The Effect of Aging on Various Physical and Mechanical Properties of Scotch Pine Wood Used in Construction of Historical Safranbolu Houses

Utjecaj starenja na neka fizikalna i mehanička svojstva škotske borovine upotrebljavane za gradnju povijesnih kuća u Safranbolu

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ABSTRACT • *Wood has been a favourite construction material since the ancient times because of its natural beauty and excellent properties, such as high specific strength, heat insulation and ease of handling and processing. It was also used in Safranbolu, where Turkish Ottoman civil architectural samples have been carefully protected and preserved without losing their originality. It was inscribed to "The World Heritage List" by UNESCO in 1994. In this study, density, Brinell hardness and compression strength perpendicular to the grain of Scotch pine (Pinus Sylvestris Lipsky.) wood, from the floor joist of 10 different demolished historical Safranbolu houses for 10 different years, were determined and compared with those of wood from freshly cut trees. The highest decrease in compression strength perpendicular to the grain of salvaged Scotch pine wood used as floor joist for 210 years was nearly 27 percent lower than those of wood from freshly cut Scotch pine. The results indicate that the physical properties, Brinell hardness and compression strength perpendicular to the grain of the Scotch pine wood were significantly affected by the 210-year service life.*

Keywords**:** *historical Safranbolu houses, historical wood flooring, cultural heritage, density, Brinell hardness, compression strength perpendicular to the grain*

SAŽETAK • *Drvo je još od antičkih vremena zbog svoje prirodne ljepote i izvrsnih svojstava kao što su velika specifična čvrstoća, toplinska izolacija i jednostavnost rukovanja i obrade često upotrebljavano kao građevni materijal. Ono je za tu namjenu iskorištavano i u Safranbolu, gdje su tursko-osmanski civilni arhitektonski primjerci pažljivo zaštićeni i očuvani bez narušavanja njihova originalnog izgleda. Ta je kulturna baština 1994. godine upisana u Popis svjetske baštine UNESCO-a. U ovom su istraživanju prikazani rezultati mjerenja gustoće, tvrdoće*

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prema Brinellu i tlačne čvrstoće okomito na vlakanca na uzorcima drva škotskog bora (Pinus sylvestris Lipsky.) napravljenima od podnih greda iz deset različitih demoliranih povijesnih kuća iz Safranbola iz deset različitih godina. Te su vrijednosti uspoređene s vrijednostima izmjerenima na uzorcima od drva svježe srušenih stabala škotskog bora. Najveće smanjenje tlačne čvrstoće okomito na vlakanca izmjereno je na uzorcima od škotske borovine koja je 210 godina služila kao podna greda. Ta je tlačna čvrstoća bila gotovo 27 % manja od tlačne čvrstoće drva svježe srušenih stabala škotskoga bora. Rezultati pokazuju da je na fizikalna svojstva škotske borovine, tvrdoću prema Brinellu i čvrstoću okomito na vlakanca znatno utjecalo 210 uporabnih godina.

Ključne riječi: *povijesne kuće u Safranbolu, povijesni drveni pod, kulturna baština, gustoća, tvrdoća prema Brinellu, tlačna čvrstoća okomito na vlakanca*

1 INTRODUCTION
1. UVOD

Wood is a naturally durable material that has been recognized for centuries throughout the world for its versatile and attractive engineering and structural properties. However, like other biological materials, wood is susceptible to environmental degradation. When wood is exposed outdoor and above ground, a complex combination of chemical, mechanical and light energy factors contribute to what is described as weathering (Feist, 1982).

Safranbolu is a place where Turkish Ottoman civil architectural buildings have been carefully protected and preserved without losing their originality. It was inscribed to "The World Heritage List" by UNESCO in 1994 as one of the cities that has preserved and protected the characteristics of history to the present day. Hence, Safranbolu has become popular all over the world and the number of domestic and foreign tourists has gradually been increasing.

Safranbolu houses are very specific because they represent ancient urban life and architecture. Safranbolu houses are the structural cornerstones of Turkish urban culture, developed hundreds of years ago and still inhabited nowadays.

Wood is warm to touch and easy to process. Nonetheless, because of its biological nature, unprotected wood is susceptible to weathering, photooxidative degradation and acid precipitation. Although the weathering of woods depends on many environmental factors, such as solar radiation (ultraviolet, visible and infrared light), moisture (dew, rain, snow and humidity), temperature, oxygen and air pollutants, it is generally accepted that only a relatively narrow band of the electromagnetic spectrum of sunlight, i.e., ultraviolet light, is responsible for the primary photochemical process in the weathering or oxidative degradation of wood (Hon and Feist, 1980).

The interaction of photons with polymeric compounds distributed on the wood surface involves some exceedingly complex chemistry and physics. From a chemical point of view, it is not surprising that all chemical wood components - namely, cellulose, hemicelluloses, lignin, and extractive - are susceptible to degradation by sunlight or ultraviolet light. The consequence of this photoreaction normally leads to drastic changes in wood appearance, i.e., discoloration, loss of gloss and lightness, roughening and checking of surfaces and destruction of mechanical and physical properties (Hon, 1983; Turkulin and Sell, 1997).

It is well known that if wood is not exposed to inclement weather conditions, if it is not in contact with the ground and if used at relatively low moisture content in covered structures, it performs well without any treatment (Breyer, 1993).

Weathering of the wood surface due to the combined action of light and water causes surface darkening and leads to formation of macroscopic to microscopic intercellular and intracellular cracks or checks. Strength of cell wall bonds is lost near the wood surface (Feist and Hon, 1983).

In the future, a large amount of wood members from dismantled structures will be available for possible reuse. Wood members that have been protected throughout their life span will be more important than members that have not been protected (Chai *et al*., 2000; Falk *et al*., 1999). Therefore, the effects of service life and age on the mechanical properties of wood that is considered for reuse should be well understood. However, few studies have been conducted on this subject (Bektaş *et al*., 2003.; Fridley *et al*., 1996.; Green *et al*., 2001; Tutuş *et al*., 2004).

It should be appreciated that every application of wood in its natural or unprocessed state is potentially affected by the tendency to a relatively large cross-grain dimensional change, whenever significant moisture content changes in service are expected. For example, the performance of every structural wood connection, with the possible exception of a glued joint, can be affected by different dimensional changes in wood members (Bozkurt, 1986).

The aim of this study is to investigate the effect of 10 different years of service life on some physical and mechanical properties of Scotch pine wood used as floor joist in historical Safranbolu houses in order to determine changes related to services life.

2 MATERIAL AND METHOD
2. MATERIJAL I METODE

2.1 Material
2.1. Materijal

Scotch pine (*Pinus sylvestris* L.) log beams were taken from the floor joist of a demolished wood house in Safranbolu. The age of Scotch pine wood used in historical structures is given in Table 1. The joists had not been exposed to outdoor weathering.

The wood of freshly cut Scotch pine trees (70 years old) from a forest located in the region of Karabuk Turkey was used as a control specimen.

Table 1 Dendrochronology of the samples
Tablica 1. Dendrokronologija uzoraka

Sample No / *Oznaka uzorka*	**Date** / *Godine*
1	1800 - 1894
2	1805
3	1810 - 1891
4	1848 - 1893
5	1868 -1883
6	1822
7	1899 - 1953
8	1924 - 1961
9	1933
10	1929 - 2000

2.2 Determination of density
2.2. Određivanje gustoće

The dry densities of the wood materials used for the preparation of treatment samples were determined according to TS 2472. Accordingly, samples were dried in an oven up to 103 ± 2 °C until they reached constant weights. Then, the samples were cooled in a desiccator containing calcium chloride and weighed in an analytic balance with ± 0.01 g sensitivity. Afterwards, the dimensions of the wood materials were measured by a compass with ± 0.001 mm sensitivity and the volumes were determined by the stereometric method. The oven dry density δ_o (g/cm³) was calculated with the following equation:

$$\delta_o = M_o / V_o \qquad (1)$$

Where M_o is the oven-dry weight (g) and V_o is the dry volume (cm³) of wood.

2.3 Brinell hardness
2.3. Tvrdoća prema Brinellu

Both salvaged and freshly cut Scotch pine wood specimens, used to determine mechanical properties, were exposed to 20 °C ± 2 °C and 65 ±5 percent relative humidity (*RH*) until a moisture content (*MC*) of approximately 12 % before the specimens were tested. The following mechanical tests were then performed on a Hardness Tester FV-700 testing machine.

Brinell hardness specimens, 5 cm (longitudinal length), 5 cm (radial length), 5 cm (tangential length), were tested using a Hardness Tester FV-700 according to ASTM-D-4366. In this test, a hemispherical head with a 1 cm diameter was forced into the center of the specimens to a depth of 1 mm with the head speed of 15 min/mm. The load required was recorded in kgf and reported as Newton (N).

$$HB = \frac{2 \cdot F}{\pi \cdot D \cdot (D - \sqrt{D^2 - d^2})}, \text{ kg/mm}^2 \qquad (2)$$

2.4 Compression strength perpendicular to the grain
2.4. Tlačna čvrstoća okomito na vlakanca

The wood samples cut from sapwood were exposed for 3 months to 20 ± 2 °C and 65 ± 3 % relative humidity in a climatization room until they reached constant weight.

Compression strength perpendicular to the grain TS 2473 was determined on match basis. By using a universal test machine, 6 mm/min shear force was applied to the samples. The experiment results are measured, and the compression strength σ_b (N/mm²) can be calculated from the equation (3).

$$\sigma_b = F_{max} / A \qquad (3)$$

Where:
F_{max} – maximum force at crush (N)
A – sample cross section area (mm²)

2.5 Statistical analyses
2.5. Statistička analiza

For each physical property of the salvaged and freshly cut Scotch pine wood, averages of 30 measurements were considered. Data for each test were statistically analyzed by using SPSS program. The results were statistically evaluated using analysis of variance (ANOVA) and regression mean separation tests.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

According to Table 1, dendrochronological characteristics of 10 different historical Safranbolu houses were determined. The oldest historical structure sample was 210 years old. Among the specimens, the one that is nearest to today's houses is approximately 10-70 years old. The average densities are given in Table 2.

Table 2 A comparison of various physical properties of salvaged Scotch pine wood and freshly cut Scotch pine wood (g/cm³)
Tablica 2. Usporedba različitih fizikalnih svojstava uzoraka od starog drva škotskog bora sa svojstvima uzoraka od svježe srušenih stabala

Sample No. *Oznaka uzorka*	**Air-dry density** *Gustoća prosušenog drva* g/cm³	**Oven-dry density** *Gustoća standardno suhog drva* g/cm³
1	0.399	0.350
2	0.394	0.348
3	0.404	0.357
4	0.406	0.358
5	0.435	0.382
6	0.437	0.383
7	0.439	0.388
8	0.442	0.389
9	0.451	0.398
10	0.459	0.404
Control (freshly cut wood) / *Kontrolni uzorak (svježe oboreno drvo)*	0.52	0.46

The highest density (0.520 g/cm³) was obtained in freshly cut samples of Scotch Pine wood. The lowest density (0.394 g/cm³) was obtained in salvaged Scotch pine wood used as floor joist for 210 years. The averages of Brinell hardness are given in Table 3.

The highest values of Brinell hardness (5.1 N/mm²) was obtained in freshly cut samples of Scotch Pine wood. The lowest values of Brinell hardness (3.1

Table 3 Average values of Brinell hardness (N/mm²)
Tablica 3. Prosječne vrijednosti tvrdoće prema Brinellu

Sample No. *Oznaka uzorka*	**Sample number** *Broj uzoraka*	**Brinell hardness** *Tvrdoća prema Brinellu* N/mm²
1	30	3.1
2	30	3.1
3	30	3.3
4	30	3.5
5	30	3.8
6	30	3.8
7	30	4.1
8	30	4.5
9	30	4.6
10	30	5
Control (freshly cut wood) *Kontrolni uzorak (svježe oboreno drvo)*	30	5.1

N/mm²) was obtained in salvaged Scotch pine wood used as floor joist for 210 years. The results of multivariance analysis (Brinell hardness) are given in Table 4.

According to the variance analysis, the effects of the years, the effects of the density, and the effects of the years and density together are statistically significant. The results of regression analysis are given Table 5.

According to the regression analysis, in order to determine air dry density and Brinell hardness as well as the relationship between them, regression equations were studied, and it was determined that the best linear equation for all Brinell hardnesses and densities was $HB = a + b \cdot \delta_{12}$. The averages of compression strength perpendicular to the grain are given in Table 6.

The highest compression strength perpendicular to the grain (26.43 N/mm²) was obtained in specimens taken from freshly cut Scotch Pine. The lowest compression strength perpendicular to the grain (19.16 N/

Table 4 Results of multivariance analysis (Brinell hardness)
Tablica 4. Rezultati multivarijantne analize podataka o tvrdoći prema Brinellu

Source *Izvor*	**Type III Sum of Squares** *Tip III - zbroj kvadrata*	***Df***	**Mean Square** *Kvadrat srednje vrijednosti*	***F***	**Sig.**
Corrected Model	118.504	79	1.500	1198.303	0.00
Intercept	3735.359	1	3735.359	2983947.146	0.00
A	7.872	8	0.984	786.058	0.00
B	1.094	47	2.327E-02	18.591	0.00
A* B	0.412	23	1.790E-02	14.302	0.00

a R Squared = 0.998 Factor A - Years Factor B - Density

Table 5 Regression analysis (Brinell hardness and density)
Tablica 5. Regresijska analiza (tvrdoća prema Brinellu i gustoća)

		Unstandardized Coefficients *Nestandardizirani koeficijenti*		**Standardized Coefficients** *Standardizirani koeficijenti*	***t***	**Sig.** *Razina signif.*
Model		B	Std. Error	Beta		
1	(Constant) *konstanta*	-6.799	0.236		-28.749	0.000
	Density *gustoća*	25.136	0.556	0.934	45.220	0.000

a Dependent Variable: Brinell hardness / *zavisna varijabla: tvrdoća prema Brinellu*

Table 6 Average values of compression strength perpendicular to grain
Tablica 6. Prosječne vrijednosti tlačne čvrstoće okomito na vlakanca

Sample No. *Oznaka uzorka*	**Sample number** *Broj uzoraka*	**Compression strength perpendicular to grain** *Tlačna čvrstoća okomito na vlakanca* N/mm²
1	30	19.16
2	30	19.49
3	30	20.02
4	30	19.94
5	30	21.52
6	30	21.45
7	30	21.73
8	30	22.74
9	30	22.61
10	30	24.11
Control (freshly cut wood) *Kontrolni uzorak (svježe oboreno drvo)*	30	26.43

Table 7 Results of multivariance analysis (compression strength perpendicular to grain)
Tablica 7. Rezultati multivarijantne analize vrijednosti tlačne čvrstoće okomito na vlakanca

Source *Izvor*	**Type III Sum of Squares** *Tip III - zbroj kvadrata*	***Df***	**Mean Square** *Kvadrat srednje vrijednosti*	***F***	**Sig.**
Corrected Model	167.210	79	8.446	33.161	0.00
Intercept	9226.753	1	9226.753	1440650.031	0.00
A	10.302	8	5.038	219.781	0.00
B	2.925	47	3.223E-02	11.244	0.00
A* B	1.674	23	4.277E-02	8.286	0.00

a R Squared = 0,923 Factor A - Years Factor B - Density

Table 8 Regression analysis (compression strength perpendicular to grain and density)
Tablica 8. Regresijska analiza (tlačna čvrstoća okomito na vlakanca i gustoća)

		Unstandardized Coefficients *Nestandardizirani koeficijenti*		**Standardized Coefficients** *Standardizirani koeficijenti*	***t***	**Sig.** *Razina signif.*
Model		B	Std. Error	Beta		
1	(Constant)	-4.096	1.763		-2.323	0.04
	Density	59.394	4.040	0.980	14.702	0.00

a Dependent Variable: Compression strength perpendicular to grain / *zavisna varijabla: tlačna čvrstoća okomito na vlakanca*

mm²) was obtained in salvaged Scotch pine wood used as floor joist for 210 years. The results of multivariance analysis (compression strength perpendicular to the grain) are given in Table 7.

According to the variance analysis, the effects of the years, the effects of density, and the effects of aging and density together were statistically significant. The results of regression analysis are given in Table 8.

According to the regression analysis, in order to determine the relationship between air dry density and compression strength perpendicular to the grain, regression equations were studied, and it was determined that the best linear equation for all compression strengths perpendicular to the grain and densities was $HB = a + b \cdot \delta_{12}$.

4 CONCLUSION
4. ZAKLJUČAK

For Scotch pine wood used in Safranbolu houses, the decrease in air-dry and oven dry density was approximately 23 percent and 24 percent, respectively. According to Bektas *et al*. (2003), the decrease in air-dry and oven dry density of Scotch pine wood, used for 120 years as a roof beam in a residential house in the district selected in this study, was approximately 10 percent and 8 percent, respectively. It was also reported by Chai *et al*. (2000) that the decrease in air-dry density of about 5 percent was found when southern pine wood was used as floor joist in a warehouse for 90 years.

The highest decrease in Brinell hardness of salvaged Scotch pine wood, used as floor joist for 210 years, was nearly 39 percent lower than that of freshly cut Scotch pine wood. The lowest decrease in Brinell hardness of salvaged Scotch pine wood, used as floor joist for 10-70 years, was nearly 1.9 percent lower than that of freshly cut Scotch pine wood. It was reported by Bektas *et al*. (2003) that the shear strength and Janka hardness of salvaged Scots pine wood, used as roof beams for 120 years, were, respectively, nearly 45 and 11 percent lower than those of freshly cut Scotch pine wood. It may be presumed that given almost the same load and climate conditions, the differences in the decrease of mechanical properties between Crimean juniper used for 180 years and Scots pine used for 120 years may be due to the higher natural durability of juniper wood (Richardson, 1978).

Brinell hardness is affected by the density, humidity, anatomical structure and direction of the material. According to the regression analysis, this kind of relation has been observed between the density of wooden material used in historical structures and their Brinell hardness. Decrease has been observed in both density and Brinell hardness in historical structures, especially in wooden materials for outer surfaces. However, due to continuous adsorption and desorption occurring at the change of seasons, the repetition of this event in historical structures has diminished the hysteresis difference in wooden materials and EMC. This is the reason for the decrease in the evaluation values after 70 years.

The highest decrease in compression strength perpendicular to the grain of salvaged Scotch pine wood, used as floor joist for 210 years, was nearly 27 percent lower than that of freshly cut Scotch pine wood. The lowest decrease in compression strength perpendicular to the grain of salvaged Scotch pine wood, used as floor joist for 10-70 years, was nearly 9 percent lower than that of freshly cut Scotch pine wood. The chemical components responsible for the strength properties of wood can be theoretically viewed from three distinct levels: the macroscopic (cellular) level, the microscopic (cell wall) level, and the molecular (polymeric) level. At the molecular level, the relationship of strength and chemical composition deals with the individual polymeric components that make up the cell wall. The physical and chemical properties of cellulose, hemicelluloses, and lignin play a major role in the chemistry of strength (Winandy and Rowell, 1994).

When certain organisms come into contact with wood, several types of degradation occur. The mechanical damage caused by metabolic action can result in significant losses in strength. Microbial activity via enzymatic pathways induces wood fiber degradation by chemical reactions such as hydrolysis, dehydration and oxidation (Cowling, 1961).

When Scotch pine wood was used as floor joist (in the form of logs) in the houses for different years, its physical properties (including density, compression strength perpendicular to grain and Brinell hardness ratios) were considerably affected by service life.

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