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EFFECT OF NATURAL AGING ON SELECTED PROPERTIES OF WOODEN FACADE ELEMENTS MADE OF SCOTS PINE AND CHESTNUT

Elif Topaloglu[1,♠]

https://orcid.org/0000-0003-4736-8702

ABSTRACT

Identifying wood species of each wood element of a historical wooden building and investigating the changes in wood properties due to exposed outdoors during its service life are important prerequisites for the maintenance and renovation of historical wooden buildings. In the present study, the changes in wood properties occurring during natural aging of two facade elements taken from a traditional house, which has a service life of approximately 100 years, were investigated. Destructive tests were used for the experiments. The wood species, moisture content, wood density, water absorption rate and chemical structure of both facade elements were determined. Microscopic analysis revealed that the molding was made from the wood of Scots pine (*Pinus sylvestris*) and the window jamb was made from chestnut (*Castanea sativa*). It was found that the cellulose and lignin on the outer surface of aged woods of both facade elements were degraded according to the FTIR analysis. The moisture and density values of aged wood for both facade elements were smaller than those of recent wood. The water absorption rates of aged woods of both molding and window jamb increased with natural aging.

Keywords: Chestnut, natural aging, Scots pine, weathering, wooden facade elements.

INTRODUCTION

Wood, a natural and sustainable material, is becoming more and more a popular material for exterior use. The number of constructions making wooden facades, terraces and other outdoor wooden elements is increasing. This trend has also been achieved in urban areas, and is symbolized by street furniture, wooden elements inside playgrounds, facade elements, small permanent and temporary structures (Osvaldova 2020). Although, wood has several inherent advantages compared to other materials such as concrete, stone, metals, clay, plastics, brick, it also has negative properties as biodegradability, weathering and flammability (Reinprecht 2016). Every day, throughout the year, buildings are exposed to important and evolving climate types such as ambient infrared heat radiation, solar radiation, low and high temperatures, wind, erosion, water, and time (Jelle 2012, Evangelisti *et al.* 2022). Solar radiation and water have the definite effect on weather aging of wood, and also oxygen, dust, strong wind and extreme temperatures increase the aging of wood (Reinprecht 2016). In this process, which is defined as outdoor weathering, the original surfaces of the wood become rough, the wood fibers split and turn into large cracks, the fibers may loosen, the boards may warp and pull away from fasteners. The roughened surface changes color, dirt and mildew form, splinters and fragments appear on the wooden surface (Feist 1983).

Wooden facade elements, especially in traditional wooden structures, are often affected by the above-mentioned outdoor weather factors. In addition to the damage caused by these factors, mechanical and biological damages may also occur during the service life of the structure. Therefore, knowledge of the aging process of naturally aged wood is important in terms of deciding whether to repair or replace the aged wood. Especially,

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[1]Giresun University. Technical Sciences Vocational School. Architecture and Urban Planning Department. Giresun, Turkey.

♠Corresponding author: elif.topaloglu@giresun.edu.tr

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the identification of wood species, the determination of wood moisture content, and the determination of the areas of biological or fire damage are among the necessary steps for the assessment of a historical wooden structure. Moisture content measurements would be useful in determining the degree of biological risk of each wooden element and the local environmental circumstances (Cruz *et al*. 2015). Issues such as wood anatomy, macro and microstructure of wood, chemical composition of wood are important in terms of how the wood behaves in use and decay process (Larsen and Marstein 2016). However, water penetration and drying of wood are important factors affecting the expected service life and performance of wood (Kutnik *et al*. 2014).

To date, the comprehensive studies reporting the effects of aging on wood and the change in wood properties of wood exposed to natural weathering have been reported in the review article by Kranitz *et al.* (2016) and Kropat *et al.* (2020). It is also understood that the results obtained in the light of the two comprehensive literature studies mentioned are different due to reasons such as the structure of the wood material, its service life, the external factors to which the wood exposed, site conditions, etc. Determining the change in wood properties during the service life of wood materials used in historical or traditional wooden structures is important for both the conservation of cultural heritage and the reuse of naturally aged wood. The objective of this study is to investigate the effects of natural aging on the material properties of naturally aged woods taken from a nearly 100-year-old traditional house, and to compare change of the main wood properties between recent and naturally aged Scots pine and chestnut woods.

MATERIALS AND METHODS

Materials

Two naturally aged facade elements were taken from outdoor part of a traditional house in Zeytinlik District, which was registered as an urban protected area in Giresun (40°55’ north latitude - 38°23’ east longitude), Turkey. These wooden elements were exposed to outdoor conditions. As a result of the macroscopic examinations, it was determined that these original wooden elements, approximately 100 years old, were not exposed to any biological damage, there were a few nail holes on them, color change was observed due to exposure to ultraviolet light (UV) degradation and natural weathering conditions, the surface was quite rough, and there were remnants of paint that had almost disappeared on the surface (Figure 1). Molding and window jamb are the facade elements that play an important role in the appearance of traditional Zeytinlik houses in Giresun, Turkey. Aged wood elements were cut in accordance with the specimen sizes specified in the relevant standards. Recent wood was also cut to compare the density values, moisture content and water absorption rates of aged wood. Prepared wood specimens were conditioned in a climatic chamber (20 °C ± 2 °C temperature and 65 % ± 5 % relative humidity) until they reached 12 % humidity.

Figure 1: Visual appearance of aged wooden materials.

Wood identification and determination of anatomical features

For wood identification, wood specimens of 1 cm × 1 cm × 1 cm dimensions were prepared from both wood elements and thin slices were taken from three sections (transverse, radial and tangential) using Reichert slide microtome. These slices were washed with distilled water after exposure to sodium hypochlorite for 5 min - 10 min. One to two drops of acetic acid were added to equilibrate the pH and washed again with distilled water. After, the slices were stained in safranin 0 solution and then were taken into 50 % alcohol-water mixture. Permanent preparations were made by performing standard preparation procedures (Ives 2001). The microphotographs of all three sections were taken with Olympus BX 50 digital photomicroscope and transferred to the computer. The anatomical features of each wood specimen were compared with reference collection of the KATO (Karadeniz Technical University, Herbarium) wood collection, Merev (1998) and InsideWood database (InsideWood 2018). All anatomical terms were used according to the usage of the IAWA Committee on Nomenclature (1964). Wood anatomical features analyzed are: *transverse section*-tangential and radial vessel diameter in early wood and late wood, tangential and radial tracheid diameter in early wood and late wood; *tangential section*-ray frequency (per mm), ray width and ray height. Thirty measurements or counts were performed for each anatomical feature.

ATR-FTIR (Attenuated Total Reflectance-Fourier Transform Infrared) spectroscopy analysis

The ATR-FTIR spectra of aged wood specimens were measured with Pike MIracle ATR equipped with Shimadzu IR Prestige-21 FTIR device. Absorbance values were recorded with measuring range 600 cm^{-1} - 4000 cm^{-1}, with a resolution 16 cm^{-1} and 24 scans. Spectrum scans were performed on the specimens taken from outer surface which is exposed to natural weathering conditions, and from the inner surface which is not exposed to these conditions.

Determination of moisture content (MC) and wood density

The mass and dimensions of the conditioned aged and recent wood specimens were measured and recorded. Their moisture content was determined using the oven-dry method according to TS ISO 13061-1 (2021). Wood density test was carried out according to TS ISO 13061-2 (2021) standard. Density value (kg/m^3) was determined using the mass (kg) to volume (m^3) ratio formula at 0 % and 12 % MC. Fifteen test specimens were used to determine moisture content and wood density.

Water absorption rates

The oven-dried wood specimens were placed in a beaker filled with pure water. Fifteen test specimens were used for each group. The soaking time was applied for 2 h and 24 h and then every 48 h. The weight and dimensions of the specimens taken from the water were measured. Afterwards, the specimens were placed back into the beaker with renewed water. This experiment lasted a total of 13 days. Water absorption rate (WA, %) of each group was calculated according to Equation 1 (Tomak *et al.* 2011).

$$WA = \left(\frac{W_2 - W_1}{W_1} \right) x100 \qquad (1)$$

Where W_2 = wet weight (g), W_1 = initial dry weight (g)

Statistical analysis

In the present work, Independent-Samples T Test was performed at 95 % confidence interval to determine the differences between the means of aged and recent wood specimens. Statistical analysis was performed using the SPSS Statistics 23.0 program.

RESULTS AND DISCUSSION

Wood identification and anatomical features

As a result of microscopic analyses, it was determined that the wood element used as a window jamb was chestnut (*Castanea sativa* Mill.), and the one used as molding was Scots pine (*Pinus sylvestris* L.). Scots pine and chestnut are the most commonly used wood species in many parts of traditional wooden structures in the Eastern Black Sea region of Turkey. Figure 2 shows the transverse section, radial and tangential sections of *Castanea sativa* and *Pinus sylvestris* as a result of observations made by light microscopy. *C. sativa* and *P. sylvestris* trees are among the main tree species that grow in Turkey. These tree species also grow in the city where the research area is located, and it is known that especially chestnut is used in the construction of many traditional wooden structures. Mean values of anatomical features of window jamb and molding wood specimens are shown in Table 1. The wood of *C. sativa* is "ring-porous" and the large diameter early wood vessels were scattered one by one (Figure 2a, Figure 2b). The radial diameter of early wood (209,34 µm) was greater than the tangential diameter (181,72 µm) and also the radial diameter of late wood (47,14 µm) was greater than the tangential diameter (37,77 µm). Rays are homogeneous, uniseriate homocellular rays (Figure 2e), and their frequency in 1 mm was 9 (Table 1). Growth rings *P. sylvestris* were distinct, late wood tracheids were thick-walled and narrow-lumened. There was abrupt transition from early wood to latewood (Figure 2f, Figure 2g). Rays are uniseriate and heterogeneous (Figure 2i). The ray frequency in 1 mm was 4 (Table 1). There was cross-field pitting window-like in radial section (Figure 2h). The obtained data of both wood species were compared to recent wood. The data related to recent wood features were provided from relevant literature: *P. sylvestris* (Yaman 2007), *C. sativa* (Merev 1998). It was determined that the data obtained of the aged wood were among the values specified according to the above-mentioned literature data. In addition, no change or degradation was determined in the anatomical structure of both wood species that can be attributed to natural aging.

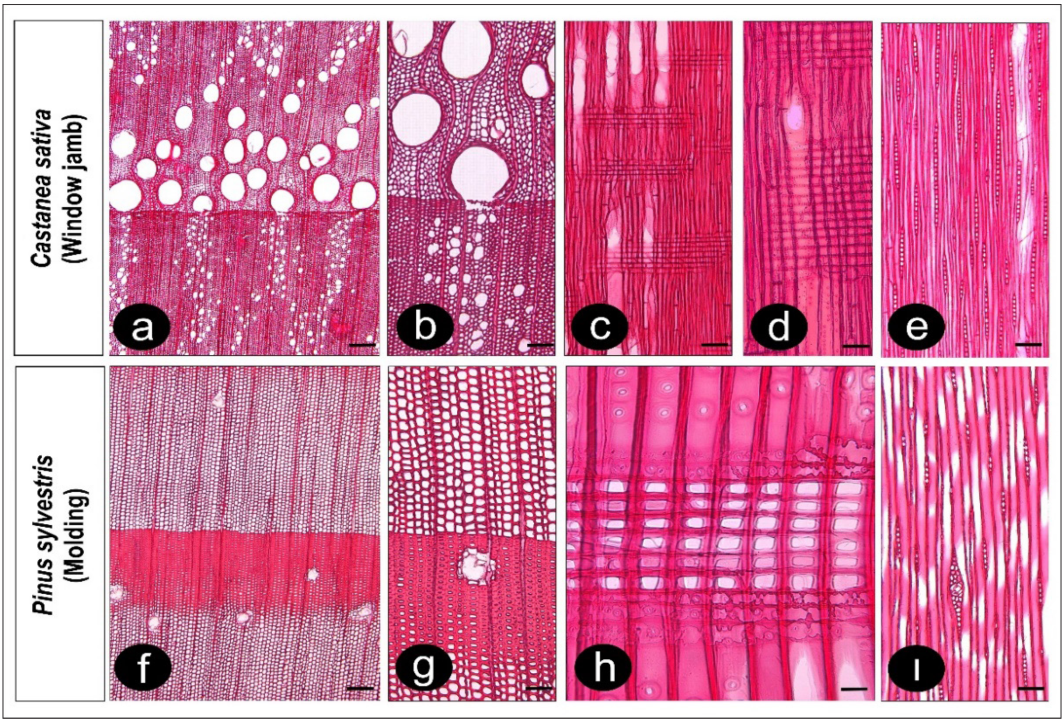

Figure 2: Microscopic photographs of the wood anatomy of window jamb and molding. ((a-b), (f-g)): transverse section, (c-d, h): radial section, (e, i): tangential section. — Scale bar for (a, f) = 250 µm, for (b, c, e, g, i) = 100 µm, for (d)= 50 µm, for (h) = 25 µm.

Table 1: Mean values of anatomical features of aged wood specimens.

Wooden Facade Elements	Anatomical Features						
Castanea sativa (Window jamb)	Vessel				Ray		
	Early wood		Latewood				
	VTD (µm)	VRD (µm)	VTD (µm)	VRD (µm)	Height (µm)	Width (µm)	Frequency (per mm)
	181,72 (40,53)	209,34 (44,47)	37,77 (9,71)	47,14 (12,06)	220,28 (70,60)	14,50 (3,09)	9 (1)
Pinus sylvestris (Molding)	Tracheid				Ray		
	Early wood		Latewood				
	TTD (µm)	TRD (µm)	TTD (µm)	TRD (µm)	Height (µm)	Width (µm)	Frequency (per mm)
	27,36 (6)	26,93 (7,63)	16,09 (3,27)	10,99 (2,04)	178,29 (26,72)	16,04 (2,68)	4 (1)

VTD: vessel tangential diameter, VRD: vessel radial diameter, TTD: tracheid tangential diameter TRD: tracheid radial diameter.

ATR-FTIR spectroscopy analysis

Figure 3 and Figure 4 show the ATR-FTIR spectra of the window jamb and molding at natural outdoor conditions. The spectrum indicated in blue was measured from the inner surface of the aged wood specimen (Figure 3b and Figure 4b), and the spectrum represented by red was measured from the outer surface of the aged wood specimen (Figure 3a and Figure 4a). It is seen that the surface exposed to outdoor conditions shows very different peaks than the inner surface. The peak intensities of the window jamb parts exposed to outdoor conditions increased significantly at 1643 cm^{-1} and 1620 cm^{-1} compared to the inner parts that are not exposed to light. At 1643 cm^{-1} band indicates the ring-conjugated C=C stretch of the coniferyl and sinapyl alcohol (Agarwal and Atalla 2010). The increase in peak intensity in this band is due to the change of lignin structure with light radiation. Similarly, at 1620 cm^{-1} band is associated with lignin and indicates the C=O stretching conjugated to the aromatic ring. It was determined that the color of the specimens darkened as a result of the oxidation of the lignin structure on the outer surfaces of both wood specimens with the effect of time and light. In addition, it was determined that the peak intensity increased significantly at 1319 cm^{-1} band, which is associated with the ring structure of syringyl and guaiacyl of the window jamb exposed to light (Nelson and O'Connor 1964, Nuopponen 2005). The degree of conjugation of lignin and multiple conjugated systems increase in aged wood specimens due to oxidation and decrease of acid-soluble lignin (Borgin *et al.* 1975). Furthermore, the peak at 1234 cm^{-1} band in window jamb almost disappeared with the aging effect. This result can be explained by the stretch of the C= bonds in the lignin structure and the deterioration of the structure of the syringyl ring structure as a result of oxidation (Faix 1991).

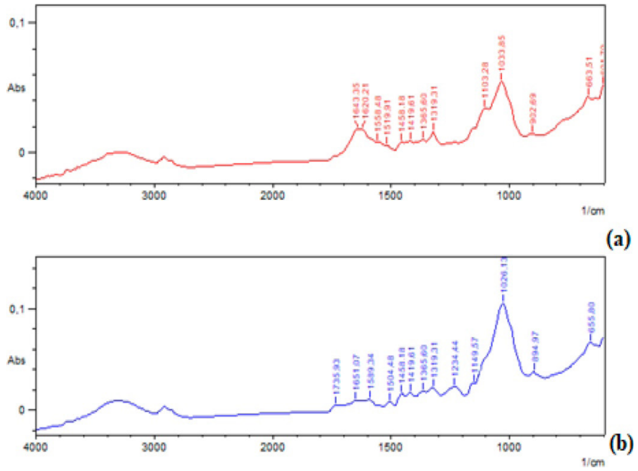

Figure 3: ATR-FTIR spectra for window jamb-*Castanea sativa*: (a) outer surface, (b) inner surface.

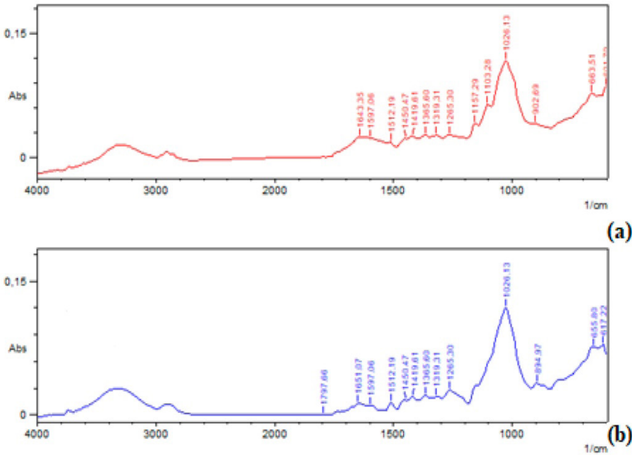

Figure 4: ATR-FTIR spectra for molding-*Pinus sylvestris*: (a) outer surface, (b) inner surface.

The peak around at 894 cm^{-1} shifted around at 902 cm^{-1} with aging for both the window jamb and molding. The peak at 895 cm^{-1} indicates the C-H deformation in cellulose, that is, amorphous cellulose and hemicelluloses (Nelson and O'Connor 1964, Kato *et al.* 1973). In addition, the characteristic peaks of cellulose, which is relatively more resistant to UV effects, became more evident at 1103 cm^{-1} and 1157 cm^{-1} with the effect of natural aging over time. Zhao *et al.* (2019) performed an FTIR analysis of Chinese fir wood samples taken from an ancient Chinese building approximately 170 years old. They found that the inner layer of old wood samples had the highest holocellulose and lignin content, while the outer layer showed the most severe aging. Although similar results were observed in the molding, no significant change was observed at 1319 cm^{-1} for molding. However, the change at 1643 cm^{-1} and 1620 cm^{-1} in molding was more moderate compared to the window jamb. According to this result, it can be said that the location of the facade elements on the building affects also their natural aging process. In addition, the characteristics of the chemical compounds of the cell wall of Gymnosperms and Angiosperms may be effective on the natural aging process of the two facade elements. Indeed, Owen and Thomas (1989) stated that the lignin structure of all softwoods is slightly different from that of hardwoods. During natural aging, hemicellulose, cellulose and lignin in wood generally undergo changes at different rates (Zhao *et al*. 2019). As reported by Anderson *et al*. (1991) the same weathering conditions may have very similar long-term effects on different trees, but in some cases these weathering effects may occur much more quickly than others.

Moisture content and density values

Table 2 shows the Independent-Samples T Test results of physical properties of aged and recent wood. As shown in Table 2, the mean moisture content of aged wood and recent wood for window jamb was found to be 11,46 % and 12,12 %, and for molding 10,63 % and 11,06 %, respectively. According to the Independent-Samples T Test results, it was determined that there was statistically significant difference (p=0,000) between moisture content of aged and recent wood for both window jamb and molding. The moisture content of recent wood was greater than that of aged wood for both of facade elements. This result can be explained as the density values of the recent wood are clearly greater than those of the aged wood for both wood species (Table 2). As is known, frequent exposure of the wood surface to rapid changes in humidity is one of the main causes of weathering (Feist 1990). In addition, the facade elements in this study were exposed to outdoor weathering conditions with natural aging throughout their service life. In the process of outdoor weathering, the water erodes the wood surface and possibly hydrolyzes the hemicelluloses, especially in the surface (Williams 2005). As reported by Inagaki *et al.* (2008) and Kranitz *et al.* (2016), the reduced adsorption of hemicelluloses or amorphous cellulose may have contributed to the lower EMC values. The moisture contents of fir and oak wood, aged between 120 and 470 years, were smaller than those of recent wood (Sonderegger *et al.* 2015). In another study, no difference in the moisture behavior was reported on of old European oak, Norway spruce and silver fir woods from the 16th and 19th centuries and those of the recent woods (Gereke *et al.* 2011).

Table 2: Results of physical properties for aged and recent wood specimens.

Physical properties	Wooden Facade Elements		Mean	Standard deviation	p
Moisture content (%)	Window jamb*	aged	11,46	0,32	0,000
		recent	12,12	0,30	
	Molding**	aged	10,63	0,30	0,000
		recent	11,06	0,28	
Air dry density (kg/m^3)	Window jamb	aged	530	40	0,002
		recent	570	10	
	Molding	aged	450	50	0,010
		recent	490	40	
Oven dry density (kg/m^3)	Window jamb	aged	500	40	0,003
		recent	540	20	
	Molding	aged	420	50	0,006
		recent	470	40	

**Castanea sativa, **Pinus sylvestris.*

The mean density values of aged and recent wood are shown in Table 2. Density is described as mass per unit volume. In general, it has been presumed that the quality of wood as a building material depends mostly on its density (Kollmann and Côté Jr 1968). The mean air dry density values of aged wood and recent wood for window jamb were found to be 530 kg/m^3 and 570 kg/m^3, and for molding 450 kg/m^3 and 490 kg/m^3, respectively. The mean oven dry density values of aged wood and recent wood for window jamb were found to be 500 kg/m^3 and 540 kg/m^3, and for molding 420 kg/m^3 and 470 kg/m^3, respectively. These results show that the density values of the recent wood are greater than those of the aged wood for both density values. That is, aged wood had relatively smaller density values than recent wood. However, according to the Independent-Samples T Test, it was determined that there were statistically significant differences (p=0,002 and p=0,010) between the density values of the recent and aged wood of both facade elements (Table 2). The cell walls of wood are composed of cellulose, hemicellulose and lignin, the three primary chemical materials (Kollmann and Côté Jr 1968). As reported by Saranpää (2003), these three important materials determine the density of the cell wall, and cell wall thickness and cell wall area are related to density. The smaller density values of the aged woods of both facade elements can be attributed to the hydrolysis of hemicelluloses on the wood surface and the degradation of lignin during outdoor weathering. Similar to our results, Vurdu *et al.* (2013) also found that the density value of the approximately 100-year-old antique Turkish fir samples was smaller than that of the control sample. In the research of Thaler *et al.* (2014), they reported that oven dry density value of recent sweet chestnut heartwood as 607 kg/m^3 and that of the old wood as 571 kg/m^3. In contrast, Krajewski *et al.* (2020) determined that there was not statistically difference between the moisture content and density values of natural aged wood and freshly cut wood of Scots pine.

Water absorption rates

Table 3 shows the results of water absorption rates for aged and recent wood. The aged wood showed a greater hygroscopicity than that of recent wood for window jamb. As a result of the water-soaking test, which was carried out for 2 h to 312 h, the water absorption rates of both aged and recent wood of the window jamb increased with time. The water absorption rate of the window jamb, which started with 21,33 % for aged wood and 16,24 % for recent wood, increased to 130,68 % for aged wood and 102,64 % for recent wood at the end of the 312th h. The water absorption rates of recent wood of window jamb were smaller than those of molding. This result can be attributed to chestnut wood has a lower void volume than Scots pine wood. As is known, the amount of water held in the wood above the fiber saturation point is limited by the void volume of the wood (Panshin and Zeeuw 1970), and the high extractive content of chestnut reduces the void volume available for water condensation (Dieste *et al.* 2013).

Table 3: Results of water absorption rates for aged and recent wood specimens.

Water-soaking time	Wooden Facade Elements		Mean	Standard deviation	p
2h	Window jamb[*]	aged	21,33	2,51	0,000
		recent	16,24	1,53	
	Molding[**]	aged	23,95	1,81	0,000
		recent	45,43	5,54	
24h	Window jamb	aged	53,45	2,67	0,000
		recent	40,94	1,39	
	Molding	aged	49,20	2,53	0,000
		recent	60,00	4,87	
72h	Window jamb	aged	80,61	4,37	0,000
		recent	62,22	2,25	
	Molding	aged	72,84	2,04	0,000
		recent	80,01	3,33	
120h	Window jamb	aged	96,78	5,87	0,000
		recent	75,22	2,10	
	Molding	aged	89,64	1,89	0,063[ns]
		recent	91,66	3,58	
168h	Window jamb	aged	108,80	4,40	0,000
		recent	84,95	2,17	
	Molding	aged	100,65	1,83	0,004
		recent	96,81	4,10	
216h	Window jamb	aged	118,11	4,21	0,000
		recent	91,99	2,33	
	Molding	aged	108,45	2,30	0,000
		recent	102,18	5,17	
264h	Window jamb	aged	124,99	3,66	0,000
		recent	97,44	2,06	
	Molding	aged	116,61	2,20	0,000
		recent	106,84	3,74	
312h	Window jamb	aged	130,68	4,55	0,000
		recent	102,64	2,26	
	Molding	aged	123,18	2,07	0,000
		recent	111,36	5,38	

[*]*Castanea sativa*, [**]*Pinus sylvestris*, [ns] no significant (p>0,05)

The water absorption rates of molding showed a similar trend to that of window jamb. From the 2nd h to the 312th h, the water absorption rates of both aged and recent wood increased (Table 3). According to the results of Independent-Samples T Test, the differences between water absorption rates of aged and recent wood for both window jamb and molding were statistically significant (p=0,000) except for water absorption rate of molding at the end of the 120th h (Table 3). The water absorption rate of aged wood for window jamb is greater than that of recent wood. This result can be explained by the leaching of degraded lignin components and oxidized extractives from the surface due to the effect of rain over time (Zimmer *et al.* 2020). Similar to this result, the sorption curves of 205-year-old aged Scots pine wood were above that of the new wood, and the cellulose crystallinity had a significant effect on the hygroscopicity of the wood (Esteban *et al.* 2006). The results for molding were relatively different. The water absorption rates of aged wood of molding up to the 120th h were smaller than those of recent wood. There was no statistical difference between aged and recent wood at the 120th h (Table 3). After this time, an adverse situation was experienced, and aged wood absorbed more water than recent wood. Kohara and Okamoto (1955) found the decrease in the hygroscopicity of two Japanese old woods with ages ranging from 240 to 1300. Vurdu *et al.* (2013) determined that the water absorption rate of the antique Scots pine samples, which have a service life of approximately 100 years, was smaller than that of the control samples at 72 h. The differences in water absorption rates between aged and recent wood of both facade elements were estimated to be due to changes in its chemical structure during natural aging and outdoor weathering.

CONCLUSIONS

The wood species of the two facade elements taken from the traditional wooden building were identified as *Pinus sylvestris* (Scots pine) for the molding and *Castanea sativa* (chestnut) for the window jamb. The data on the anatomical features of both wood species were similar to those of recent wood, and no degradation was observed in the anatomical structure of both facade elements due to natural aging and outdoor factors. The values of moisture content, air dry density and oven dry density recent wood for both facade elements were greater than those of the aged wood. The natural aging process with outdoor weathering has a significant effect on the water absorption of the wood used as a facade element in the building. The water absorption of recent *Pinus sylvestris*, which has relatively smaller wood density, was greater than those of recent *Castanea sativa* which has generally greater wood density. As the water-soaking time increased, the water absorbed by aged chestnut specimens was greater than those of recent specimens. The surface of both molding and window jamb had been aged or weathered. Especially UV light changed the structure of lignin on the outer surface of both facade elements and the surface of facade elements darkened. Although the natural aging action does not directly affect the structural integrity of historical or traditional wooden structures, it can cause problems such as structural defects, biological damage in wooden elements. For this reason, the selection of appropriate preservation methods for aged wood materials in the maintenance and conservation of historical wooden structure is also important for the reuse of aged wood materials.

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REFERENCES

Agarwal, U.P.; Atalla, R.H. 2010. Vibrational Spectroscopy. Chapter 4. In: *Lignin and Lignans: Advanced in Chemistry*. Heitner, C.; Dimmel, D.R.; Schmidt, J.A. (Eds). Boca Raton: CRC press. USA, pp. 103-136. https://naldc.nal.usda.gov/download/46343/PDF

Anderson, E.L.; Pawlak, Z.; Owen, N.L.; Feist, W.C. 1991. Infrared studies of wood weathering. Part I: Softwoods. *Applied Spectroscopy* 45(4): 641-647. https://opg.optica.org/as/abstract.cfm?URI=as-45-4-641

Borgin, K.; Faix, O.; Schweers, W. 1975. The effect of aging in lignins of wood. *Wood Science and Technology* 9: 207-211. https://doi.org/10.1007/BF00364638

Cruz, H.; Yeomans, D.; Tsakanika, E.; Macchioni, N.; Jorissen, A.; Touza, M.; Mannucci, M.; Lourenço, P.B. 2015. Guidelines for on-site assessment of historic timber structures. *International Journal of Architectural Heritage* 9(3): 277-289. https://doi.org/10.1080/15583058.2013.774070

Dieste, A.; Rodríguez, K.; Baño, V. 2013. Wood-water relations of chestnut wood used for structural purposes. *European Journal of Wood and Wood Products* 71(1): 133-134. https://doi.org/10.1007/s00107-012-0627-6

Esteban, L.G.; Fernández, F.G.; Casasús, A.G.; De palacios De Palacios, P.; Gril, J. 2006. Comparison of the hygroscopic behaviour of 205-year-old and recently cut juvenile wood from *Pinus sylvestris* L. *Annals of Forest Science* 63(3): 309-317. https://doi.org/10.1051/forest:2006010

Evangelisti, L.; Guattari, C.; Fontana, L.; Vollaro, R.D.L.; Asdrubali, F. 2022. On the ageing and weathering effects in assembled modular facades: On-site experimental measurements in an Italian building of the 1960s. *Journal of Building Engineering* 45: e103519. https://doi.org/10.1016/j.jobe.2021.103519

Faix, O. 1991. Classification of lignins from different botanical origins by FT-IR spectroscopy. *Holzforschung* 45: 21-27. https://doi.org/10.1515/hfsg.1991.45.s1.21

Feist, W.C. 1983. Weathering and Protection of Wood. In Proceedings of the Seventy-ninth Annual Meeting of the American Wood-Preservers' Association. 79: 195-205. 17-20 April, Kansas City, MO, USA. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.23.7686&rep=rep1&type=pdf

Feist, W.C. 1990. Outdoor Wood Weathering and Protection. In *Archaeological Wood: Properties, Chemistry, and Preservation; Advances in Chemistry Series* 225. Rowell, R.M.B.; James, R. (Eds.). American Chemical Society: Washington, DC, USA. http://dx.doi.org/10.1021/ba-1990-0225.ch011

Gereke, T.; Anheuser, K.; Lehmann, E.; Kranitz, K.; Niemz, P. 2011. Moisture behaviour of recent and naturally aged wood. *Wood Research* 56(1): 33-42. http://www.woodresearch.sk/wr/201101/04.pdf

IAWA. Committee on Nomenclature. 1964. Multilingual glossary of terms used in wood anatomy. International Association of Wood Anatomist: Verlagsanstalt Buchdruckerei, Konkordia Winterthur. https://www.iawa-website.org/uploads/soft/Abstracts/IAWA_glossary.pdf

Inagaki, T.; Yonenobu, H.; Tsuchikawa, S. 2008. Near-infrared spectroscopic monitoring of the water adsorption/desorption process in modern and archaeological wood. *Applied Spectroscopy* 62(8): 860-865. https://doi.org/10.1366/000370208785284312.

InsideWood. 2018. The InsideWood Database. http://insidewood.lib.ncsu.edu/search?3

Ives, E. 2001. *A Guide to Wood Microtomy: Making Quality Microslides of Wood Sections*. Ipswich: United Kingdom.

Jelle, B.P. 2012. Accelerated climate ageing of building materials, components and structures in the laboratory. *Journal of Materials Science* 47: 6475-6496. https://doi.org/10.1007/s10853-012-6349-7

Kato, K.; Nitta, M.; Mizuno, T. 1973. Infrared spectroscopy of some mannans. *Agricultural and Biological Chemistry* 37(2): 433-435. https://doi.org/10.1080/00021369.1973.10860687

Kohara, J.; Okamoto, H. 1955. Studies of Japanese old timbers. *Scientific Reports of the Saikyo University* 7(1): 9-20. https://core.ac.uk/download/pdf/235430519.pdf

Kollmann, F.F.; Côté Jr, W.A. 1968. *Principles of Wood Science and Technolog*y. Vol. I. *Solid Wood.* Springer-Verlag: Berlin Heidelberg, Germany. https://link.springer.com/book/10.1007/978-3-642-87928-9

Krajewski, A.; Kozakiewicz, P.; Witomski, P. 2020. Comparison of selected properties of natural aged wood and contemporary timber of *Pinus sylvestris* L. investigated using standard methods and measuring of transition speed of ultrasounds along the fibre. *Wood Research* 65(3): 405-414. https://doi.org/10.37763/WR.1336-4561/65.3.405414

Kranitz, K.; Sonderegger, W.; Bues, C.T.; Niemz, P. 2016. Effects of aging on wood: a literature review. *Wood Science and Technology* 50(1): 7-22. https://doi.org/10.1007/s00226-015-0766-0

Kropat, M.; Hubbe, M.A.; Laleicke, F. 2020. Natural, accelerated, and simulated weathering of wood: A review. *BioResources* 15(4): 9998-10062. https://bioresources.cnr.ncsu.edu/resources/natural-accelerated-and-simulated-weathering-of-wood-a-review/

Kutnik, M.; Suttie, E.; Brischke, C. 2014. European standards on durability and performance of wood and wood-based products-Trends and challenges. *Wood Material Science & Engineering* 9(3): 122-133. https://doi.org/10.1080/17480272.2014.894574

Larsen, K.E.; Marstein, N. 2016. Conservation of historic timber structures. An ecological approach. Oslo. https://openarchive.icomos.org/id/eprint/1656

Merev, N. 1998. *Doğu Karadeniz Bölgesindeki Doğal Angiospermae Taksonlarının Odun Anatomisi.* KTÜ Basımevi: Trabzon, Türkiye.

Nelson, M.L.; O'Connor, R.T. 1964. Relation of certain infrared bands to cellulose crystallinity and crystal lattice type. Part II. A new infrared ratio for estimation of crystallinity in cellulose I and II. *Journal of Applied Polymer Science* 8(3): 1325-1341. https://doi.org/10.1002/app.1964.070080323

Nuopponen, M. 2005. FT-IR and UV-Raman Spectroscopic Studies on Thermal Modification of Scots pine Wood and Its Extractable Compounds. Series A, 23. Helsinki University of Technology, Laboratory of Forest Products Chemistry: Espoo, Finland. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.453.6995&rep=rep1&type=pdf

Osvaldova, L.M. 2020. *Wooden Façades and Fire Safety: Effects of Joint Type on Ignition Behaviour*. Springer: Cham. https://doi.org/10.1007/978-3-030-48883-3

Owen, N.L.; Thomas, D.W. 1989. Infrared studies of "hard" and "soft" woods. *Applied Spectroscopy* 43(3): 451-455. https://doi.org/10.1366/0003702894202760

Panshin, A.J.; Zeeuw, C. 1970. *Textbook of Wood Technology*. Volume I, McGraw-Hill, Inc.: United States of America.

Reinprecht, L. 2016. *Wood deterioration, protection and maintenance*. John Wiley & Sons. https://onlinelibrary.wiley.com/doi/book/10.1002/9781119106500

Saranpää, P. 2003. Wood density and growth. In *Wood Quality and its Biological Basis*. Barnett, J.R.; Jeronimidis, G. (Eds.). Blackwell Publishing. CRC Press.

Sonderegger, W.; Kránitz, K.; Bues, C.T.; Niemz, P. 2015. Aging effects on physical and mechanical properties of spruce, fir and oak wood. *Journal of Cultural Heritage* 16(6): 883-889. https://doi.org/10.1016/j.culher.2015.02.002

SPSS. 2021. SPSS Statistics. Version 23. IBM. https://www.ibm.com/support/pages/downloading-ibm-spss-statistics-23

Thaler, N.; Žlahtič, M.; Humar, M. 2014. Performance of recent and old sweet chestnut (*Castanea sativa*) wood. *International Biodeterioration & Biodegradation* 94: 141-145. https://doi.org/10.1016/j.ibiod.2014.06.016

TS. 2021. Physical and mechanical properties of wood. Test methods for small clear wood specimens. Part 1: Determination of moisture content for physical and mechanical tests. TS ISO 13061-1. Turkish Standards Institute: Ankara, Turkey.

TS. 2021. Physical and mechanical properties of wood. Test methods for small clear wood specimens. Part 2: Determination of density for physical and mechanical tests. TS ISO 13061-2. Turkish Standards Institute: Ankara, Turkey.

Tomak, E.D.; Viitanen, H.; Yildiz, U.C.; Hughes, M. 2011. The combined effects of boron and oil heat treatment on the properties of beech and Scots pine wood. Part 2: Water absorption, compression strength, color changes, and decay resistance. *Journal of Materials Science* 46(3): 608-615. https://doi.org/10.1007/s10853-010-4860-2

Vurdu, H.; Kesik, H.İ.; Kurtuluş, O.Ç.; Özkan, O.E. 2013. Some physical and mechanical properties of antique and fresh cut Pinus sylvestris and Abies nordmanniana subsp. bornmulleriana woods. *Pro Ligno* 9(4): 562-567. http://www.proligno.ro/en/articles/2013/4/Vurdu_final.pdf

Williams, R.S. 2005. Weathering of Wood. In: *Handbook of Wood Chemistry and Wood Composites.* Rowell, R.M. (Ed.). Taylor and Francis CRC Press: Boca Raton, Florida, USA. https://www.fpl.fs.usda.gov/documnts/pdf2005/fpl_2005_williams001.pdf

Yaman, B. 2007. Comparative wood anatomy of *Pinus sylvestris* and its var. *compacta* in the West Black Sea Region of Turkey. *IAWA Journal* 28(1): 75-81. https://brill.com/view/journals/iawa/28/1/article-p75_8.xml?ebody=pdf-49903

Zhao, C.; Zhang, X.; Liu, L.; Yu, Y.; Zheng, W.; Song, P. 2019. Probing chemical changes in holocellulose and lignin of timbers in ancient buildings. *Polymers* 11(5): e809. https://doi.org/10.3390/polym11050809

Zimmer, K.; Flindall, O.; Gobakken, L.R.; Nygaard, M. 2020. Weathering of unpainted wooden façades-Experience and examples 2020. NIBIO Rapport 6 (5). http://hdl.handle.net/11250/2638753