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COLOR AND GLOSS EVALUATION IN DECORATIVE STAIN APPLIED TO CASES OF *Pinus radiata* WOOD TREATED WITH COPPER AZOLE MICRONIZED TYPE C

R. Garay^{1,*}, M. Inostroza², A. Ducaud³

ABSTRACT

Six treatments (one control and five decoration coatings) were applied to radiata pine wood treated with micronized copper azole for outdoor use at a rate of 3,08 kg/m³ retention. One decoration coating was applied prior to impregnation, prestain and two decoration coatings were applied in a mixture with the micronized copper azole preservative Black Cylinder and Red Cylinder. The following two varnishes were tested: a water-based varnish and a solvent-based varnish. Additionally, untreated radiata pine specimens were tested as a reference. The changes in the gloss and color of these five decorative coatings were evaluated after undergoing natural aging tests for three months and accelerated aging trials during exposure to ultra-violet radiation of 340 nm for 500 hours. In the accelerated aging trials treatments, changes in gloss and color showed the lowest variations in treatment trials prestain and Black Cylinder and the highest variations in treatment trial Red Cylinder. In the aging tests trials, changes in gloss and color showed the lowest variations in treatment trials prestain and Black Cylinder. The costs of each decorative coating were assessed in terms of performance according to timber volume coated. The lowest cost of the three decoration treatments was prestain, with a value of 16 US\$/m³, followed by Black Cylinder with a value of 24 US\$/m³. Compared with the alternative siding products available in the market, such as fiber cement and vinyl siding, colored wood treated with prestain is competitive with vinyl siding, with 58% lower costs than fiber-cement.

Keywords: CIELAB coordinates, radiata pine, wood decorative coating, wood preservatives, wood impregnated.

INTRODUCTION

The global trend regarding wood preservatives based on copper oxides, chromium and arsenic (CCA) is to gradually replace these materials with more sustainable products. In Chile, lesser environmentally impacting preservatives have been introduced in recent years, such as copper azole preservative (CA-B) and micronized copper azole, type C (μ CA-C), which deliver increased effectiveness at lower retention rates, resulting in lower costs and easier penetration. Moreover, such products can be used under the same conditions as CCA-treated wood, with the exception of marine applications (NCH 819 2012).

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However, the area of wood protective coatings has significantly improved in terms of efficiency and sustainability. The current trend is to use porous and water-based products, thus delivering innovative solutions, at lower costs and with lower toxicities at both the surface and core of the wood, as is the case with lacquers or “stains” and fast-drying varnishes (AITIM 2012).

The final color of wood treated with Type-C micronized copper azole is a faint greenish color (LIGNUM 2014), which, compared with the CCA treatment, is less intense and mistakenly considered as a sign of bad or poor treatment. Even when the application of Type-C micronized copper azole is efficient, a negative impression is perceived in the marketplace, considering that a greenish color is a sign of properly treated wood. Adding a more attractive coloration to μ CA-C could improve market acceptance. Therefore, additional research is needed to identify new combinations of preservatives and sustainable, market-acceptable colors.

This new feature of color-treated wood can add decorative value and hide visual defects, such as stains, improving the range of raw materials used by treated wood producers, providing an aesthetic to outdoor woods (AITIM 2008).

When the wood is stained through processes, such as dye or tannic, protection against termite attack is low, according to Tascioglu *et al.* (2014) who evaluated the potential anti-termite properties of some common wood stains tested against *Coptotermes formosanus*. Four different wood species stain treated with 3 different chemicals at the 0,1 kg/m² retention level were exposed to the termite feeding no-choice test under laboratory conditions. The mean mass losses, mortality rates and consumption rates based on weight were calculated before and after the test, while the hardwood species (beech and chestnut) were unaffected by the treatments, and the softwood species showed dramatic losses in mass reductions in response to some staining treatments. Scots pine and spruce sapwood exhibited significant losses in mass reductions when treated with the chemical stain.

A change in the gloss of lasures is expected and is not a critical property to determine its effectiveness, as observed in varnishes (Garay 2007, 2008, 2009a, 2009b, 2009c, 2010, 2012, Dieguez 1994, Dieguez 1997). In the present study, the losses are reduced (3 to 4 %) for the commercial lasures studied, as this loss is presumed under outdoor conditions, and, therefore, these products are marketed as glossy or matte. During the test, thermal degradation, thermal fluctuations from day to night and moisture phenomena, which together foster physical and chemical changes in wood, such as vitrea transition temperature, were observed. A typical case is the exudation or migration of substances (resins) from wood product temperature increases, in response to exposure, generating brighter surfaces, although it is the same substrate, these phenomena occur in microzones, where there is increased presence of this substance.

Temiz *et al.* (2006) compared the copper emission rates from wood treated with chromated copper arsenate (CCA), alkaline copper quaternary (ACQ), Tanalith E and Wolmanit CX according to OECD guidelines. These authors reported that the percentage of copper leached from wood treated with alternative copper-based preservatives was higher than that of CCA-treated wood. Temiz *et al.* (2014) examined the leaching and decay resistance of alder and pine wood treated with copper-based wood preservatives, and the results suggested that CCA releases less copper than all other copper-based wood preservatives. This finding might reflect the fact that the copper in CCA is more strongly bonded than in some of the alternative wood preservatives, alternative formulations with a higher copper or different fixation mechanisms. The presence of a stain can help to reduce this leaching, although in the present study the leaching of copper was not determined. However, it is possible to infer, *a priori*, that the stain avoided to some undetermined extent, the leaching of preservatives.

Ghosh *et al.* (2015) examined the loss of gloss of shellac and polyurethane finishes exposed to UV, indicating that the coatings similar lost their gloss primarily in the first 40 hrs. Thereafter, the loss of gloss was rather uniform until the end of the experiment. Hence, the UV degradation, with respect to the gloss, primarily occurs during the initial period of exposure, with mean percentage reductions in gloss reflecting exposure to UV light of approximately 12 to 16%.

The first part of the color change process reflects the formation of chromophoric groups, such as carbonyl and carboxyl groups, primarily resulting from the degradation of α -carbonyl, biphenyl and ring-conjugated double bond structures in lignin and the transfer of the extractives from within to

the surface of the wood (Lin and Kringstad 1970, Hon and Feist 1992). A relatively rapid change has been reported for wood material exposed to UV light in the external environment for a short period or under accelerated weathering (Feist and Hon 1984, Williams 2005, Peker *et al.* 2012). In this study, the greatest color change occurred at 200 hours, considered, at this time, as the highest concentration source of these chemical and physical changes in wood.

Yeniocak *et al.* (2015) used eco-friendly wood stained with extracts from beetroot (*Beta vulgaris*) and determined the color stability of this stain to UV light irradiation. Scots pine (*Pinus sylvestris*), oriental beech (*Fagus orientalis*), oak (*Quercus petraea*) and walnut (*Juglans regia*) wood specimens were used for this study. After treatment with stain, wood specimens were exposed to UV irradiation for periods of 50, 100 and 150 hours. The results showed that the color change values for all wood specimens colored with beetroot extract had better performance compared with synthetic dye. Beetroot extracts can be used as an upper surface dyestuff for indoor application and toys. Therefore, wood paints could be developed as more economical and eco-friendly alternatives to synthetic dyes.

Moreover, Lebow (2014) reported a challenge to assessment procedures in a study of the effects of precipitation pattern on the leaching of preservative from treated wood and implications for accelerated testing, expressing concern for the methods used to evaluate the leaching of wood preservatives, an aspect which was not considered in this study. However, to some extent, the loss of the stain color might reflect product weatherability. Lebow suggested that although the study intended to simulate in-service leaching, this approach might not represent commercially produced lumber (Baines 2005) or produce the moisture conditions reported for wood products exposed to natural weathering (Lebow *et al.* 2008). A study comparing outdoor leaching to the OECD method concluded that the laboratory method risked underestimating in-service leaching (Morsing and Lindegaard 2004).

Archer provided evidence that copper retards photodegradation. Lignin forms free radicals (phenoxils) (Archer 2006), which interact with copper to form a phenolate, retarding the appearance of phenoxy-type free radicals involved in the color change (Kamdern and Grelier 2002).

The objective of the present study was to evaluate the color and gloss characteristics of decorative protection applied to wood for exterior use and treated with Type-C micronized copper azole. Were measured the variables of gloss and color of six decorative protections applied to wood for exterior use, by testing natural and accelerated aging. Also were calculated the costs based on performance per surface covered and each decoration protection applied to treated wood for outdoor use, compared with two alternative coatings available on the market.

MATERIALS AND METHODS

Materials

Substrate and Protection

The substrate used in both tests was *Pinus radiata* (D. Don.) treated with micronized copper plus tebuconazole and propyconazole (μ CA-C), also known as Type-C micronized copper preservative, at 3,08 kg/m³, risk class 3 (R3), based on use and risk in service NCH 819, 2012. (Manufacturer's Arch-Quimetal Ltda. Chile, a company associated with Arch Wood Protection).

Three commercial products were used, namely, industrially applied colored lacquers, used according to the manufacturers' instructions, and the control samples, corresponding to wood treated with Type-C micronized copper azole. Additionally, two commercial varnishes were applied on treated and non-treated radiata pine control samples (Table 1).

Table 1. Description of treatments included in the test.

Treatments:	Treatment Description	Treatment Number
T1	Non-treated radiata pine wood (M I)	Reference
T2	M I treated with μ CA-C at 3,08 kg/m ³	1
T3	M I μ copper azole and Prestain P at 8%	2
T4	M I μ copper azole and Red Cylinder at 1%	3
T5	M I μ copper azole and Black Cylinder at 1%	4
T6	M I μ copper azole and water-based varnish	5
T7	M I μ copper azole and solvent-based varnish	6

Infrastructure

The facilities of the Wood Technology Center, School of Forestry Sciences, University of Chile, were used for the preparation of the samples and the treatment and application of the colored coating. The natural aging tested specimens were installed at the Department of Wood and Bio-Materials Engineering. The test was conducted at 0, 1, 2 and 3 months of North and South exposure.

METHODS

The methodology included the assessment of the color and gloss decoration features of the protection applied to the wood samples treated with Type-C micronized copper azole, according to the manufacturer's instructions. The samples were subjected to outdoor tests (natural aging) for three months and laboratory tests using Type-B UV light irradiation at a wavelength of 340 nm (accelerated aging) for 500 hours.

Variables assessed

Both trials were evaluated using a glossmeter and datacolor, Gloss Mitter BYK, with an incidence angle of 60° and a Datacolor 650 color meter, with corporate ORION software.

Gloss Variation (ISO 2813:1994). To determine the gloss variation, a gloss measurement device was used, with an incidence angle value of 60°, which measures the reflectance degrees (reflected gloss). The gloss loss average value was calculated for the exposed samples (LG ex) and the reference samples (LG ref).

The gloss variation was calculated based on the difference between these two parameters:

$$\% \text{ gloss variation} = LG = (LG_{ex} - LG_{ref}) \quad (1)$$

Color Difference ΔE (ISO 7724:1997). Measurements were made on CIELAB coordinates, which determine the color difference between the initial standard as a reference and the tested sample after three months. The measurements were obtained using a Datacolor 650 color meter and ORION software.

The color variation was measured in CIELAB coordinates for determining the color difference (ΔE^*) between a standard used as a reference and the tested sample, achieved using a Data Color colorimeter, which records data on a computer. The illuminating light D65, which describes the average conditions of lighting during the mid-day in Europe (data that is delivered by default in the colorimeter), was considered. The CIELAB (CIE L *a *b) coordinates derived from the color model were used to describe the colors that the human eye can perceive (objectively) and expressed in numerical terms or in a spectral reflectance graph. The CIELAB comprises the following three coordinates:

L^* = brightness (+ light = white, -light = black)

a^* = red/green coordinate (+indicates red, -a indicates green)

b^* = yellow/blue coordinate (+ b indicates yellow, blue indicates -b).

The color difference between two samples was represented as the parameter ΔE^* calculated as:

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

Where ΔL is the difference between ($L_i - L_f$), Δa is the difference between ($a_i - a_f$) and Δb is the difference between ($b_i - b_f$). It is the initial measurement and f is the final measurement. Levels of perceived color difference.

Positive values of ΔL^* show whitening, and negative values of ΔL^* indicate a shift toward gray. Positive values of Δa^* indicate reddening, and negative values of Δa^* show a shift towards green. Positive values of Δb^* represent yellowing, and negative values of Δb^* represent a shift towards blue.

The ΔE parameter*, defined according to the classification of Hikita *et al* (2001), is as follows:

ΔE^* Varies from 0 to 0,5 the color is negligible change

ΔE^* Ranges from 0,5 to 1,5 is slightly perceptible.

ΔE^* Ranges from 1,5 to 3,0 is barely noticeable on the surface.

ΔE^* Ranges from 3,0 to 6,0 is appreciable.

ΔE^* Ranges from 6,0 to 12 is very significant

Substrate Preparation:

The surface of the samples was flat, smooth, planed but not sanded, at 12% CH, as per the indications contained in Norm EN 927-3, which establishes the use of samples for natural aging assays, with a tangent cut of 300 mm x 80 mm x 20 mm, sapwood only, and accelerated aging assays, with sample dimensions of 150 mm x 80 mm x 0.7 mm.

For impregnated wood, we employed a vacuum pressure treatment cylinder 0,1964 m³; micronized copper, plus tebuconazole and propyconazole (μ CA-C) at 3,08 Kg/m³; a pressure pump, 10 kg/cm²; and an immersion tub. For the application of protection, a roller and solution container were used. The samples were prepared by groups and duly identified in flasks containing the appropriate solution, avoiding floating through a metal mesh and with enough solution to maintain exposure to the air during the process. The bottles possessed upper opening to enable air flow, arranged in an autoclave under an initial vacuum of -0,6 Bar (-17,7'' Hg) to maintain the vacuum for one hour. Subsequently, the air valve was opened to atmospheric pressure. The air was injected under an internal pressure of 30 psi (2,1 kg/cm²), which was maintained for a period of four hours. The valves were closed, and the specimens were left inside overnight (14 hours). The next day, the samples were removed and the non-buoyancy of the samples was confirmed. The surface was dried with an absorbent paper and weighed (P2). Impregnation was pretested with water to corroborate the absorption rate, which was between 100-105% of the initial weight (P1). The withholding preservative (kg/m³) was calculated using the following formula:

$$Retention \left(kg / m^3 \right) = (GC / V) \quad (3)$$

Where:

G = (P2 - P1) = grams of treating solution absorbed by the block (block to the initial weight before treatment of the initial weight subtracted more treating solution absorbed).

C = grams of preservative in 100 g of treating solution and V = volume of the block cm³.

Sample Vol. = 0,0001984 m³

Weight difference = 80,595081 grams

Gross absorption = 0,080595081 kilos or liters

Net Absorption = 406,2252067 kilos/m³

Concentration = 0,007582001 kilos/liter

Concentration (%) = 0,758200119 p/v

After the blocks were impregnated and their weights were set to obtain the absorbed volume, these groups were exposed to laboratory conditions for 48 h and, subsequently, transported to a conditioning chamber at 26 °C and 70 % relative humidity. This procedure lasted 21 days, and subsequently the specimens were weighed (P3) to 0,01 g and the initial dry weight was determined at a CH of 16% ± 1%. Subsequently, the surface treatments were applied according to manufacturer's instructions.

Prior to exposure, each sample was controlled in terms of mass (by weight), and percentage of gloss and color, using measurement instruments and taking pictures as a reference. These data were used as the starting point for the test, assuming no gloss variations or color variations in the treatment samples at the zero time. Protection was applied according to the manufacturer's instructions to condition the samples until the moisture contents were balanced.

Each test was conducted using a unique methodology, and, therefore, the descriptions are provided separately.

Accelerated Aging Test

This test is based on standard UNE-EN-ISO 11507, of 1997 Accelerated Aging. The artificial aging and color and gloss change measurements were conducted at the Sherwin Williams Laboratory in Chile. A QUV chamber, with fluorescent lights of 0,55 watts/m²/hour emission of Type-B and UV rays, with a wavelength of 340 nm, was used. A total of twenty-eight 150 x 80 x10 mm samples (4 per treatment) were used, and 4 samples were used as a pattern. The UV exposure measurements were conducted at 0, 100, 200, 300, 400 and 500 hours.

Natural Aging Test

This test is based on the EN 927, part 3: Natural aging-Paint Coatings and Varnishes. Outdoor Wood Coating Materials and Systems, which assesses the coating systems resistance to natural aging and determined changes in decoration and protection properties of the coatings after six months of north and south exposure. The natural aging test was conducted at Wood Engineering Department of Science Forestry of the University of Chile in Santiago, Chile, between March and May of 2014.

The basic equipment required for the test were a wooden sawbuck with inclination at an angle of 45° in relation to the horizontal, oriented towards the north and south. Others implements, such as a 12 megapixel camera and a balance with a capacity of 500 g and an accuracy of 0,01 g, were used.

A total of 42 samples were mounted on sawbucks with an inclination of 45°, 21 samples with northern exposure, (7 treatment samples with 3 repetitions each one) and 21 treatment samples with southern exposure.

To fulfill the objectives of the present study, the aesthetic color and gloss characteristic variations resulting from UV rays were determined, and the parameters measured gloss variation percentages (%GU) and color difference ΔE , using a gloss measurement device and a color meter for three months.

The measurements were obtained at the start of the test and after three months of outdoor exposure, with an up-to-date total of the two measurements. Each measurement controlled the gloss percentage and color difference.

RESULTS

Gloss and Color Aesthetic Features

Test conducted for artificial aging (EA) through exposure to UV rays at a 340-nm wavelength for 500 hours

The table 2 shows the Treatment T1: Untreated radiata pine, reference: (T11- T14 repetitions).

Table 2. Treatment T1: Untreated radiata pine, reference: (T11- T14 repetitions).

Time (h)	Gloss <60°	Color Delta E
	T1	T1
0	4,9%	0,00
100	4,7%	14,04
200	4,5%	28,07
300	4,9%	17,00
400	5,1%	18,17
500	5,3%	18,29

Figures 1 and 2 show an increase in the gloss percentage of 0,4% and a color difference $\Delta E = 18,29$ for samples at time 0 and after 500 hours.

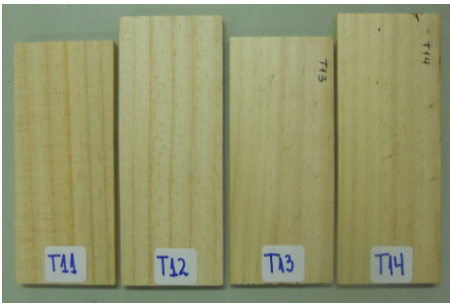


Figure 1. Treatment T1. (Time: 0 hours).

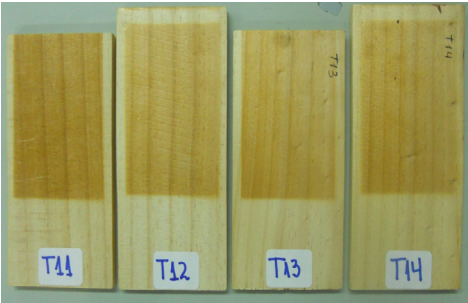


Figure 2. Treatment T1. (Time 500 hours).

Table 3 shows treatment T2 Radiata pine treated with micronized copper plus tebuconazole and

propyconazole, at 3,08 kg/m³, class R3 (T21 -T24 repetitions).

Table 3. Treatment T2: Radiata pine treated with micronized copper plus tebuconazole and propyconazole, at 3,08 kg/m³, class R3 (T21 -T24 repetitions).

Time (hours)	Gloss <60°	Color ΔE
	T2	T2
0	2,9%	0,00
100	2,6%	15,45
200	2,3%	30,91
300	2,5%	18,65
400	2,9%	20,01
500	2,9%	20,95

Figures 3 and 4 shows that the gloss percentage is 0%, and the color difference ΔE is 20,95 from Time 0 through 500 hours.



Figure 3. Treatment T2. (Time 0 hours).



Figure 4. Treatment T2. (Time 500 hours).

Table 4 shows the Treatment T3: Radiata pine treated with micronized copper plus tebuconazole and propyconazole and Prestain P at 8% (T31 -T34 repetitions).

Table 4. Treatment T3: Radiata pine treated with micronized copper plus tebuconazole and propyconazole and Prestain P at 8% (T31 -T34 repetitions).

Time (hours)	Gloss <60°	Color Delta E
	T3	T3
0	0,8%	0,00
100	0,8%	1,80
200	0,7%	3,61
300	0,7%	1,76
400	0,7%	1,53
500	0,7%	1,45

Figures 5 and 6 show that the gloss percentage decreased 0,1% at the end of the assay and the color change ΔE was 1,45 from Time 0 to 500 hours.



Figure 5. Treatment T3. (Time 0 hours).

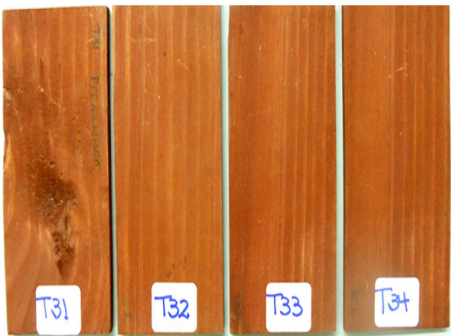


Figure 6. Treatment T3. (Time 500 hours).

The table 5 shows the Treatment T4: Radiata pine wood treated with micronized copper plus tebuconazole and propyconazole, and Red Cylinder at 1% in mixture (T41 -T44 repetitions).

Table 5. Treatment T4: Radiata pine wood treated with micronized copper plus tebuconazole and propyconazole, and Red Cylinder at 1% in mixture (T41 -T44 repetitions).

Time (hrs.)	Gloss <60°	Color Delta E
	T4	T4
0	1,8%	0,00
100	2,7%	9,68
200	3,5%	19,36
300	3,2%	13,22
400	3,6%	13,95
500	3,6%	13,47

Figures 7 and 8 show a 1,8% increase in the gloss percentage and a color difference ΔE of 13,47.



Figure 7. Treatment T4. (Time 0 hours).



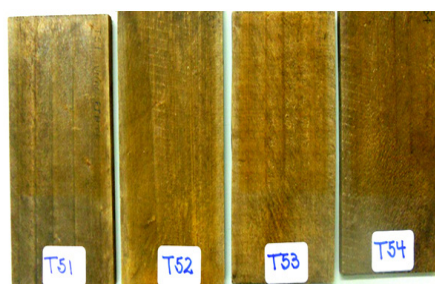
Figure 8. Treatment T4. (Time 500 hours).

The table 6 shows the Treatment T5: Radiata pine treated with micronized copper plus tebuconazole and propyconazole, and 1% Black Cylinder in the mixture (T51 -T54 repetitions).

Table 6. Treatment T5: Radiata pine treated with micronized copper plus tebuconazole and propiconazole, and 1% Black Cylinder in the mixture (T51 -T54 repetitions).

Time (hours)	Gloss <60°	Color Delta E
	T5	T5
0	1,1%	0,00
100	1,2%	2,76
200	1,3%	5,52
300	1,2%	3,26
400	1,3%	3,44
500	1,3%	3,58

Figures 9 and 10 show a 0,2% increase in the gloss percentage and a color difference ΔE of 3,58.

**Figure 9.** Treatment T5. (Time 0 hours).**Figure 10.** Treatment T5. (Time 500 hours).

The table 7 shows the Treatment T6: Radiata pine treated with micronized copper plus tebuconazole and propiconazole and water-based varnish, after treatment. (T61 -T64 repetitions).

Table 7. Treatment T6: Radiata pine treated with micronized copper plus tebuconazole and propiconazole and water-based varnish, after treatment. (T61 -T64 repetitions).

Time (h)	Gloss <60°	Color Delta E
	T6	T6
0	37,4%	0,00
100	36,4%	13,20
200	35,4%	26,40
300	37,3%	15,08
400	33,6%	15,73
500	33,7%	16,47

Figures 11 and 12 show a 3,7% decrease in gloss percentage and a color variation ΔE of 16,47.

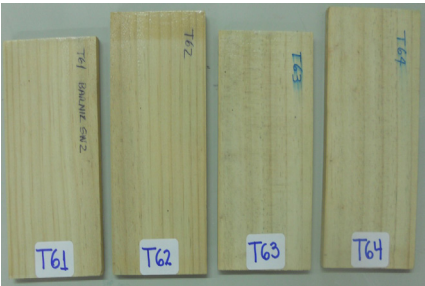


Figure 11. Treatment T6. (Time 0 hours)

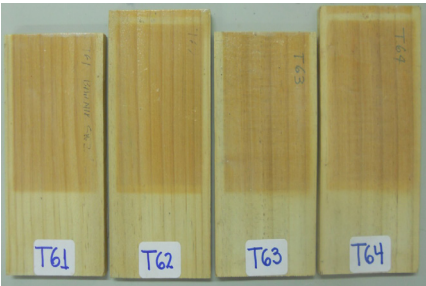


Figure 12. Treatment T6 (Time 500 hours)

The table 8 shows the Treatment T7: Radiata pine treated with micronized copper plus tebuconazole and propyconazole, and SW solvent-based varnish, after treatment. (T71 -T74 repetitions).

Table 8. Treatment T7: Radiata pine treated with micronized copper plus tebuconazole and propyconazole, and SW solvent-based varnish, after treatment. (T71 -T74 repetitions).

Time (h)	Gloss <60°	Delta E (Cielab)
	T7	T7
0	38,7%	0,00
100	38,0%	8, 97
200	37,3%	17,94
300	35,7%	12,38
400	35,5%	15,50
500	37,5%	16,70

Figures 13 and 14 show a 1,2% decrease in the gloss percentage and a color difference ΔE of 16,7.

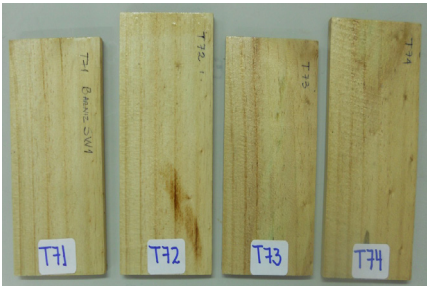


Figure 13. Treatment T7 (Time 0 hours).

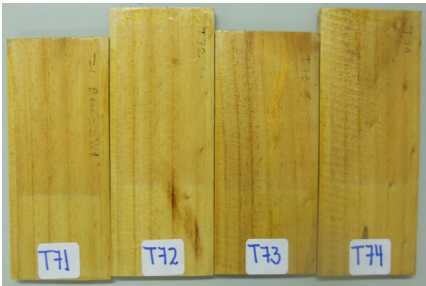


Figure 14. Treatment T7 (Time 500 hours).

Natural Aging Test (EN)

Gloss and color aesthetic features after three months

Figures 15 and 16 show a general view of the natural aging assay installed in Santiago, Chile at the beginning and after 90 days.

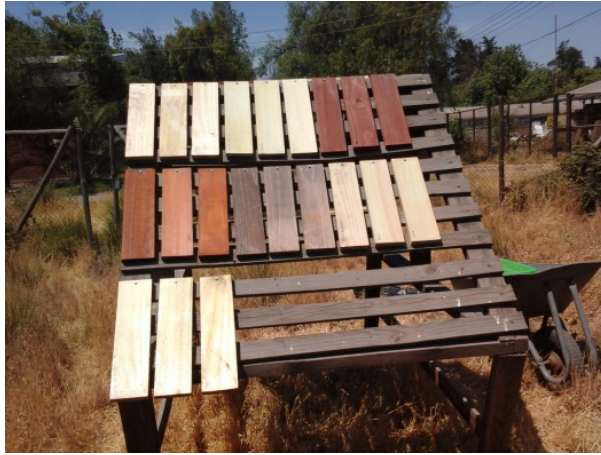


Figure 15. Natural aging Time 0 (N).



Figure 16. Natural aging 90 days exposure (T3).

ANALYSIS AND DISCUSSION OF THE RESULTS

Accelerated Aging Test (EA), UV radiation for 500 hours

Variation in gloss percentage and Variation in Color ΔE

Figure 17 shows that the lowest percentage of gloss loss between the beginning and the end of the treatment occurred in treatment T3, corresponding to Prestain P, with 0,1% loss, followed by treatment T7, the solvent-based varnish, with 1,2% gloss loss, and finally T6, with a 3,7% loss, reflecting the anti-froth products present in fast-drying varnishes (verbal communication with SW).

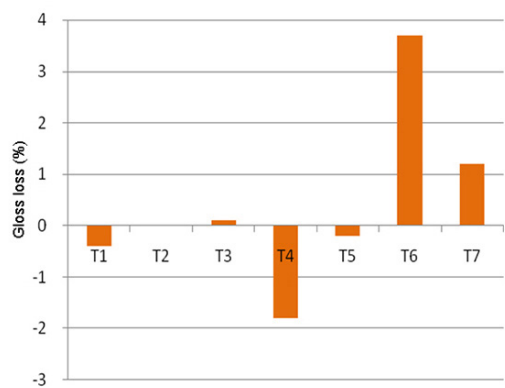


Figure 17. Gloss loss and increase (%) for 500 hours

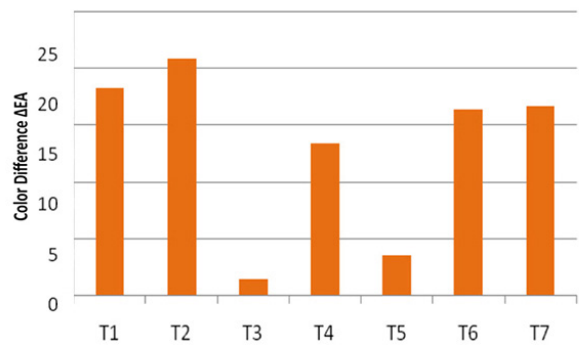


Figure 18. Difference in color ΔE (Cielab) for 500 hours.

The highest percentage of gloss increase occurred in T4, corresponding to the decoration protection Red Cylinder, with a value of -1,8% followed by reference treatment T1, with -0,4%, corresponding to treated pine, with a 1,8% gloss increase, and treatment T5, with -0,2% treated with protection Black Cylinder.

Notably, the gloss percentage remained unchanged after 500 hours in the case of control sample T2, corresponding to pine treated with micronized copper azole and no coating.

Figure 18 shows that decoration protection with least color variation are the Prestain P treatment (T3) with $\Delta E = 1,45$ and Black Cylinder (T5) with a value of $\Delta E = 3,58$.

The maximum color variation, equivalent to 20,95 occurred in control treatment T2. Subsequently, treatments with varnish show similar color variation ranges, where treatment with solvent-based varnish T7 presents a ΔE of 16,70 and treatment with water-based varnish T6 presents a ΔE of 16,47. Treatment with protective Red Cylinder T4 presents a color difference (ΔE) of 13,47.

With respect to the increase in gloss and color that where observed at 200 hours of exposure, more studies are needed, but it might be due to the surface degradation which intensifies these parameters, particularly in a matte-finished product.

Cui *et al.* (2004) established that for $\Delta E < 6$, color changes are not negligible, and, therefore, only Prestain P (T3) and Black Cylinder (T5) treatments would be included in this category.

Natural Aging Test (three months)

Variation in Gloss in % (loss) and Color Difference ΔE (CIELAB Coordinates)

Figure 19 shows that the least variations in terms of percentage of gloss loss corresponded to treatment T3 (Prestain P), with a value of 0,55% followed by T5 (Black Cylinder), with a value of 0,75% and T4 (Red Cylinder) with 0,78% gloss loss.

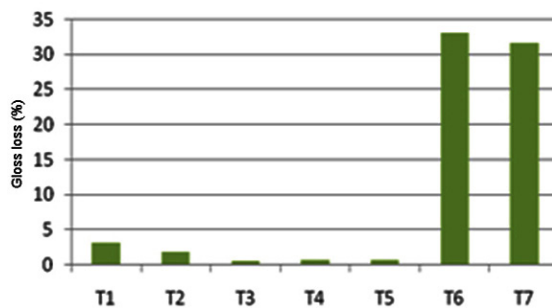


Figure 19. Gloss loss (%) at three months.

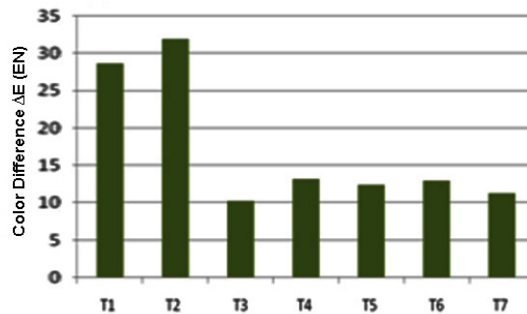


Figure 20. Color difference (ΔE) at three months.

Maximum gloss loss percentages correspond to treatment T6 (water-based varnish) with 33,12% T7 (solvent based varnish) with 31,7% and the control treatment (T2), with a value of 1,85% surpassed by reference treatment T1, with 3,23% corresponding to untreated pine.

Figure 20 shows that the smallest color differences correspond to treatment T3 (Prestain P), with a ΔE of 10,26 followed by T7 (solvent-based varnish) with a ΔE of 11,24 and T5 (Black Cylinder), with a ΔE of 12,41.

The maximum color differences correspond to treatments T2 (control) with a ΔE of 31,85 which exceeds the reference treatment T1 with a ΔE of 28,54 followed by T4 (Red Cylinder), with a ΔE of 13,16 and T6 (water-based varnish), with a ΔE of 12,99.

Cost analysis

These values consider dye consumption and the investments required for application on the wood, amortized over five years and a monthly output of 500 m³.

The increased cost to the impregnated wood would be 14% for prestain P coating, an increase of 17% for Black cylinder decorative coating and 21% for Red cylinder.

Table 9. Costs of in situ-to wood-applied decorative coatings.

COSTS	T7	T6
M ² /GALON	35	35
USD/GALON	26	33
USD/M2	0,74	0,95
M ³ /PIECE	0,00072	0,00072
M ² /PIECE	0,036	0,036
USD/PIECE	0,02653	0,03416
USD/M ³	37	47

Table 9 shows that the lowest cost of *in situ*-to-wood-applied coatings corresponds to solvent-based varnish (T7) with a value of 37 US\$/m³ (the best performance in gloss and color among all *in situ* coatings). This value does not consider the workforce cost to apply the product onto the wood.

The cost analysis for industrially applied decorative coatings showed that the prestain P (T3) decorative coating increases the value of the impregnated wood 14%, and the cylinder black (T5) decorative coating increases the value 17,5 % (Table 10), but the final user has no installation costs.

Table 10. Costs of industrially applied decorative wood coatings .

COSTS	T3	T5	T4
US\$/m ³	30	35	43

Cost analysis for *in situ*-applied decorative coatings shows that the treatment with solvent based varnish (T7) increases the value of the impregnated wood 18,4% and for the water-based varnish treatment (T6) the value of impregnated wood increases 23,7% (Table 9).

Moreover, a cost-per-unit study was calculated, for the most used facade claddings in the country, such as fiber cement siding, vinyl siding and wood siding (wood paneling). The values were complemented with the results from this study to show that the impregnated wood decking treated with Prestain P is highly competitive, close in cost to vinyl siding and nearly 33% cheaper than fiber cement (Table 11).

Table 11. Comparative costs between claddings, installed on a 1-m² wall façade.

Estimated Cost	Vinyl Siding	Wood Siding	Fiber Cement Siding
1 m ² wall structure	32	32	32
coating	17	18	43
Total	49	50	75

Considering the costs, calculations were made for treatments showing better performance in terms of gloss loss and color differences, namely, Prestain P (T3) and Black Cylinder (T5). These values were compared against the following two competitor products: fiber cement siding and vinyl siding.

The results showed that, among the three decorative coatings industrially applied to wood through impregnation, those with best performance, i.e., increased permanence in decorative gloss and color and lower cost, were Prestain P (T3), followed by Black Cylinder (T5), whereas the T4 treatment (cylinder red) did not meet the desirable characteristics of gloss and color; therefore, this treatment was discarded as a recommendation.

Between the two decorative coatings applied *in situ* onto impregnated wood, which have better performance in gloss and color retention features, with solvent-based varnish (T7) showed the lowest cost.

CONCLUSIONS

In the UV radiation exposure test, the treatments with the decoration coatings with the least difference in gloss for wood treated with micronized copper azole correspond to the application of Prestain P (T3), followed by Cylinder Black (T5).

In the accelerated aging UV radiation exposure treatments (EA), the treatments with the decoration coatings with the least color difference (ΔE) for wood treated with micronized copper azole correspond to the application of Prestain P (T3), followed by Black Cylinder (T5).

In the natural aging test (EN), the percentage of gloss loss in the case of Prestain P treatments (T3) and Black Cylinder (T5) showed the lowest values. The color differences with the least changes were achieved with the Prestain P treatments (T3), solvent-based varnish (T7), and Black Cylinder (T5).

When comparing the costs of these alternative coatings for facades installed per m², the costs of industrially colored impregnated wood suggested that treatment with Prestain P (T3) is the most efficient option, i.e., the lowest cost per m², followed by Black cylinder (T5), solvent-based varnish decorative coating (T7), and water-based varnish (T6), including the implementation costs of labor. The final options are vinyl siding and unpainted fiber cement siding.

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