ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 15 N° 4 2019
pp. 173-178

AGING EFFECT OF SOME VARNISH COATED WOOD SPECIES ON COLOR DIFFERENCE AND SURFACE ROUGHNESS

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Abstract:

The objective of this study was to evaluate the surface roughness and the color change of eight wood species, namely, Juglans regia, Paulownia tomentosa, Acer sempervirens, Querqus alba , Larix decidua, Tarrietia utilis, Tilia cordata, Fraxinus excelsior, coated with water-soluble varnish in contrast to uncoated control samples before and after artificial weathering test. A long term artificial weathering test was carried out in order to investigate the influence of UV light and water spray condition on wood colour and surface roughness. Two main roughness parameters, mean arithmetic deviation of profile (Ra) and mean peak-to-valley height (Rz) obtained from the surface of wood, were used to evaluate the effect of weathering on the surface roughness of the samples. Additionally, the results are presented in ΔE and L a *b* coordinates according to the CIELab system. Total color change was increased with increasing exposure time of artificial weathering. Uncoated (control) wood samples exhibited higher color changes than the other wood samples in all the stages of weathering process. Surface roughness of the uncoated samples resulted in higher mean peak*-***to-valley height (Rz) values.***

Key words*: weathering; roughness; color change; water-soluble varnish; wood.*

INTRODUCTION

Weathering is considered the common expression depicting outdoor degradation of wood and demonstrates itself physically and chemically (for example, cracking, and photodegradation of organic materials). Ultraviolet (UV) radiation in sunlight catalyzes photodegradation of organic materials intensified by moisture, temperature change, freeze–thaw cycles. Degradation takes place near the surface of wood and finishes (Poletto 2017).

Weathering takes many forms depending on the material; wood and wood products initially show color change and slight checking. Leaching of water-soluble extractives, chemical changes, and discoloration of the surface by microorganisms cause color change. As weathering goes on, wood evolves checks on parietal surfaces and checks and cracks near the ends of boards, and wood fibers slowly erode from the surface. Wood consists of three types of organic components: carbohydrates (cellulose and hemicelluloses), lignin, and extractives (Jankowska 2015, Turkoglu et al. 2015).

Meanwhile this procedure, wood can face serious alterations of its physical and structural properties attributable to the incorporative effect of sunlight, oxygen, moisture, atmospheric pollutants and micro-organisms. The synergy of oxygen and sunlight radiation influences oxidation of lignin and hemicellulose and depolymerisation of cellulose. Many of the reaction products are water-soluble so they are easily ejected from the wood surface by rain, exacerbating a roughened and discoloured surface (Teacă et al. 2013).

Wood products used under outdoor conditions are treated or finished applying altered types of chemicals with the purpose of protection so that the overall mean life of the product is elongated. Two primitive types of finishing methods are ordinary used to upgrade resistance of wood surfaces contrary to weathering. The first one is the application of finishes to the surface in the form of thin layers or coatings with limited penetration (Wiliiams 2010).

Effect on Wood Finishes

Finish resins (ingredients that form films or penetrate wood) are organic polymers, and as with lignin in wood, UV radiation degrades the polymer, causing slow erosion. Erosion rate depends on the resistance of the polymer to UV radiation. Paints and stains based on latex polymers are more resistant to UV radiation than those based on oil-alkyds. UV radiation does not usually degrade paint pigments; therefore, as resin degrades, pigments loosen and erode from the surface. Degraded resin and loose pigments give film-forming finishes a chalky appearance. Pigment erodes from oil-based semitransparent stains to expose wood.

Wood finishes (paint, varnish, and stain, for example) give a desired appearance, protect wood surfaces, and provide a cleanable surface (Williams 2010). Many people consider appearance most important when choosing finishes for wood (lumber and wood composites). However, from a technical aspect, protection is most important for wood used outdoors, and providing a cleanable surface is most important for wood used indoors. Despite the use of coatings to restrict weathering, degradation of wood beneath the coating still occurs, although at a reduced rate. Ordinarily, the degradation of wood has been examined by weight loss measurements, colour measurements, mechanical tests, FT-IR spectroscopy, optical and electron microscopy (Francesca Lionetto et al. 2012).

The aim of this research was to evaluate the color change and the influence on surface roughness of several wood species uncoated and coated with water soluble varnish.

METHODS AND MATERIALS

Wood material

Eight different species of wood (5 of each specie), Juglans regia, Paulownia tomentosa, Acer sempervirens, Querqus alba, Larix decidua, Tarrietia utilis, Tilia cordata, Fraxinus excelsior, were used for the experiments. Samples with dimensions of 50mm by 50mm by 10mm were conditioned in a climate room having a relative humidity of 65% and a temperature of 20∘C until they reach equilibrium moisture content of 11%. All samples of each species were cut from the same air-dried board to ensure high homogeneity.

Water-soluble Varnish

The finishing procedures have a great significance for technical, economical and aesthetical assessment of the wood. Wood surfaces coated with a varnish can be secured from certain negative conditions such as moisture, changes in dimensions and amplification by microorganisms and fungi. The moisture content of the wood is significant for bending, drying, impregnating, and finishing procedures. During water absorption by wood materials, water molecules are held by the hydroxyl groups (OH) of cellulose and lignin until saturation (Kollmann and Côté 1984). This occurence is important for the varnish which is cured by polymerization. Afterward occuring moisture level plays a critical role in achievement of the wood finishing processes (Wheeler 1983; De Meijer and Militz 2001; De Meijer 2002).

Weathering test

Artificial weathering was carried out according to the European standard EN ISO 11341 equipped with a filtered xenon-arc UV lamp for 2000h. The test was carried out for coated with varnish and uncoated samples for 0 - 600h (5 cycles). The duration of each wetting cycle test was 120 min where 18 min was the wetting time and the 102 min was the dry period (Relative humidity 40-60%).

Surface roughness measurements

As concerns surface roughness, the Mitutoyo Surftest SJ-210 instrument was employed for surface roughness measurements. The *Rz* roughness parameter was measured to evaluate surface roughness of unweathered and weathered samples' surfaces according to ISO 1997. The equipment has stylus with 0.5μ radius and 90∘ contact angle running at a speed of 0.5mm/s. Random measurements with a span of 15mm were taken from the surface across the grain orientation. Mean peak-to-valley height (Rz) which is well accepted roughness parameter was used as an indicator of the surface quality of the samples. Average roughness (*Ra*) which is the parameter characterized by ISO 1997 was recorded. The Ra is by far the most commonly used parameter in surface finish measurement and was expressed as the arithmetic mean of the absolute values of the profile deviations from the mean line. Five replicates were used for each group to evaluate surface roughness.

ONLINE ISSN 2069-7430
ISSN-L 1841-4737

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Color Measurement of the Samples

Color changes during weathering were steadily observed at the same spot of the specimens based on the method of the (CIELAB) using color parameters, L*, lightness, a*, along the X axis red (+) to green (-), and b* along the Y axis yellow (+) to blue (-). Color differences ΔE* of the samples were evaluated according to the equation: ΔE* = (ΔL*2+Δa*2+Δb*2)1/2.

Positive values of Δb* indicated an increase of yellow color, while negative values indicated an increase of blue color. Positive values of Δa* resulted in a tendency of the wood surface to be reddish, while negative values exhibited a tendency to be greenish. The negative ΔL* values apparently happened due to the fact that the wood surface becomes rougher and darker during UV light irradiation. Measurements were performed according to ISO 7724-2 1984 standard.

RESULTS AND DISCUSSION

The roughness of wood is a complex phenomenon because wood is an unisotropic and heterogenous material and several factors such as anatomical differences, growing characteristics, machining properties of wood, pretreatments applied to wood before machining should be considered for the evaluating on the surface roughness of wood (Aydin & Colakoglu 2003). Table 1, demonstrates surface roughness parameters Ra and Rz which showed that coated samples are significantly smoother that uncoated. Acer sempervirens was found to be smoother than other wood species, but on the other hand Tarrieta Utilis and Fraxinus excelsior seems to be rougher. Generally, the values mean roughness profile (Ra) decreased after weathering process (600h) in same cases such as in Juglans regia, Paulownia tomentosa and Fraxinus excelsior as concerns uncoated samples. The most significant finding is that roughness of coated samples intensified after exposure to UV light and water spray conditions, except for Paulownia tomentosa samples where an important decrease was observed.

Table 1

Surface Roughness of coated and uncoated wood species

ROUGHNES								
	Unweathered sample		Weathered sample		Coated-unweathered		Coated-Weathered	
Wood species	Ra(μm)	Rz(μm)	Ra(μm)	Rz(μm)	Ra(μm)	Rz(μm)	Ra(μm)	Rz(μm)
Juglans regia	2,11	16,1	1,92	12,61	0,71	3,7	0,68	4,52
Paulownia tomentosa	3,33	18,74	2,05	9,75	1,75	12,69	1,08	5,47
Acer sempervirens	1,51	10,05	3,88	19,93	0,89	5,32	2,01	11,01
Querqus alba	1,78	11,65	3,5	21,71	2,49	7,99	3,94	21,07
Larix decidua	3,35	24,85	3,86	22,72	1,7	9,7	2,81	16,98
Tarrietia utilis	11,23	62,97	11,13	66	7,67	39,5	2,51	15,21
Tilia cordata	3,9	25,96	3,45	18,36	2,1	13,46	2,98	16,47
Fraxinus excelsior	7,5	44,47	2,75	16,81	0,7	4,31	6,6	37,84

Color Change of the Samples

It is an undeniable fact that the color change of the wood is not only an optic deficiency but also reflects the chemical modification of the components in wood due to photo-degradation. The color change is attributed to the carbonyl groups as a consequent of the modification of lignin and other related compounds (Temiz et al. 2005).

Table 2

Color change (ΔE) of coated and uncoated wood species

	Color change															
	Juglans regia		Paulownia tomentosa		Acer sempervirens		Quercus alba		Larix decidua		Tarrietia utilis		Tilia cordata		Fraxinus excelsior	
	ΔE1	ΔE2	ΔE1	ΔE2	ΔE1	ΔE2	ΔE1	ΔE2	ΔE1	ΔE2	ΔE1	ΔE2	ΔE1	ΔE2	ΔE1	ΔE2
24/12/2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24h	9,75	4,50	8,92	6,82	3,41	2,21	5,16	8,55	11,21	9,41	11,31	8,80	9,71	7,66	5,98	5,02
48h	6,38	3,48	7,44	6,28	3,05	1,45	7,19	8,57	13,78	9,06	12,58	7,18	13,63	7,43	3,99	6,01
72h	1,29	7,82	9,49	9,27	4,78	3,62	5,74	8,78	13,04	9,71	10,68	6,62	24,52	9,76	7,60	9,06
96h	4,48	8,51	7,97	6,83	6,32	4,26	6,04	8,60	15,25	10,22	10,65	6,18	13,69	10,62	8,12	13,72
120h	11,57	8,58	9,51	7,91	2,49	3,83	4,53	9,70	14,22	8,86	8,22	5,17	15,41	10,69	8,36	6,55
172h	9,26	11,84	8,52	6,61	5,26	4,44	4,46	7,35	18,54	13,56	9,88	5,72	11,30	12,48	9,07	7,78
316h	12,64	12,55	11,47	8,58	6,28	4,68	7,04	4,74	16,43	21,54	12,57	13,64	7,65	16,91	11,42	7,96
388h	18,19	13,02	5,80	5,03	8,81	2,23	10,40	4,20	16,16	9,90	13,69	8,25	12,48	10,48	14,17	7,21
600h	16,47	14,68	10,12	3,91	3,55	2,84	10,95	1,42	13,20	9,08	17,11	10,02	7,56	6,97	16,12	5,71

*1: Uncoated samples, 2: Coated samples

Tables 2, 3, 4 and 5 displays the color changes of some wood species samples in the form of CIELAB parameters, namely ΔL*, Δa*, Δb*, and ΔE* after they were exposed to 24 – 600 hours of weathering. According to the results uncoated samples present higher color change after weathering excluding Paulownia tomentosa samples which show lower color change (ΔE) at the end of weathering test (600h). The color change rate of the surface of the samples was initially fast and then the rate of discoloration reduced during the 172 hours of exposure. In general, samples coated with water-soluble varnish exhibit soften color change influence. The color change of the samples took place during the initial stage of weathering test. The selected wood species seems to perform different during the weathering test due to their anatomical structure. The structural differences of wood species are the most significant factors that influence weathering results (Williams 2010).

Table 3

Color change (ΔL) of coated and uncoated wood species

	Color change															
	Juglans regia		Paulownia tomentosa		Acer sempervirens		Quercus alba		Larix decidua		Tarrietia utilis		Tilia cordata		Fraxinus excelsior	
	ΔL1	ΔL2	ΔL1	ΔL2	ΔL1	ΔL2	ΔL1	ΔL2	ΔL1	ΔL2	ΔL1	ΔL2	ΔL1	ΔL2	ΔL1	ΔL2
24/12/2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24h	3,58	0,73	-1,52	3,95	-2,09	-0,62	-3,80	-4,93	-8,30	-8,23	-11,30	-8,71	-8,38	-3,83	2,71	1,65
48h	-0,05	1,88	-0,04	2,99	-2,28	-1,14	-4,10	-4,39	-11,97	-7,45	-10,80	-6,47	-12,17	-4,68	1,26	2,52
72h	0,42	3,21	-1,39	2,34	42,75	-1,36	-4,85	-4,44	-12,28	-7,68	-10,04	-5,96	-13,68	-5,63	4,22	1,90
96h	2,60	5,09	-1,12	2,99	-2,31	-0,74	-4,35	-4,58	-14,49	-8,09	-8,53	-3,67	-11,76	-4,97	4,64	2,09
120h	5,39	5,81	-0,50	5,05	-1,47	0,56	-2,64	-2,66	-13,62	-6,77	-3,29	-0,93	-7,79	-2,49	6,04	4,04
172h	7,56	7,97	0,85	3,13	-2,99	-0,52	-2,44	-4,32	-18,49	-9,90	-2,03	-2,23	-10,23	-5,08	8,43	0,70
316h	9,62	10,26	1,15	3,09	-0,46	0,79	1,69	-2,76	-15,30	-10,35	3,13	1,74	-6,38	-3,47	11,14	2,08
388h	15,68	11,95	3,17	3,52	2,05	1,42	2,78	-3,30	-12,04	-9,31	3,37	4,59	-4,25	-4,60	12,10	5,74
600h	13,78	12,73	-0,10	3,59	2,57	1,83	4,64	-1,40	-8,44	-8,03	9,00	6,63	-2,33	-3,79	14,37	3,73

*1: Uncoated samples, 2: Coated samples

As concerns color Lightness (ΔL) of wood species samples we can observe that Juglans regia and Fraxinus excelsior samples affected profoundly in contrast to other wood species. Additionally, the water-soluble varnish did not prevent the Lightness difference (ΔL) as regards Juglans regia samples. The highest average value of ΔL* was found out for uncoated samples of Juglans regia. It was also determined that ΔL* was the most susceptible parameter to demonstrate the surface quality of the samples as results of UV irradiation and water spray during weathering process. The negative lightness (ΔL*) values take place during weathering because the surface of the samples becomes darker, which is opposite of the positive lightness stability (ΔL*) values. In the initial stages of weathering test, dark woods tend to become light and light woods, dark. Lastly, all wood species become gray if completely exposed to UV light and water spray. Wood obtains gray color as a result of the leaching of the decomposition products of lignin (Dawson et al. 2008).

Table 4

Color change (Δa) of coated and uncoated wood species

	Color change																
	Juglans regia		Paulownia tomentosa		Acer sempervirens		Querqus alba		Larix decidua		Tarrietia utilis		Tilia cordata		Fraxinus excelsior	
	Δa1	Δa2	Δa1	Δa2	Δa1	Δa2	Δa1	Δa2	Δa1	Δa2	Δa1	Δa2	Δa1	Δa2	Δa1	Δa2
24/12/2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24h	0,27	1,29	7,91	-0,43	0,26	-1,95	-0,49	2,06	-0,24	2,84	0,32	-1,03	0,70	-0,29	-0,56	1,27
48h	-2,79	1,06	6,24	0,39	1,40	-0,63	-2,60	1,59	1,11	2,58	1,17	-3,05	1,41	1,13	2,04	1,13
72h	0,15	0,47	9,25	-0,80	1,16	-0,24	-1,11	2,51	4,14	2,87	-1,25	-2,86	-7,22	2,03	-2,36	1,12
96h	-2,64	-0,08	3,63	0,99	-3,62	-1,13	-2,57	1,55	2,75	2,97	-2,97	-4,63	-0,77	1,99	-2,55	1,55
120h	-3,13	-0,90	8,97	-0,54	-1,85	-1,30	-3,36	3,06	1,15	2,59	-7,43	-4,76	-7,34	0,37	-3,39	3,55
172h	-5,34	-0,29	6,93	1,71	0,61	0,92	-3,44	1,95	1,22	4,67	-6,66	-4,97	-2,98	1,19	-3,33	6,37
316h	-7,59	0,02	8,31	-1,49	-6,20	-0,11	-6,62	2,39	-2,47	17,04	-9,82	-5,39	-2,30	-3,48	-2,14	6,85
388h	-7,91	-1,65	-4,57	0,24	-8,43	-0,22	-5,64	2,17	-1,46	3,34	-7,85	-6,77	-10,82	0,11	-4,15	4,33
600h	-5,75	-0,70	9,95	1,56	-1,43	-0,04	-6,95	-0,20	-4,11	2,92	-10,87	-7,51	-0,84	0,53	-5,94	4,28

*1: Uncoated samples, 2: Coated samples

Moreover, it was found that Δa* and Δb* were reduced with an increasing exposure time in an accelerated test cycle for the control samples from all wood species except for Paulownia tomentosa samples regarding Δa* coordinate and Tilia cordata concerning Δb* coordinate which showed a small increase in particular exposure time (72h-316h). It is obvious that the chromaticity coordinates, Δa* and Δb* were fewer affected by the water spraying during the tests.

Table 5

Color change (Δb) of coated and uncoated wood species

	Color change																
	Juglans regia		Paulownia tomentosa		Acer sempervirens		Querqus alba		Larix decidua		Tarrietia utilis		Tilia cordata		Fraxinus excelsior	
	Δb1	Δb2	Δb1	Δb2	Δb1	Δb2	Δb1	Δb2	Δb1	Δb2	Δb1	Δb2	Δb1	Δb2	Δb1	Δb2
24/12/2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24h	9,07	4,25	3,83	5,54	2,68	0,84	3,45	6,68	7,53	3,57	-0,16	0,60	4,85	6,63	5,30	4,57
48h	5,74	2,73	4,05	5,51	-1,47	0,64	5,30	7,19	6,73	4,47	-6,35	0,69	5,98	5,67	3,19	5,34
72h	1,21	7,12	-1,62	8,94	-0,95	3,34	2,86	7,15	1,44	5,21	-3,42	0,19	19,02	7,71	5,87	8,79
96h	2,52	6,83	7,01	6,07	4,64	4,04	3,31	7,12	3,86	5,51	-5,64	1,82	6,97	9,17	6,16	13,48
120h	9,75	6,26	-3,12	6,07	-0,80	3,56	1,51	8,82	3,91	5,10	-1,25	1,81	11,08	10,39	4,68	3,74
172h	0,27	8,76	-4,88	5,57	-4,29	4,31	-1,45	5,62	-0,53	8,01	-7,01	1,75	3,75	11,34	0,29	4,43
316h	-3,11	7,24	-7,82	7,86	0,91	4,61	-1,70	3,04	-5,45	-8,17	-7,19	12,41	-3,54	16,19	-1,29	3,48
388h	-4,73	4,90	1,65	3,58	-1,51	1,71	-8,28	1,45	-10,68	-0,46	-10,70	-1,11	4,55	9,42	-6,09	0,57
600h	-6,96	7,28	1,85	0,02	-1,99	2,17	-7,08	-0,17	-9,28	-3,09	-9,67	-0,45	7,14	5,83	-4,24	-0,68

*1: Uncoated samples, 2: Coated samples

The results of previous studies display that the coatings containing UV absorber substantially prevented the color changes of the wood surface during weathering (Irmouli et al. 2012).

CONCLUSIONS

The roughness and color change of wood are very important properties for its aesthetic and decorative appearance. Artificial weathering caused an increase in surface roughness. The conducted test confirmed visual degradation of coatings over time as a result of a UV radiation and water spray. Results revealed that changes in color occurred already after 24h of artificial weathering with a decrease in Δa and Δ, and variable results in ΔL. Positive values of the color coordinates indicated that the wood surfaces changed from their original color to a reddish and yellowish color. The highest color change was detected in the samples coated with polyurethane varnish alone. Surfaces became rougher after weathering in comparison with the initial surfaces of wood samples. Roughness of coated samples intensified after exposure to UV light and water spray conditions, except for Paulownia tomentosa samples where an important decrease was observed.

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