Ç., S.B.T., M.C.B. and N.A.; Investigation: A.D.Ç., S.B.T., M.C.B. and N.A.; Material and Methodology: A.D.Ç., S.B.T., M.C.B. and N.A.; Visualization: A.D.Ç., S.B.T., M.C.B. and N.A.; Writing-Original Draft: A.D.Ç., S.B.T., M.C.B. and N.A.; Writing-review & Editing: A.D.Ç., S.B.T., M.C.B. and N.A. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

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