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Properties of Clear Coated Spruce (*Picea orientalis*) and Beech (*Fagus orientalis*) Woods for Evaluating Outdoor Utilizations

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ABSTRACT
It has become an important issue for protecting wood that is not harmful to users, while wooden design elements provide many opportunities and amenity to visitors. Some new types of wood-protecting agents have gained importance due to their low-toxic chemical formulations. The study presents the experimental study on outdoor exposure impact on clear coated of two different of Spruce and Beech wood species. It was found that increasing coating number is usually having positive effects, lowering the water absorption of both spruce and beech woods. The lowest water absorption value of 1.7% found at fifth-time coated beech wood, which shows approximately 97.2% lower than the control sample. However, increasing coating time (durations) was found to have further lowering effects on water absorption for beech wood species. It was found that the three-month duration of weathering was not affected by the surface scratch resistance (hardness) of control spruce and beech woods, while it is usually increasing effects on waterborne varnish-treated samples regardless of treatment conditions. This is clearly indicating physicochemical modification and creating tension on wood surfaces in outdoor conditions. However, weathering significantly affects the surface color and gloss properties of selected wood samples. The increasing coating layer was found to be not affected by improving lightness values for spruce wood. The similar trend was also observed with treatment time up to 3.0 min, and beyond this level, the wood surfaces were found to be lighter (ΔL: + values). Moreover, varnish treatment variables (coating layer and time) were also not any improvement effects found for beech wood. The lowest ΔL value of-9.78 (in metric) was found for sample Be, followed by B4 (ΔL:-9.38) and B5 (ΔL:-9.0), samples, respectively. It is important that the surface total color difference (ΔE) of wood substrates appeared to be well correlated with coating number and time of duration for both spruce and beech woods. It was realized that increasing the coating number is not effective for improving gloss properties for spruce wood, while some variations in glossiness for beech wood could be realized by changing the treatment parameters.

Keywods: Waterborne varnish, landscape elements, beech, spruce, weathering, color properties.

INTRODUCTION
While the landscape describes an environment, consists of mostly greenish infrastructures, the architecture evokes a constructive work that was completed from the very beginning and will

age over time [1,2]. It has already been well established that wooden material is an effective material for both architects and users in planning space by positively addressing people's feelings, particularly aesthetic features, which are very important even though the pattern changes according to the cutting direction of the wood [1-3]. It has well-presented that wood can be blended naturally with landscape elements to create a masterpiece with challenging projects. Because of its versatility, variety of natural colors, and flexibility properties, it could be used in numerous applications to provide a natural way to add value with a level of warmth and soften with possibilities for creating unique elements [1,4,5]. Some of the examples of areas where wooden materials are generally preferred are urban and neighborhood parks, residential gardens, children's playgrounds, sports fields, squares, zoos, curbing structures, garden beds, walkways, retaining walls, borders and edgings, pergolas, planter boxes, and so on. However, wood can act as the focal point of green infrastructures, gardens, yards, and other landscape elements [1-5]. Hence, wood could be preferred for multiple purposes in landscape architecture applications in interior and exterior spaces, creating options for designers for the place of use, usage expectations and desires thanks to its many types [1,3,5].

However, the use of wood in interior and exterior design is only possible with well-known wood materials. The use of the material in design disciplines will be possible by revealing its relations with other materials, extending its usage life, and revealing the properties of wood in terms of aesthetics and functionality [1,6,7]. Moreover, landscape architects should be considered environmental products that measure and verify the life cycle of products with the need to convince the people to do it. In this context, selecting the correct surface coating agent can enhance the beauty of wood pieces, which requires considering the dominant tones in the finish [1,4,5].

There have been numerous surface protective agents, available on the market. But it should be considered the right choice in forming a protective layer in accordance with the end use of the wood material. The most commonly used varnish types are two-component solvent-based (oily varnishes) that are usually cured by a combination of both physically and chemically [4,5, 8-10]. But these types of agents contain some toxic chemicals (volatile organic compounds; VOC), which are released (emitted) during the service of wood products. Therefore, many varnish types with more environmentally friendly formulations have emerged recently.

The water-based (waterborne) varnish systems, whose solvent is water instead of oil or alcohol, have become increased gradually in recent years [9,11,12]. Although these systems have some advantages over synthetic solvent-based varnish systems, they also have some drawbacks that their effectiveness is limited when applied to only a single layer, could cause some discolorations on certain woods (tannin contains woods), may not be effective for some wood types (resinous woods), and needs to apply multiple layers for effective protection. Numerous studies have already been conducted for selecting and application of wood substrates for outside use [1, 4,5, 9-13]. It was reported that hardwood and softwood species show a systematic trend to surface discoloration that occurs and is clearly visible as a natural texture with natural weathering progress. However, the degree of changes varies with different wood species [3-5].

Although numerous literatures can be found for surface protective agents for woods, a systematic approach for the application of water-based varnish systems on specific woods under outdoor conditions is clearly needed. To find out, selected wood specimens were subjected to waterborne varnish treatment and used to determine resistance against natural weathering conditions. After specific time to outdoor exposure, the level of photo-discoloration, surface hardness and water absorption properties were determined based on controls. Therefore, the objective of this study is to discuss some of the most common concepts of surface protection of wood in the context of weathering and suitability for outdoor use, emphasized in landscape applications. Their importance in predicting the selected wood-weathering interactions of two different species is discussed herein.

MATERIAL AND METHODS

Spruce (*Picea orientalis*) and Eastern Beech (*Fagus orientalis*) woods were selected for investigation. The spruce and beech woods were acquired from the Black Sea region in Turkey. The samples were cut into small pieces (5x5x1 cm) and dried in laboratory conditions to an air-dry level (12%) before the experiments. A waterborne type colorless varnish used in this study was purchased from a retail store. The varnish was used as an emulsion formulation that belonged to the company's prospective, as supplied without any further purifications.

The varnish applications on samples were carried out for two different procedures. In one procedure; in a soaking for 1 to 5 minutes, separately, then the drying was carried out at room temperature for 8 hours. In the second procedure, in a soaking for 1 to 5 times, separately, the drying was carried out in each stage for 2 hours and final drying in a room temperature for 8 hours. The all varnish-treated samples were soaked in distilled water at room temperature (23 °C, ±2) for 24 hours, and water absorption (WA%) was calculated. The water absorption measurements were made with a digital balance, accurate to ± 0.01 gr. After the termination of each experiment, the percentage maximum water intake was calculated by using the following equations:

$$\text{Max. water absorption (\%)} = 100*(\text{Wet weight - Oven dry weight})/\text{Oven dry weight} \quad (1)$$

The natural weathering tests were conducted on both control and waterborne varnish treated samples for three months of duration on the south side of Sobu Heights in Isparta, Turkey. The coating film hardness was determined by the pencil hardness (scratch resistance) test according to the standard ASTM D3363. This testing checks one standard for film hardness by comparing the ability of a graphite/clay pencil led to scratch the cured film. In the instrument, the pencil is held firmly against the film at a 45° angle and pushed away from the operator. The hardest pencil is applied first. The first pencil that does not mark the film before being marked determines the "pencil hardness" of the film. This is expressed by the number and/or letter denoting the hardness of the pencil.

Wood color studies are generally quantified by the CIE L*, a*, b* standard (1976) created by the Commission Internationale de l'E´clairage with a three-axis system, i.e., lightness (L*) from 0% (black) to 100% (white); a* from green (-a) to red (+a); and b* from blue (-b) to yellow (+b). The CIE color parameters of L*, a*, and b* were determined for un-weathered control and three month weathered samples by the CIE L,a,b (1976), and their corresponding variations with the treatments, i.e. ΔL*, Δa*, and Δb*, were calculated automatically by instrument. The total color difference of samples (ΔE*) with functions of L*a*b*, calculated as following equations;

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

A portable X-rite SP68 spectrophotometer was used to measure all colorimetry measurements of samples. The instrument was calibrated with white and black standards. The measurements were made using a D65 illuminant and a 10-degree standard observer. The three measurements for each treatment sample (conditions) of the wood species were made, and average color values were calculated. The surface whiteness and yellowness color properties were also determined according to standard ASTM E-313, and ASTM D-1925, respectively. The gloss measurements were carried out with the Glossgard II. gloss meter (60^0).

While many combinations were utilized during the surface treatment and natural weathering procedure of wood samples, some code numbers and abbreviations were established throughout the study, given in Figures and Tables. The wood samples shown in Figures and Tables are: B: Beech; S: Spruce; 1,2,3,4 and 5: one-, two-, three-, four-, and five-time coatings (number of coatings); a,b,c,d and e: control, one-, two-, three-, four-, and five minute soaked samples. Figure 1 shows some representative of small wood samples used in this study.

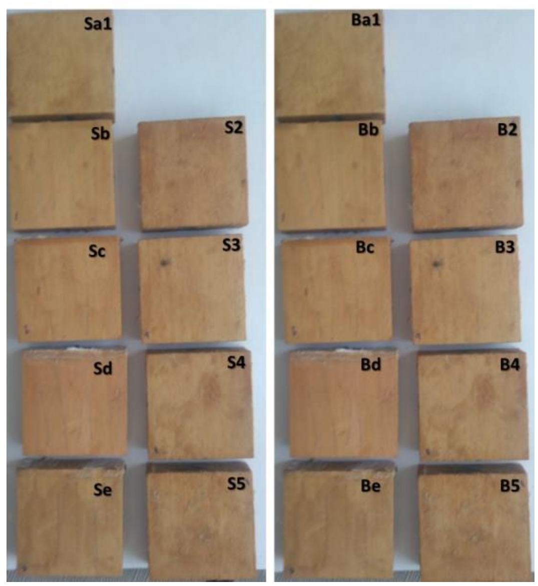

Figure 1: Control and treated small wood samples

RESULTS AND DISCUSSIONS

Wood-based design elements have been preferred in many architectural planning purposes due to their aesthetic properties. It has already well established that surface treated or natural wood can be degraded, especially those left outdoors for a long time, such as well examples are shown in Figure 2 (a-f). The Figure 2 clearly shows the desired appearances changed depends on the placement of sitting elements. As a result of those changes, the wooden sitting elements began to exhibit various level of discolorations after outdoor exposure (Fig.2c-f). In certain circumstances, the effects of atmospheric conditions (weathering or light radiation) are likely to play a considerably greater part for discoloration of wooden materials. The samples 2c, d, e and f appeared to show higher amount of color change compare to Fig. 2a, after outdoor exposure.

Figure 2: Outdoor exposured some clear coated wooden sitting elements (a, b and c: well protected sitting elements, d, e andf: peeled off transparent sitting units)

It is well known that water penetration into wood is very sensitive to the surface coating layer, and this must be taken into account for the measurement of the water intake. The water absorption properties of weathered spruce and beech samples at two different treatment conditions (Coating number and soaking time) in waterborne varnish are presented in Figures 3-4, respectively. It appears that there is a relatively inverse relationship with both treatment conditions for both types of woods. The highest water absorption of 111.7% was found for the spruce control sample (S0; untreated), while the lowest value of 4.8% observed with the fifth-time coated sample (S5). Increasing treatment time is also having positive effects, lowering water absorption (Figure 3).

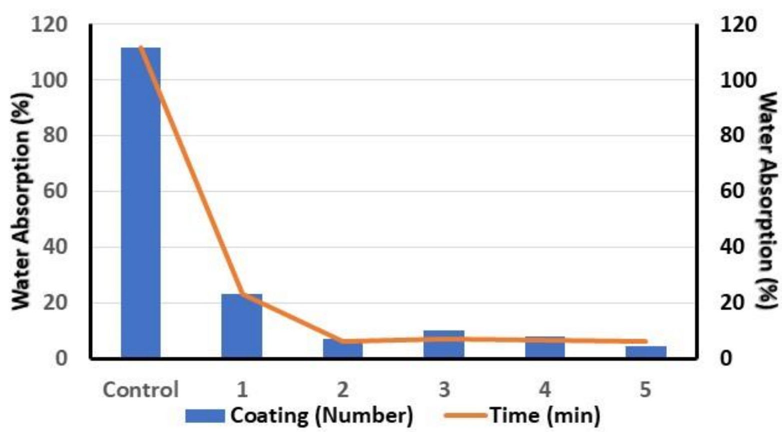

Figure 3: Treatment conditions effects on weathered spruce wood

Moreover, a less similar trend was also observed for beech woods (Figure 4). The lowest water intake of 1.7% found at the fifth-time coated sample (B5) which indicates approximately 97.2% lower value compared to the untreated control sample (B0). The increasing varnish treatment time also has further effects, lowering water absorption for beech samples. These results could be expected, considering lowering water absorption well correlated with coating layer thickness and/or varnish layer allowed to be deeper penetration into samples. These are also in good agreement with the results reported surface treatment agent variables and treatment conditions effects on wood substrates (2,4,5,14,15].

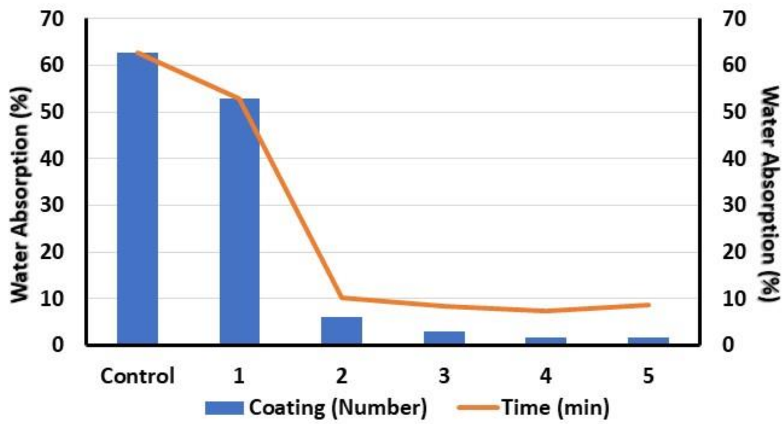

Figure 4: Treatment conditions effects on weathered beech wood

The resistance of varnish layers against scratching is usually called *surface hardness*. In this sense, the comparatively scratch resistance of spruce and beech woods, measured with a pencil hardness instrument, is given in Table 1. The control beech and spruce woods showed the highest hardness and were not affected by the weathering. The only one level higher scratch resistance was found for weathered Sa (4H) and Sb samples (5H), respectively. However, all weathered beech woods show one-level higher scratch resistance values at counterpart controls. Surprisingly, varnish-applied and then weathered samples had usually higher scratch resistance than control samples. It could be explained that the surface hardness (Pencil hardness test) is a property of a coating film, and measured hardness is influenced by the substrate hardness. It has already been well predicted that the harsh outdoor conditions could have effects on both chemically and physically. These changes could create tension on the surface before erosion and/or cracking, which may be increasing effects on surface hardness at various levels. The experimental results found in this study clearly support this hypothesis.

Table 1: The waterborne varnish treated samples subjected to weathering procedures

Spruce	Control	Weathered	Beech	Control	Weathered
S0	5H	5H	**B0**	6H	6H
S1	3H	4H	**B1**	3H	4H
S2	2H	2H	**B2**	2H	3H
S3	3H	3H	**B3**	2H	3H
S4	3H	3H	**B4**	3H	4H
S5	3H	3H	**B5**	2H	3H
Sa	3H	4H	**Ba**	3H	4H
Sb	4H	5H	**Bb**	2H	3H
Sc	3H	3H	**Bc**	2H	3H
Sd	4H	4H	**Bd**	3H	4H
Se	4H	4H	**Be**	2H	3H

The comparative CIE L*, a*, b* colour properties of protective coating applied and weathered wood samples are shown in Table 2. The measured results confirm that color properties changed considerably. For spruce wood; it can be seen that the increasing coating number has not any positive effects for lowering lightness values that all ΔL value found to be negatives. This clearly implies that wood surfaces turn to darkish color regardless of coating thickness. However, the similar results have also found with treatment time up to 3.0 min that beyond this level, the wood surfaces found to be lighter (ΔL: + values). The lowest ΔL value of -7.83 was found with sample Sc, followed by Sb (ΔL: -9.68) and S4 (ΔL: -3.69) while the lighter surfaces were found with samples Sd (ΔL: 2.73) and Se (ΔL: 9.17), respectively. For beech wood; the lightness properties of the samples from both procedures were found to be lowering (ΔL:- values) in all conditions and no any positive lightness values were found. Moreover, the lowest ΔL value of-9.78 was found for sample Be and followed by B4 (ΔL:-9.38) and B5 (ΔL:-9.0) while the lowest changes was found with sample B3 (ΔL: -5.38).

However it is notable that surface redness/greenish color properties (Δa*) of spruce samples show higher redness (Δa: + values) in all conditions than controls. The highest redness value of Δa: 1.81 was found with sample Sc followed by Se (Δa:1.80) and Sb (Δa:1.70), respectively. Like lightness, similar trend was also found for redness/greenish properties for beech samples that that beyond 3.0 min treatment time, the beech wood's surface found to be more reddish color. The more greenish like color was also found with sample Bb (Δa:-0.98) and followed by B1 and B3 (Δa:-0.78), respectively.

For yellowness/blueness properties (Δb*), for both spruce and beech samples show higher yellowness (+Δb) values than control in all treatment conditions. The highest yellowness value of Δb: 5.06 found for samples S1 and Sa for spruce and Δb: 6.97 found for sample Bc for beech. Surface whiteness (E-313) and yellowness (D-1925) values usually correlate CIE L*,a*,b* properties that all weathered samples show lowering whiteness while increaing yellowness color properties regardsless of treatment conditions for both spruce and beech wood samples. These results could be expected considering wood having different anatomical and chemical properties could influence treatments differently. Hence, it should be suggested that the different wood species might influence the wood-color interactions to some degree differently [1,9,13,16]. However, a number of researchers has already reported that yellow color of weathered woods was mainly due to oligomeric chromophores, which probably came from the chromophores of the lignin moiety and lignin is the main constituent responsible for the discoloration of woods [17].

Table 2: Surface color change of wood species exposure in outdoor conditions (Values in metric)

Samples	ΔL	Δa	Δb	E313 Whiteness	D1925 Yellowness
Spruce Woods					
S1	-3.07 (2.48)	0.99 (0.11)	5.06 (1.06)	-9.87 (2.62)	10.92 (1.11)
S2	-2.20 (0.62)	0.65 (0.24)	3.45 (0.20)	-6.29 (0.59)	8.37 (0.63)
S3	-2.94 (0.52)	0.88 (0.22)	3.08 (0.44)	-5.26 (0.62)	7.27 (1.69)

S4	-3.69 (0.36)	0.28 (0.24)	4.33 (0.71)	-7.20 (1.15)	10.53 (1.67)
S5	-0.19 (1.18)	0.28 (0.13)	4.11 (0.82)	-8.52 (2.22)	7.81 (0.89)
Sa	-3.07 (2.48)	0.99 (0.11)	5.06 (1.06)	-9.87 (2.62)	10.92 (1.11)
Sb	-7.68 (0.53)	1.70 (0.07)	4.97 (0.80)	-8.55 (1.59)	14.75 (1.47)
Sc	-7.83 (0.94)	1.81 (0.19)	3.83 (0.46)	-6.24 (5.15)	13.04 (0.68)
Sd	2.73 (0.31)	1.37 (0.48)	3.38 (0.74)	-5.31 (1.55)	11.78 (1.70)
Se	9.17 (0.80)	1.80 (0.24)	3.54 (1.54)	-5.01 (3.23)	13.37 (2.52)
Beech Woods					
B1	-5.55 (2.53)	-0.78 (0.51)	6.13 (1.28)	-12.52 (3.42)	13.85 (0.40)
B2	-5.79 (0.67)	-0.69 (0.64)	5.30 (0.80)	-10.32 (1.24)	12.67 (2.64)
B3	-5.01 (1.34)	-0.78 (0.18)	4.9 (0.27)	-9.85 (0.67)	11.32 (1.14)
B4	-5.84 (0.42)	-0.8 (0.42)	4.7 (0.12)	-9.18 (0.09)	11.47 (0.14)
B5	-9.0 (1.89)	-0.44 (0.32)	4.44 (0.35)	-7.56 (1.13)	14.61 (1.56)
Ba	-5.55 (2.53)	-0.78 (0.51)	6.13 (1.28)	-12.52 (3.42)	13.85 (0.40)
Bb	-6.67 (0.72)	-0.98 (0.23)	5.99 (0.18)	-11.70 (0.14)	14.43 (1.62)
Bc	-8.06 (2.09)	0.12 (0.88)	6.97 (0.32)	-12.86 (1.23)	18.18 (2.54)
Bd	-9.38 (0.69)	0.67 (0.09)	6.06 (0.46)	-10.71 (1.07)	18.07 (0.36)
Be	-9.78 (1.97)	0.61 (1.05)	6.06 (0.74)	-10.55 (1.95)	18.33 (2.40)

*The numbers in parentheses are standard deviations

Many researchers suggested that ΔE was could be a better predictor than CIE, L*,a*,b* for most property of woods [17-20]. The surface total color difference (ΔE) of wood substrates appeared to be well correlated with coating number and duration time for spruce and beech woods (Figure 5). However, beech wood appeared to more sensitive for discoloration than spruce wood at similar treatment conditions. These comparisons between the treatment variables and the measured results reveal that the color-change response of a wood can be accurately predicted based on the treatment conditions.

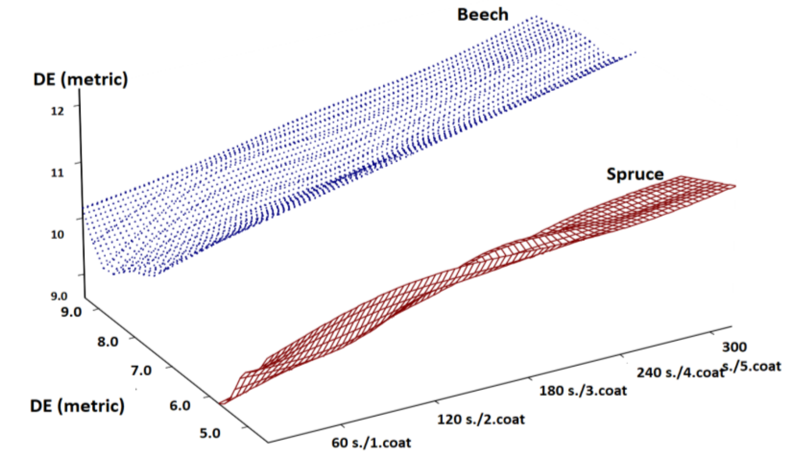

Figure 5: Surface coating conditions effects on total color changes (ΔE) of spruce and beech wood

The measured color values presented above are clearly indicated that the color changes of a coated wood substrate are a phenomenon and contains many variables (e.g., wood-based, varnish-based, treatment condition-based) and very difficult to explain all changes in a one way. But it is clear that color modification could be decreased by choosing optimal treatment conditions.

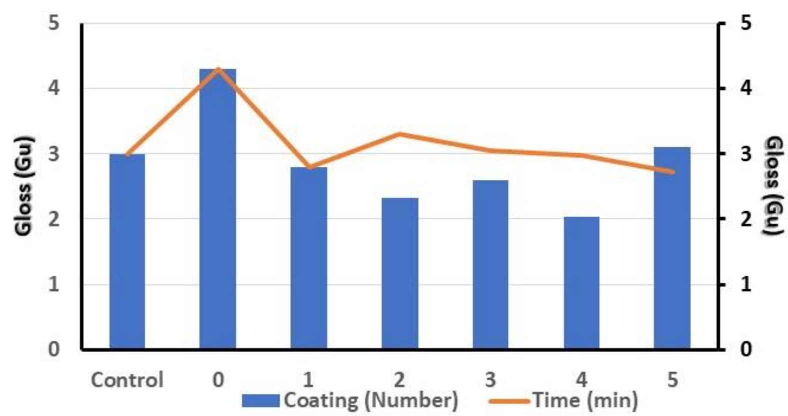

Figure 5: The coating conditions effects on glossiness (Gu) of weathered spruce wood

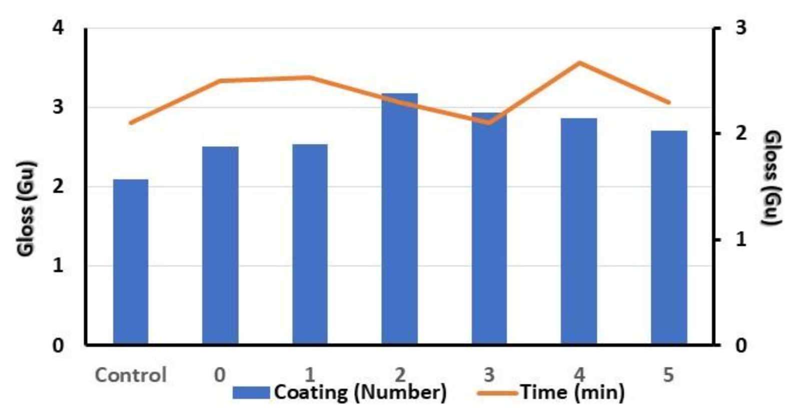

Figure 6: The coating conditions effects on glossiness (Gu) of weathered beech wood

A comparative summary of the surface glossiness changes of weathered samples with varnish treatment (coating time and number) are shown in Figure 5 (for spruce) and Figure 6 (for beech). It could be seen that increasing coating number not effective for protecting gloss properties for spruce wood. Similar trend was also found with coatings that increasing coating layer is not effects protecting glossiness. The highest gloss value of 4.3 Gu was found with only one minute and only once coated control spruce sample. However, some variations in glossiness for beech wood could be realized by changing the treatment parameters. In general, increasing coating layer provides effective protection of glossiness up to three level (3.17 Gu) then it is decreases. Moreover, it appears to be some level correlated with treatment time as well.

CONCLUSION

The wood consumers and producers have become to avoid the use of toxic chemicals in their close environments. In this respect, development of new technologies based on low environmental impact agents and sustainable principles are emerging issue in recent years. Waterborne varnish which contains reduced toxic solvent in its formulations have become favor surface coating agents in many applications. However, experimental results show how beech and spruce wood species respond in real time at environmental conditions according to surface clear coating variations, changing their surface properties. These issues are very important during urban furniture establishments with wood-based elements while it may affect the integrity of the wooden components and, ultimately, the integrity of the entire design practices. The experimental results clearly stated that water intake and surface discoloration usually correlated with number of coatings and varnish treatment durations. This may very important and should be considered when established wooden landscape design elements to outdoor condition.

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