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A STUDY ON SUITABILITY OF SOME WOOD SPECIES FOR LANDSCAPE APPLICATIONS: SURFACE COLOR, HARDNESS AND ROUGHNESS CHANGES AT OUTDOOR CONDITIONS

Candan Kus Sahin[1], Mehmet Topay[1], Ahmet Ali Var[2]
[1]Suleyman Demirel University
Turkey
[2]Isparta University of Applied Sciences
Turkey

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ABSTRACT

In this study, each of the commonly used two types of woods (softwood and hardwood) from five species was studied. All wood species show a systematic trend to change to higher values of surface roughness with natural weathering progress. The Black pine, Calabrian pine and beech wood samples show a more or less smooth trend, whereas basswood gives the highest surface roughness changes under all conditions. However, the hardwood species, except basswood, have higher hardness properties both initially and at the end of weathering process when compared to softwoods. The surface discoloration that occurs is clearly visible as a natural texturing. However, the degree of, and the pattern of texturing, may vary with different kinds of woods; the color changes also vary to some extent. It was revealed that the discoloration is strongly dependent on the botanical origin of wood species. The lower lightness changes (ΔL %) were found for all three pine species (16.2 to 37.2%) when compared to fir (54.9%) and spruce samples (91.8%). The Scotch pine wood showed highest values for the contribution of red color initially and low redness change on the surface after the weathering process, among the other softwood species.

KEYWORDS: Wood, landscape practices, color, weathering, discoloration, CIE lab.

INTRODUCTION

Wood was one of the earliest materials to serve as a source for shelters, weapons, and energy for the early nomadic cultures. The knowledge of early wood use is based on fragments, drawings, and other conserved representations. Indeed, wood as a feature used in the landscape can be found in nearly all cultures throughout history. Even in very early times (i.e., stone and masonry cultures), it was used in the construction of some garden structures (i.e., pergolas, arbors, boxes, fences) (Winterbottom 2000). Its wide range of versatility includes: warmth and richness, light weight, ability to span long distances, and workability takes people back to the landscape. Thanks in part to its natural origin with aesthetic features, wood is also well suited to apply in many landscape practice implementations (Auer 1982, Cristoforo 1976, Sahin and Onay 2020, Skarvelis and Mantanis 2013, Winterbottom 2000).

However, unprotected wood that absorbs solar UV light undergoes a color, texture and usually, physical changes. These changes result in its degradation when exposed to the weather conditions (Hon, et al. 1985, Kržišnik et al. 2018, Oberhofnerová et al. 2017, Sahin and Mantanis 2011). But, the level of degradation ranges from marginal surface discoloration affecting the aesthetic appeal to extensive loss of mechanical properties. The discoloration of wood at the outside usually called "non-microbial" discolorations, differ from fungal activity (Cassens and Feist 1991, McDonald et al. 1996).

However, one of the important problems when using of wood in atmospheric conditions is the uneven discoloration of the wood surface, which appeared mostly as aged of the outdoor-used woods while the surface layer darkened in natural color (Lykidis et al. 2016, Sahin and Mantanis 2011). Chang et al. (2015) have utilized wood waste with gypsum as binder to produce a new type of bricks for construction purposes. They measured the sunlight effects on those wood-based materials to change the color (hue) characteristics. They reported that these allotropic bricks can be applied to the external walls of buildings, providing landscape friendly buildings. Lo Monaco (2015) performed colorimetric analysis on aging treated (light exposure up to 504 hours) coppices of beech wood with using the CIE L*a*b* system in order to predict the wood color characteristics as a function of the exposure time, and vice versa to assess the exposure time needed to obtain the desired color coordinates. They found that beech wood from aged coppices in central Italy has interesting qualitative features, suggesting a more profitable use of their wood for various outside applications rather than being used for firewood. Tolvaj and Mitsui (2010) investigated irradiation characteristics of beech (*Fagus crenata* Blume), Black locust (*Robinia pseudoacacia* L.), Japanese cedar (*Cryptomeria japonica* D. Don) and spruce (*Picea abies* Karst.) woods by sunlight, xenon light and mercury vapor light. It was found that the samples showed a rapid color change during the initial period of treatment but the rate of change decreased with treatment time. Kannar and his group (2018) found that the yellowness properties of spruce wood's changed (increased) at outdoor conditions while the leaching partly removed the yellow and red chromophore molecules generated by the UV radiation. But the samples shown slightly lighter after water leaching.

Although plenty of literature can be found for color characteristics of wood samples that are used indoors or under outdoor conditions, a better understanding of specific wood discoloration under outside conditions is clearly needed. To find out, selected wood specimens were used to determine resistance against weathering conditions. After specific time to atmospheric exposure, the level of photo-discoloration was determined based on degrees of discoloration, surface roughness and hardness changes of the selected woods listed below.

MATERIALS AND METHODS

In the present study two types of wood (softwood and hardwood) of five species were used. The softwood species of scotch pine (*Pinus sylvestris*), Calabrian pine (*Pinus buritia*), black pine (*Pinus nigra*), Uludag fir, (*Abies bornmulleriana*), spruce (*Picea orientalis*), and the hardwood species of cherry (*Prunus avium*), chestnut (*Castanea sativa*), beech (*Fagus orientalis*), basswood (*Tilia Americana*) and oak (*Quercus alba*) were selected for the experiments. The three small samples of each wood species were cut in the form of 60 x 60 x 10 mm pieces and conditioned at 20°C and 65% relative humidity in controlled room conditions to reach air dry moisture content of 12% level.

The natural outdoor exposure (weathering process) was conducted at the south side of a park (Cunur park) located in Isparta city, Turkey. The specially prepared samples were aged for a 12 months period. The measurements were taken after of six and 12 months, respectively. For the colour measurements, the radial surfaces of samples were used in order to determine the appropriate colour properties of samples.

To evaluate the surface quality of the wood samples of the different species after natural weathering conditions, there are a range of methods to measure surface roughness of wood species such as; simple touch on surface, macroscopic view and microscopic determination on the surface. However, "true measurement" of surface roughness requires a calibrated means of determining the peaks and valleys of the surface being evaluated. The value given is typically an average based on the distance of the area measured and the heights of the peaks and valleys. For that reason, surface roughness measurements were done with a Contact Stylus Profilometer type Time TR 200 device. With this equipment it is possible to build a two-dimensional surface profile after a direct measurement of the necessary parameters. The root-mean-square deviation of the profile, (Pq) was utilized to analyze surfaces. All the definitions used and parameters measured or calculated in this study are given in ISO 4287 (1998) and DIN 4768 (1990) standards.

The discoloration of wood specimens was determined using a color spectrophotometer (X-Rite SP 968 Spectrophotometer). Measurements were made using standard illumination and a standard observer. The CIE L*a*b* color scale (CIE, 1976), where L* stands for lightness, a* stands for redness, and b* stands for yellowness, was used to quantify the changes in color. The color variables of the surface layer of woods, and the difference in color, ΔE*, between them, were determined. The surface whiteness and yellowness color properties were also determined according to standard ASTM E-313, and ASTMD-1925, respectively.

The shore hardness, like many other tests, measures the depth of an indentation in the material created by a given force on a standardized presser foot. This depth is dependent on the hardness of the material and its viscoelastic properties. A Shore Hardness (Scale D) instrument was utilized to measure the hardness properties of the wood samples. The tests were conducted according to the ASTM D2240 standard. This test allows for a measurement of the initial hardness and for the indentation hardness after a given period of time. The surface hardness properties of wood samples were measured for each direction; five measurements were made of each sample.

RESULTS AND DISCUSSIONS

Tab. 1 summarizes the surface roughness changes against control (%) of wood species (0 months) under natural weathering (six and 12 months) conditions. It is observed that the one month exposure of wood species leads to some level of increase in surface roughness.

Tab. 1: Surface roughness change (%) of wood species at weathering conditions.

	0 month (Control, μm)	1 month	6 months	12 months
Softwoods				
Scoth pine	1.32	21.3	515.9	N/A
Black pine	3.92	18.4	20.9	58.9
Calabrian pine	2.83	37.1	91.3	271.1
Fir	2.33	59.2	95.3	N/A
Spruce	2.13	96.2	165.8	N/A
Hardwoods				
Chestnut	1.13	102.2	155.9	N/A
Cherry	3.54	72.8	75.4	N/A
Beech	3.34	25.8	69.6	74.7
Basswood	6.08	N/A	N/A	N/A
Oak	1.28	31.4	216.3	N/A

The lowest surface roughness changes were observed with Black pine (18.4%) following by scotch pine (21.3%), beech (25.8%), Calabrian pine (37.1%), oak (31.4%), fir (59.2%), cherry (72.8%), spruce (96.2%), and basswood (N/A) respectively. It appears that different wood species undergo considerable different surface roughness (%) changes. However, all wood species show a systematic trend to higher surface roughness values with prolonged natural weathering progress. The maximum surface roughness changes were obtained after 12 months weathering conditions in all wood species. Under those conditions, except Black pine (58.9%), beech (74.7%), and Calabrian pine (271.1%), show theoretically immeasurable surface roughness values (out of measurable range of 400 μm) which is change greater than 1000%). It has already been explained by a number of researchers that the wetting and drying cycles of wood exposed outdoors could result in rough surfaces caused by typically raised grain (Cassens and Feist 1991).

However, the characteristics of surface roughness are very complicated and not well understood for most wood species. To determine the causes of roughness one has to understand factors such as: wood cell wall structure, humidity conditions, annual ring orientation and density. These factors have a pronounced impact on surface roughness changes as reported in literature (Cassens and Feist 1991, McDonald et al. 1996). Hence, variations among surface roughness properties of wood specimens were very complicated and it is not intend to explain all changes. But, it is reasonable to explain that outdoor conditions could cause complex interactions resulting in slowly breaking down wood constituents and weakening fiber bonds. Moreover, moisture fluctuations cause surface layers to swell and shrink in addition to contraction due to degradation, while stable deeper layers restrain these movements, so that weakened fiber bonds fail and result in surface erosion and deformations. But it is noticeable that, black pine, Calabrian pine and beech wood show a more or less smooth trend whereas basswood shows the highest surface roughness changes (very easy to change surface roughness properties) under all conditions.

Fig. 1 shows the comparative hardness changes of wood species against natural weathering process. As seen in Fig. 1, the prolonged outdoor exposure beyond 6 months has further deteriorating effects on all wood species.

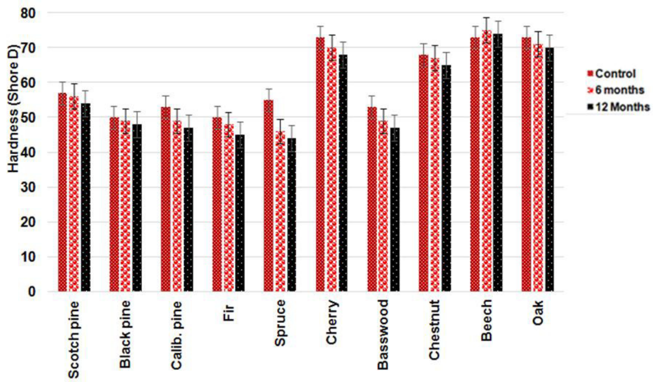

Fig. 1: Surface hardness change of wood species at various conditions.

As expected, hardwood species except basswood have higher hardness properties initially while at the end of weathering process the hardwoods properties compare to those of softwoods. However, after the 12 months natural weathering process, the highest hardness values for hardwoods were determined for both oak (73) and beech (70) and followed by cherry (68), chestnut (65) and basswood (47) species, respectively. On the other hand, after the 12 months natural weathering process, the highest hardness values for softwoods were exhibited by scotch pine (54), followed by Black pine (48), Calabrian pine and fir (47), and spruce (44) species, respectively. It is noticeable that after the 12 months natural weathering process, softwood species showed 4.0 to 20.0% hardness reduction whereas hardwoods showed 4.2 to 11.3% hardness reduction. The results found in this study are clearly consistent with literature findings that the hardwoods usually have higher hardness values initially and are more resistant to outdoor conditions than softwoods.

Wood used in landscape applications, such as; for pergolas, fences, decks, containers, tables, boxes, could create its own appearance. However, it has already been mentioned above that wood used under outside conditions have under gone complex photo degradation reactions to lose of its beauty and aesthetic appearance (discoloration). The brightest woods turn a dark color, but in the short time all species turn into various color combinations. These changes happen because of the action of light, moisture and temperature. It is realized that surface discoloration and erosion, can be visible as natural texturing, takes place. Discoloration of woody material may result in loss of quality and value of the wood. As seen in Fig. 2, even exposure for short duration of time to atmospheric conditions, occasionally produce discolored woods. The degree of, and the pattern of texturing may vary with different kinds of woods, as do the extent of roughness and color modification.

Fig. 2: Surface natural appearance of wood species at various conditions: A- Control, B- one month, C- six months, D- 12 months of natural weathering durations at outside.

For better understanding and quantification of discoloration level of wood species after exposure to atmospheric conditions, spectrophotographic measurements were done and results presented in Tab. 2 for softwood species and in Tab. 3 for hardwood species, respectively. According to the results from the color measurements, the discoloration is strongly dependent on the botanical origin of wood species (Tab. 2, Tab. 3). However, it is important to note that the differences in color values measured in this study were not necessarily all so large that they could be considered to be unacceptable by the end-users of wood.

The lightening as a result of natural weathering was clearly shown in Tab. 2. However, the lower lightness changes (ΔL^*) were found for all three pine species (16.2 - 37.2) compare to fir (54.9) and spruce samples (91.8). It is well known that light-colored wood specimens underwent photo-bleaching reactions when exposed to weathering conditions. The results found in this study are in good agreement with earlier findings (Esteves et al. 2008).

Tab. 2: Surface colour change of softwood species at various conditions (weathered at 12 months duration).

Species	ΔL	Δa	Δb	ΔE (Metric)
Scoth pine	32.3	31.1	44.4	34.3
Black pine	16.2	61.6	35.4	31.2
Calib. pine	37.5	57.8	54.4	48.6
Fir	54.9	41.6	60.5	58.5
Spruce	91.8	40.9	44.1	48.2

The Scotch pine wood showed highest values for the contribution of red color initially and low redness change (Δa*= +4.4 to +3.03; 31.1% change) on the surface after weathering process, among the other softwood species. However, the color coordinates of yellow (+b) to blue (-b) of wood samples also displayed exhibited a high variations. Interestingly, natural weathering favored a dramatic reduction of yellow color for fir wood (Δb* = 14.6 to 5.77; which equals a 60.5% change). Tolvaj and Faix (1995) reported that the yellow color of wood was mainly due to the lignin moiety of the wood. However, the effects of wood cell wall chemicals on the color of wood are very complicated and beyond the bounds of this study to explain.

A number of researchers have already proposed that ΔE (total color differences) could be a better predictor than ΔL*, Δa* and b* for most color properties of woods (Chang et al. 2015, Janin et al. 2001, Lo Monaco 2015, Tolvaj and Mitsui 2010). However, the softwood substrates appeared to be better correlated with ΔE than the other color (Δa and b) parameters. Moreover, for softwood species, the ΔE values showed a trend that was somewhat similar to that of ΔL*, Δa* and b* values. The highest ΔE of 58.5 was found for fir wood, followed by Calabrian pine (48.6), spruce (48.2), Black pine (34.3) and Scotch pine (31.1) species, respectively. These comparisons between the surfaces and the measured results clearly reveal that the color-change response of a wood can be accurately predicted based on the ΔE values.

The marked effect of surface color changes for hardwood species with natural weathering conditions are also clearly evident in Tab. 3. However, the results in Tab. 3 confirm that surface color properties of the woods from the hardwood species were found to be very high. This is probably due to the fact that hardwoods have more dark color initially; hence the discoloration is higher compared to softwood species. These results are clearly consistent with literature findings (Kucuktuvek et al. 2017, Oberhofnerová and Pánek 2016).

Moreover, the explanation of discoloration patterns of hardwoods looks like they were complicated since the general characteristics of the smaller the initial L* value of hardwoods. The high ΔL* values (changes %) were found for beech (-146.1), followed by oak (-9.7) and cherry (-8.9), respectively. In contrast, basswood and chestnut species show some lightness increases. It has already been explained that the discoloration of dark-colored wood specimens (i.e. hardwoods) are much more complicated, whereas these patterns shifted slightly toward those observed for light-colored woods (Sahin, et al. 2011).

Tab. 3: Surface colour change (%) of hardwood species at various conditions (C- control, W- weathered at 12 months duration).

Species	ΔL	Δa	Δb	ΔE (Metric)
Cherry	-8.9	-18.9	40.9	15.4
Basswood	62.8	48.1	92.2	75.3
Chestnut	23.1	-6.5	36.4	31.3
Beech	-146.7	-254.1	-4.1	63.3
Oak	-9.7	47.9	81.8	49.1

However, the ΔE shows a systematic trend to higher values for hardwoods compared to softwood species. The maximum ΔE changes were found for basswood (75.3), followed by beech (63.3) and oak woods (39.3), respectively. In addition, very low ΔE changes (15.4) were found in the cherry samples.

It is important to repeat that the discolorations are not well understood for most wood species. To determine the causes of discolorations one has to understand factors such as: wood chemical composition, ambient temperature, humidity, and light conditions. Hence, variations among discoloration patterns of wood specimens are complicated and this study does not intend to explain all these color characteristics. It should be also emphasized that the determination of the Δa* and Δb* values must be considered as being only suggestive.

Fig. 3 shows whiteness and yellowness changes of wood species after a weathering process. It should be realized that the whiteness and yellowness reduction more or less followed a similar trend for both softwood and hardwood species. However, it can be also found that hardwood species (except basswood) have usually less whiteness and yellowness values compared to softwood species.

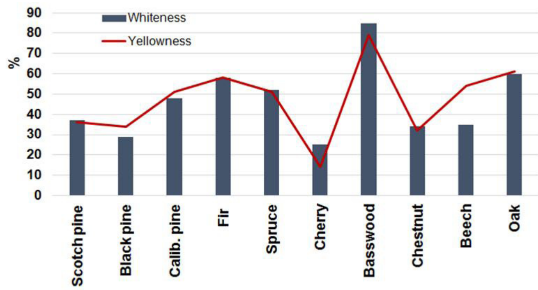

Fig. 3: Whiteness and yellowness properties of woods after weathering process (12 months).

The highest whiteness values were found to be for basswood (84.8%) followed by oak (59.7%), fir (58.2%), spruce (52.4%), Calibrian pine (48.1%), Scotch pine (36.9%), beech (34.5%), chestnut (33.6%), Black pine (29.3%), and cherry (24.8%), in that order. A more or less similar trend was also found for whiteness values. The highest yellowness were found to be for basswood (79.2%) followed by oak (61.3%), fir (58.3%), beech (53.6%), Calabrian pine (51.3%), spruce (51.1%), Scotch pine (36.1%), Black pine (34.3%), chestnut (31.7%), and cherry (14.2%), in that order. As mentioned above, this is also in good agreement with literature findings that the hardwoods that have more dark color initially resulting in discoloration that is usually higher compared to softwood species (Hill 2006, Palashev 1994). But, the discoloration patterns of wood are complicated since many variables affect the natural color of wood. Moreover, a number of attempts were conducted on the effects of outdoor conditions on color modification of woods. Consistently, weathering processes make the wood surface darker (Dirckx et al. 1992, Hill 2006, Palashev 1994, Pastore et al. 2004).

CONCLUSIONS

An attempt was made to analyze wood surface property changes due to exposure to natural outdoor conditions of the most frequently traded wood species in Turkey and all of Europe. However, the natural surface appearance and color of wood are very important quality criteria in the utilization, especially for outdoor applications (i.e., landscape architecture). It has been clearly revealed that the susceptibility to surface appearance change (roughness, hardness and discoloration) is variable and strongly dependent on the botanical origin of species as well the nature of the wood itself.

It is observed different wood species undergo considerable different surface roughness (%) changes. In 12 months, weathering conditions black pine, beech, and Calabrian pine show very high surface roughness values. However, at this level of weathering, it is also observed that softwood species showed 4.0 to 20.0% hardness reduction whereas hardwoods showed 4.2 to 11.3% hardness reduction. However, the Scotch pine wood showed highest values for the contribution of red color initially and low redness change (Δa^*= +4.4 to +3.03; 31.1% change) on the surface after weathering process, among the other softwood species. The softwoods look like well correlated with ΔE than the other color (Δa and b) parameters while the ΔE shows a systematic trend to higher values for hardwoods compared to softwood species. It can be concluded that except for basswood, hardwoods are more suitable species for using under outdoor conditions rather than softwood species when surface hardness properties are considered.

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Candan Kus Sahin*, Mehmet Topay
Suleyman Demirel University
Faculty of Architecture
Department of Landscape Architecture,
32260 Isparta
Turkey
*Corresponding author: candansahin@sdu.edu.tr

Ahmet Ali Var
Isparta University of Applied Sciences
Faculty of Forestry
Department of Forest Products Engineering
32040 Isparta
Turkey