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Effect of Artificial Aging at the Deterioration Wheel on the Color of Finish Treated Woods of *Pinus sylvestris* and *Quercus robur*

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Abstract: The durability of exterior wood finishes is not guaranteed with current finishing systems. Thus, the objective of this study was to evaluate the color change of different finishes applied of wood of most commercialized wood in Morocco, in order to find the best wood-finishing couple having the higher durability in outdoor use. Accelerated aging wheel tests were carried out according to, the following principle: the samples are successively exposed to ambient air, then immerged in water and exposed again to ambient air but under UV radiations. A wheel spin is performed in 90 min and a complete cycle is performed in 3 weeks, so that, a complete cycle counts 336 wheel revolutions. The samples tested on this aging wheel are woodblocks made of two wood species: Scots pine (*Pinus sylvestris*) and Pedunculate oak (*Quercus robur*). These samples were coated with four different finishes (two polyurethane finishes F_1 and F_2 and two acrylic finishes F_3 and F_4) and exposed to accelerated weathering for 12 weeks. Colorimetric measurements in color system CIELab: Gloss (L*), green-red (a*) and blue-yellow (b*) coordinates, color saturation (C*) and tone angle (h*) were performed using an X-Rite Model SP62 spectrophotometer before and after aging treatments. The results showed that rotating wheel aging caused a decrease in the L* value and a change in the surface color of all the finishing pairs studied. For wood/finishing couples including *Quercus robur* as a wooden support, the *Quercus robur*/ F_3 has the best resistance to color change while for wood/finish with *Pinus sylvestris* as a wooden support, the *Pinus sylvestris*/F_5 has the best resistance to color change.

Key words: Wood, finish, gloss, color, accelerated aging, rotating wheel

INTRODUCTION

The main factors generating degradation of outdoor wood products are exposure to ultraviolet light and water (Feist and Hon, 1984; Yalinkilic *et al*., 1999; Zhang *et al*., 2009; George *et al*., 2005). To protect the natural appearance of wood and its original color from the weather and climatic aggressions, researches on transparent or semi-transparent coatings such as varnishes, stains or paints have been carried out (Jirous-Rajkovic and Turkulin, 2002; Jirous-Rajkovic *et al*., 2004; Grull *et al*., 2011; Scrinzi *et al*., 2011). One of the reference tests permitting to evaluate the aging of wood/ finish system consists in the Gardner degradation aging wheel. The tested samples are wooden supports the surface of which has been coated. This test has the advantage to be performed much faster than natural aging (Turkoglu *et al*., 2015; Kerber *et al*., 2016) which presents two major drawbacks: the duration is often longer than 1 year and the repeatability and reproducibility are not good.

Artificial or accelerated aging affects the color of treated or unfinished wood (Temiz *et al*., 2005; Zahri *et al*., 2007; Cakicier *et al*., 2011; Baysal *et al*., 2014, 216; Teles and Costa, 2014; Krystofiak *et al*., 2016; Yalcin *et al*., 2017). The variation in the finishing color observed varies according to the nature of the finishing product, the type of wood (Gierlinger *et al*., 2004; Zanuncio *et al*., 2014, 2015 Hakam *et al*., 2018) and its treatment whatever it is thermal (Ayadi *et al*., 2003; Bekhta and Niemz, 2003;

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Cademartori *et al*., 2013; Demirci *et al*., 2013) or chemical (Baysal *et al*., 2017). Other studies have been devoted to the effect of accelerated aging on the adhesion of finishes (Sonmez *et al*., 2009).

MATERIALS AND METHODS

A wood/finish system is a sample that consists of a wood support and one or more finishing products applied on the surface of this wood. The choice of wood/finishing systems was made in close consultation with the manufacturers of the wood-finishing sector in Morocco. Two wood species were selected to manufacture the wood supports: Scots pine (*Pinus sylvestris*) and Pedunculate oak (*Quercus robur*). Table 1 gives some characteristics of the wood support used.

Manufacture of test samples: Specimens measuring 30×15×1.8 mm were cut lengthwise along the longitudinal axis of symmetry (L) in width along the tangential axis of symmetry (T) and at depth along the axis of radial symmetry (R). All wooden specimens were equilibrated in a climatic chamber at 65±5% relative humidity and at 20°C before coating with the finish, so that, the equilibrium moisture of the all specimens was 12%.

Finishing products: As for wood, the four commercial water finishes used were chosen in consultation with the wood-finishing industry in Morocco. Two finishes based on polyurethane resin (F_1 and F_2) and two based on acrylic resin (F_3 and F_4). Table 2 gives some indications on the commercial finishes used.

Coating of wooden surfaces: According to, the recommendations of the product data sheets of each product, the chosen finishing products were applied on one of the tangential faces of each specimen. The other faces were closed with a sealant, applied for 3 days, one layer per day. Before starting the tests, the test pieces have been stored at ambient air to dry for 1 week.

Accelerated aging: The accelerated aging process was performed on a Gardner-type deterioration wheel (Fig. 1), according to the following principle: the samples were successively exposed to three different ambiences: the first one was ambient air, the second one consisted in the immersion into water and the third one was ambient air coupling with radiations generated by UV lamps (El Imame, 2018).

A wheel spin was performed in 90 min and the duration of a complete cycle was 3 weeks. The samples were exposed to accelerated weathering for 12 weeks. This device simulates climatic aggressions by subjecting the wood-finishing system to alternating periods of exposure to UV radiation and periods of immersion in distilled water, so that, coated wood samples were periodically dried and re-humidified.

Color measurements: Colorimetric analysis of the wood-finish systems was performed using an X-rite SP 62 spectrophotometer. The measured parameters were: the brightness (L*), the chromatic, green-red (a*) and blue-yellow (b*) coordinates with reference to the CIELab color coordinate system. The value used for each parameter was the average value of three measurements. L* can vary from 100 (white) to zero (black). From the values of L*, a* and b*, the difference in brightness (ΔL*) and chromatic coordinates (Δa* and Δb*), the hue

Table 1: Characteristics of the wood supports used

Variabels	(*Pinus sylvestris*)	(*Quercus robur*)
Wood	Softwood	Hardwood
Specific density*	0.55	0.74
Structure	No vessel	Porous rings
Width of ring (mm)	1.4	1.4

*Tropix 7 (Gerard *et al*., 2011)

Table 2: Characteristics of the finishes used

Finish	Base resin	Product type
F_1	Polyurethane	Clear aqueous varnish
F_2	Polyurethane	White matt aqueous varnish
F_3	Acrylic	Aqueous stain transparent matte
F_4	Acrylic	Aqueous stain opaque white matte

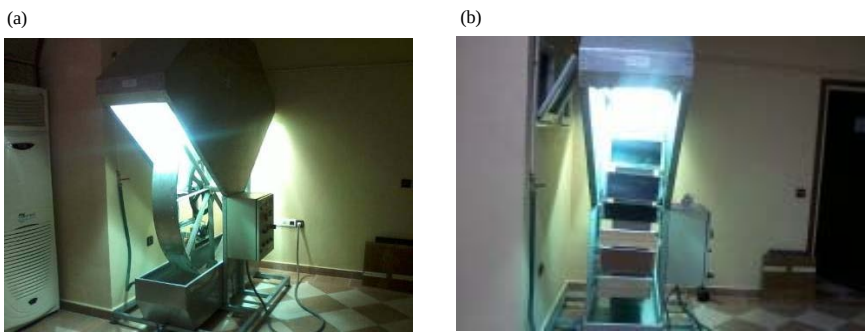


Fig. 1: a, b) Gardner degradation wheel

angle (h*), the color saturation (C*) and the overall color difference (ΔE*) were calculated using the following formulas:

$$\Delta L^* = L^*f - L^*i$$

$$\Delta a^* = a^*f - a^*i$$

$$\Delta b^* = b^*f - b^*i$$

$$h^* = \text{arctg}\ (b^*/a^*)$$

$$C^* = (a^{*2} + b^{*2})^{1/2}$$

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

Where:
L*f, a*f, b*f are L*, a*, b* specimens after wheel aging tests and L*i, a*i, b*i are L*, a*, b* pre-test samples.

RESULTS AND DISCUSSION

Table 3 presents the values of L*, a* and b* based on the initial color coordinates for each wood/finish pair. Table 4 presents the values of (ΔL*) (Δa*) (Δb*) (ΔE*) (C*) and (h*), calculated from the values of L*, a*, b* based on the coordinates of initial color for each couple wood/finish. Table 5 shows some samples before and after aging on the wheel. White coatings showed significant discolorations compared to transparent or opaque coatings. Intensity of color change was higher in white-clad oak than in pine with the same coating.

As can be seen in Table 3 and 4, the L* values of all finishing torques decrease after wheel aging while the a* values increase, except for *Pinus sylvestris*/F_4.

The positive values of (a*) show a tendency of the finish surface to become reddisher, for all wood/finish combinations.

The green-red coordinate (a*) of all the pairs (*Pinus sylvestris*/Finition) was higher than that of the pairs (*Quercus robur*/Finition). The blue-yellow coordinate (b*) increases for pairs (*Pinus sylvestris*/ Finition) but decreases for pairs (*Quercus robur*/F_3).

Table 3: Results of colour measurements

		L*		a*		b*	
Finish	Wood species	Before	After	Before	After	Before	After
F_1	P	59.16	51.21	13.28	14.44	22.45	28.80
	C	58.06	53.34	8.72	12.18	23.84	32.64
F_2	P	57.73	50.00	14.54	16.02	26.55	29.86
	C	51.21	51.36	9.77	12.27	23.93	31.48
F_3	P	52.64	48.07	17.28	16.82	31.32	31.42
	C	50.01	45.97	11.03	13.44	25.25	31.06
F_4	P	58.64	51.18	14.15	18.01	23.78	32.02
	C	35.80	51.83	9.30	13.93	23.79	31.60

Table 4: Results of color measurements

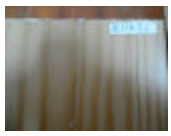
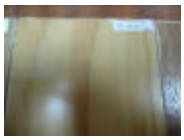
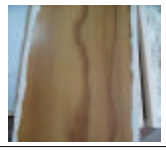
						c*		h*	
Finish	Wood species	ΔL*	Δa*	Δb*	ΔE*	Before	After	Before	After
F_1	P	-7.96	1.16	6.35	10.25	26.08	32.21	1.04	1.11
	C	-4.72	2.41	8.80	10.27	30.28	33.89	1.07	1.08
F_2	P	-7.73	1.48	3.31	8.54	25.38	34.84	1.22	1.21
	C	0.14	4.62	7.55	8.85	25.84	33.78	1.18	1.20
F_3	P	-4.57	-0.46	0.09	4.59	35.77	35.63	1.07	1.08
	C	-4.03	3.46	5.81	7.87	27.67	36.73	1.03	1.06
F_4	P	-7.46	3.86	8.23	11.74	27.55	33.84	1.16	1.16
	C	16.03	2.50	7.81	10.25	25.55	34.54	1.20	1.16

(P for *Pinus sylvestris* and C for *Quercus robur*)

Table 5: Surface aspects of some samples before and after aging on the decay wheel

Wood/Finish	*Quercus robur*/F_3	*Quercus robur*/F_4	*Quercus robur*/F_1	*Quercus robur*/F_2
Sample before wheel aging tests				
Sample after wheel aging test				

Table 5: Continue

Wood/Finish	*Pinus sylvestris*/F_1	*Pinus sylvestris*/F_4	*Pinus sylvestris*/F_2	*Pinus sylvestris*/F_3
Samples before wheel aging test				
Samples after wheel aging test				

Based on the results obtained, the ranking of the sustainability of the *Quercus robur*/Finition systems in descending order is: *Quercus robur*/F_3, *Quercus robur*/F_1, *Quercus robur*/F_2, *Quercus robur*/F_4. Considering now all the couples *Pinus sylvestris*/Finish, the sustainability ranking in descending order is: *Pinus sylvestris*/F_5, *Pinus sylvestris*/F_4, *Pinus sylvestris*/F_1, *Pinus sylvestris*/F_2.

CONCLUSION

The finish protects wood against changes in humidity, temperature and sun radiation and can be considered as an important step in valuing wood products. Moreover, the service life of these wood products is often associated with the durability of its finishing coating. In this study, the effect of accelerated degradation on the gloss and color of Scots pine (*Pinus sylvestris*) and Pedunculate oak (*Quercus robur*) specimens coated with varnish and stain was investigated by performing gloss tests and the surface color. The choice of wood/finishing systems was made in consultation with the wood-finishing industry in Morocco. Two finishes based on polyurethane resin (F_1 and F_2) and two based on acrylic resin (F_3 and F_4) were chosen. The results showed that the degradation caused a decrease in gloss and a change in the color of all the specimens studied. This study made it possible to rank the durability of the wood/finish systems studied. The ranking of the sustainability of *Quercus robur*/finition systems in descending order is: *Quercus robur*/F_3, *Quercus robur*/F_1, *Quercus robur*/F_2, *Quercus robur*/F_4 and ranking of the sustainability of *Pinus sylvestris*/finishing systems in descending order is: *Pinus sylvestris*/F_5, *Pinus sylvestris*/F_1, *Pinus sylvestris*/F_4, *Pinus sylvestris*/F_2.

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