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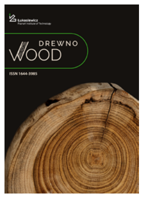

Natural Durability of Some Wood Species in Ground Contact at Four Sites in Turkey. Part 2: The Mechanical Properties

Ceyhun Kiliç[a] *
Sibel Yildiz[b]

[a] Eastern Blacksea Forestry Research Institute, General Directorate of Forestry, Turkey
[b] Forest Industry Engineering, Karadeniz Technical University, Turkey

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The first part of this study (Natural Durability of Some Wood Species in Ground Contact at Four Sites in Turkey Part 1: The Physical Properties) was published in the 67th volume of Drewno. This study involved the examination of heartwood, sapwood, and CCB (Copper Chromium Boron) impregnated sapwood samples measuring 20x20x300 mm from various tree species including Scots pine (*Pinus sylvestris* L.), Caucasian spruce (*Picea orientalis* (L.) Peterm), European beech (*Fagus orientalis* L.) and common alder (*Alnus glutinosa* subsp. barbata). These samples were subjected to soil contact, specifically in hazard class 4 conditions as defined by EN 252 (2014), for a duration of three years. The study was conducted in four different provinces of Turkey, namely Trabzon, Muğla, Çanakkale, and Elazığ, each characterized by distinct climatic conditions. The bending strength, modulus of elasticity and compression strength of the samples collected back from test sites were examined. The highest bending strength, modulus of elasticity and compression strength were observed in Elazığ (dry climate). In Çanakkale, Muğla and Trabzon (humid climate), relatively lower values were recorded. Within particular climate types, it was found that Scots pine and Caucasian spruce wood samples had higher resistance than the European beech and common alder samples. The heartwood of coniferous trees especially was found to be more durable than the sapwood. In addition, no deformation was observed in any of the impregnated wood samples. The durability of all treated wood samples met the minimum requirements for soil contact.

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Introduction

In various fields, renewable resource-derived wood serves as an environmentally friendly engineering material (Homan and Jorissen, 2004). Therefore, interest in using wood is gradually increasing (Hill, 2007). Wood is preferred over concrete, steel, and plastics because it is healthier, beneficial to nature, stores carbon, demands less energy to process, and is easier to recycle. Despite its advantages, several decomposers cause damage to wood (Ramage et al., 2017; Zhong and Ma, 2022). Indoor applications mostly expose wood to regulated humidity and temperature, along with a small amount of ultraviolet light (UV). However, in outdoor conditions, it is subjected to harsh weathering agents such as sunlight, moisture (rain, snow, dew), mechanical forces (wind, dirt), biological organisms (fungi, insects), soil properties, and variable temperature changes (Highley, 1995; Smit, 2010). For wood in contact with soil, soil composition and climate parameters may be key risk

* Corresponding author: ceyhunkilic@gmail.com

factors. These degrading agents may cause changes and mechanical structure failures in the wood (Feist and Hon, 1984; Williams, 2005; Kılıç et al., 2023). Knowledge of soil composition and climate is vital for outdoor timber components. Therefore, for many years, researchers have extensively studied the natural weathering of various wood species worldwide (Opoku, 2007). Studies have clearly shown that the performance of wood species against natural weathering agents depends on many factors, such as wood species, heartwood–sapwood proportions, sample dimensions, exposure time, test period, test location, weather factors, test equipment angle with the ground, and direction. Wood exposed to outdoor conditions performs differently depending on chemical treatment, material quality, decay resistance, and climate. Thus, wood material should be assessed based on the local climate (Winandy and McDonald, 1993; Highley, 1999). Climatic change reduces wood's decay resistance and service life (Highley, 1995). To ensure long-term durability in its intended use, wood must be impregnated or chosen from durable species. Unfortunately, limited studies have been carried out to evaluate the effects of weathering on wood exposed to soil. The European standard EN 252 (2014) determines the inherent resilience of wood in contact with soil. Through the burying of wood piles up to half of their length in the soil, the soil contact test method exposes them to microorganisms (Baines, 1984; EN 252, 2014). The climate and soil composition of Türkiye differ by region. Within the country there are four distinct climate types. Depending on the soil composition and climate, it is anticipated that wood strength may deteriorate at varying rates, and it is therefore necessary to assess and compare the strength of wood in different geographic areas (Kılıç and Yıldız, 2024). In the first part of the study, the physical properties of the specimens, including visual decay, mass loss, and density, along with the detailed soil analysis, were investigated following exposure according to the EN 252 standard (Kılıç and Yıldız, 2024). In another study, the color change of the same specimens and their associated climatic index were analyzed (Kılıç et al., 2023). The current study addressed the mechanical properties of the samples, focusing on bending strength, modulus of elasticity, and compressive strength parallel to the grain direction. Through this investigation, the dataset is substantially expanded, contributing to a more comprehensive characterization of the material's performance under environmental exposure. To achieve this, sapwood/heartwood samples and CCB-impregnated sapwood samples of Scots pine (*Pinus sylvestris* L), Caucasian spruce (*Picea orientalis* (L.) Peterm), European beech (*Fagus orientalis* L.), and common alder (*Alnus glutinosa* subsp. barbata) were exposed to field tests, in accordance with the European standard EN 252 (2014), for three years in the provinces of Trabzon, Muğla, Çanakkale, and Elazığ to determine the natural durability and strength of the wood types. The bending strength, elastic modulus, and compression strength were determined.

Material and methods

1. Material

The samples consisted of winter-harvested Scots pine, Caucasian spruce, European beech, and common alder logs. The CCB used in this study was supplied by Emsan Korusan Company. Measurements and analyses were conducted at the Laboratory of Forest Industry Engineering at KTU Faculty of Forestry. Caucasian spruce and Scots pine were similar in color. Marking was performed with benzidine (Koch and Kreig, 1938; Holz, 1959; Rust, 1999). Common alder and European beech sapwood and heartwood are similar in color and moisture content. These woods have false heartwood. Heartwood was extracted from the central core of the logs, and samples of heartwood and sapwood were examined (Panshin and De Zeeuw, 1980).

2. Impregnation method

For a detailed description of the impregnation and research methods, see part 1 (Kılıç and Yıldız, 2024).

3. Bending strength

Bending strength testing was carried out on a Universal Test Device in accordance with the TS ISO 13061-3 (2021) standard. The load was applied from the center of the samples, and the loading speed of the device was set to 2 mm/min to ensure that fracture occurred in 1.5 ± 0.5 minutes (Fig. 1).

The bending strength (σ_e) for the maximum load (F_{max}) at the moment of fracture was calculated using Equation 1.

$$\sigma_e = \frac{3F_{max}\mathrm{L}}{2\mathrm{b}h^2} \quad (1)$$

L: the space between the support points (mm), b: the width of the sample (mm), h: the thickness of the sample (mm).

4. Modulus of elasticity in static bending

The modulus of elasticity (E) was measured on a Universal Test Device in accordance with TS ISO 13061-4 (2021) and calculated by Equation 2 based on the difference in the bending strength values (Δf) in the samples for the load difference (ΔF).

Fig. 1. Determination of bending strength and modulus of elasticity in samples

$$E = \frac{\Delta F L^3}{4bh^3\Delta f}\ x\ N/mm^2 \qquad (2)$$

L: the space between the support points (mm), b: the width of the sample (mm), h: the thickness of the sample (mm).

5. Compression strength parallel to grain

Following the bending and modulus of elasticity tests, 30 mm sections of the above-ground and underground parts of the samples were cut to create 20x20x30 mm samples for testing of compressive strength parallel to the grain (Fig. 2). Separate values were recorded for underground and above-ground samples.

Testing was carried out on a Universal Test Device in accordance with the TS ISO 13061-17 (2017) standard. Before the test, the cross-sectional area (A) where the load was applied was measured, the maximum load at the moment of fracture (F_{max}) was determined, and the compression strength (σ_b) was calculated using Equation 3.

$$\sigma_b = \frac{F_{max}}{A}\ N/mm^2 \qquad (3)$$

6. Statistical analysis

SPSS 22.0 was used to analyze data from the study at 95% confidence. Statistical differences were calculated using simple analysis of variance. The Duncan homogeneity test determined which variants and wood types differed. Whether soil contact test data differed was assessed. When comparing the data as a result, it was evaluated whether there was a difference between the variations.

Results and discussion

Results were obtained for bending strength, modulus of elasticity, and compression strength parallel to the grain.

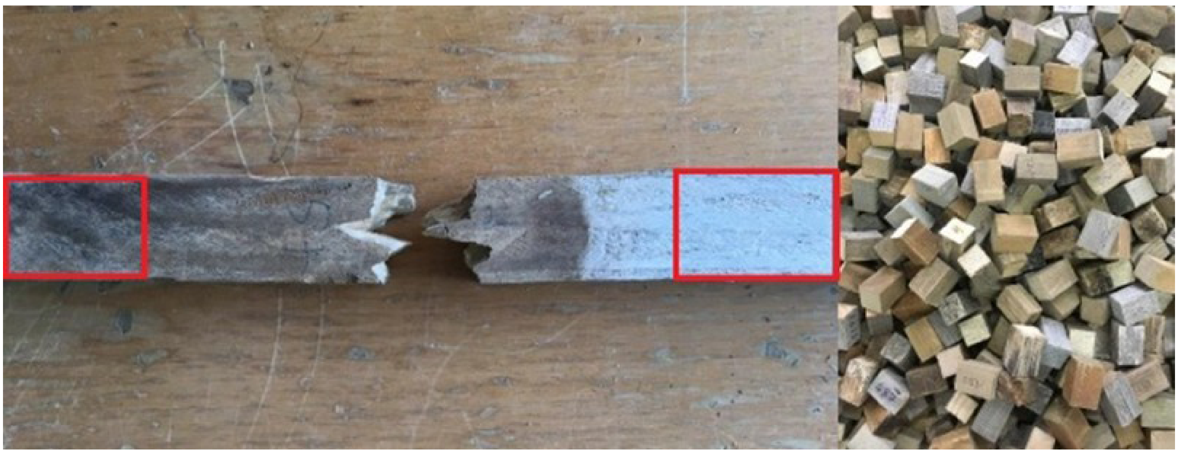

Fig. 2. Preparing samples for testing of compressive strength parallel to the grain

1. Bending strength

In Trabzon, the highest bending strength was observed in Scots pine sapwood (56.08 N/mm^2). Test samples of European beech sapwood and common alder heartwood were excluded from the experiment due to intense decay. The lowest bending strength value among the available test samples was calculated for common alder sapwood (15.69 N/mm^2). Scots pine achieved better performance than other tree species in the Black Sea climate, which has a high climatic index and is temperate. There was not much change in the bending strength of the impregnated European beech and common alder wood compared with the impregnated control samples. Applications such as impregnation or heat treatment are recommended for these types, which are particularly unstable in outdoor use. Yıldız et al. (2011) left untreated and heat-treated samples of 2x2x30 cm^3 sized common alder wood in contact with soil in a trial area in Samsun, which experiences the Black Sea climate. The untreated control samples lost 50% more flexural strength than the heat-treated test samples. In Muğla, the highest bending strength was observed in Caucasian spruce heartwood (69.22 N/mm^2). Test samples of European beech sapwood/heartwood and common alder sapwood/heartwood were excluded from the experiment due to intense decay. Scots pine was less resistant than Caucasian spruce, but still had a reasonable value of 62.23 N/mm^2. In Çanakkale, the highest bending strength was observed in Scots pine heartwood (78.67 N/mm^2). Test samples of European beech sapwood/heartwood and common alder sapwood/heartwood were excluded from the experiment due to intense decay, and Scots pine sapwood due to termite attack. The lowest bending strength value for available test samples was calculated for Caucasian spruce sapwood (40.59 N/mm^2). Considering the country's climate, especially in the Mediterranean and mixed climate types, which are among the climates most conducive to fungal decay, Scots pine and spruce stand out particularly in terms of bending strength. In Elazığ, the highest bending strength was observed for Caucasian spruce sapwood (82.17 N/mm^2), and the lowest for European beech sapwood (45.18 N/mm^2). Although European beech and common alder woods exhibited low resistance in the Black Sea, Mediterranean, and mixed climates, they achieved significantly better performance in the terrestrial climate. In terms of the overall scope of wood species, it can be said that the bending strength values of the samples in contact with soil for three years in the terrestrial climate were quite good. The dry climate in the region and relatively low humidity are considered important factors contributing to these results. The bending strengths of the heartwood of Scots pine and Caucasian spruce were found to be lower than those of the sapwood. In the Black Sea climate, Scots pine heartwood underwent a 60% loss of bending strength, while Caucasian spruce heartwood exhibited a 65% strength loss. This may be attributed to lignin loss caused by rain and UV exposure over three years, which could lead to wood vulnerability. As the lignin content increases, the resistance in wood also increases (Ali et al., 2011). Heartwood in coniferous trees contains more extractives than living wood, but less lignin and cellulose (Merev, 2003). According to a previous study, in bending strength tests conducted after a soil contact test, Scots pine wood samples exhibited greater resistance than spruce wood. Fungal activity caused up to 65% loss of bending strength in spruce wood (Metsä-Kortelainen and Viitanen, 2010). The severe dotting and white rot formation observed in the later years of soil contact, particularly in European beech and common alder woods, are believed to adversely affect resistance values. While weight losses of 1–2% cause serious resistance losses in wood (Sivrikaya, 2003), it is expected that such resistance losses will be seen in weight losses up to 60% in the current study, and some samples will not be included in mechanical tests. While organisms that do not cause decay in the initial stages are present in untreated woods, gradually decaying organisms become effective after three months (Sivrikaya, 2003). In a previous study, in which beech wood classified in the non-durable class and used as a control sample was subjected to a five-year soil contact test, it was reported that the beech wood decayed within an average of three years (Flæte et al., 2009).

2. Modulus of elasticity

In Trabzon, the highest elasticity modulus was observed in Scots pine sapwood (5229.82 N/mm^2). Test samples of European beech sapwood and common alder heartwood were excluded from the experiment due to intense decay. The lowest elasticity modulus value for available test samples was calculated for common alder sapwood (2294.69 N/mm^2). Common alder sapwood and European beech sapwood were in the same homogeneity group. The changes between 2% and10% in the impregnated samples between the first, second and third can be attributed to the difference in the retention amount and some changes in the structure of the wood due to impregnation. The impregnation performance of species such as European beech and common alder, which are in the non-durable class, and Scots pine and Caucasian spruce, which are in the less durable class (Findlay, 1985), once again reveals the importance of impregnation. After the impregnation process, woods with low natural strength can be included in a higher strength class. In a previous study, eastern white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*),

Fig. 3. From left to right: sapwood, heartwood, and impregnated wood

Fig. 4. Unimpregnated beech sapwood test samples from the present study (left). Unimpregnated beech sapwood test samples from a previous study (Zeleniuc et al., 2003)

and balsam fir (*Abies balsamea*) were found to have similar durability to southern pine (*Pinus* spp.) when impregnated with CCA or copper-based preservatives (Lebow et al., 2018). In Muğla, the highest modulus of elasticity value was observed in Scots pine sapwood (5922.90 N/mm^2). Test samples of European beech sapwood/heartwood and common alder sapwood/heartwood were excluded from the experiment due to intense decay. The lowest modulus of elasticity value for available test samples was calculated for Caucasian spruce heartwood (4790.90 N/mm^2). In Çanakkale, the highest elasticity modulus was observed in Scots pine heartwood (6499.58 N/mm^2). Test samples of European beech sapwood/heartwood and common alder sapwood/heartwood were excluded from the experiment due to intense decay, and Scots pine sapwood due to termite attack. The lowest modulus of elasticity value for available test samples was calculated for Caucasian spruce sapwood (4088.14 N/mm^2). The Mediterranean climate is highly conducive to fungal degradation (Saitta et al., 2011). Impregnating wood can achieve an extended service life, particularly in this climate. In this study, impregnated test samples showed better modulus of elasticity performance than their corresponding sapwood and heartwood. In a prior study, *Pinus palustris* specimens were treated with two distinct impregnation materials and maintained in a high decay risk classification. After 25 years, successful outcomes were achieved in combating rot fungi and termites (Nicholas, 2018). In another study, both impregnated and unimpregnated Scots pine test specimens were exposed to degradation tests in direct contact with the soil. No deterioration was found in impregnated Scots pine samples; however, unimpregnated ones deteriorated rapidly. A notable finding of that study was that the degradation rate diminished when the temperature at the experimental sites declined (Alfredsen et al., 2017). In Elazığ, the highest modulus of elasticity was observed for Caucasian spruce sapwood (6525.30 N/mm^2), and the lowest for European beech heartwood (4116.93 N/mm^2). It is thought that the type II white decay fungus detected in some specimens in all climate types may have affected the elasticity modulus results, since it gives some elasticity to the wood (Yıldız et al., 2013). In Trabzon, Scots pine; in Muğla

Table 1. Bending strength of wood samples exposed for 3 years (N/mm^2)

Wood	Part	Trabzon			Muğla			Çanakkale			Elazığ		
		1*	**2****	**3*****	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Scots pine	Sapwood	59.95 gh	57.53 fg	56.08 fg	75.24 efghijk	78.54 ghijk	65.86 efg	68.24 fghi	74.37 ghijk	-	82.01 ijklmno	76.53 fghijklmn	60.50 cde
	Impregnated	84.22 jkl	97.26 n	97.53 n	82.10 ijk	97.84 l	95.31 l	84.90 klmn	95.12 n	93.82 n	85.70 jklmnop	95.54 p	93.41 op
	Heartwood	69.30 hi	62.90 gh	40.88 de	75.80 fghijk	68.03 efgh	62.23 de	72.85 ghij	67.00 fgh	78.67 hijkl	75.58 fghijklmn	71.84 efghi	76.17 fghijklmn
Caucasian spruce	Sapwood	53.02 fg	38.55 d	37.49 d	65.41 defg	66.05 efg	53.38 cd	60.37 ef	-	40.59 d	66.82 defgh	81.89 ijklmno	82.17 ijklmno
	Impregnated	76.95 ijk	94.59 mn	88.69 lmn	70.49 efghij	83.42 jk	78.31 ghijk	73.22 ghijk	88.64 lmn	75.71 ghijk	72.73 efghijk	80.94 ijklmno	70.99 efghi
	Heartwood	67.55 hi	57.68 fg	33.58 cd	68.77 efgh	67.87 efgh	69.22 efghi	73.57 ghijk	73.29 ghijk	66.75 fg	78.41 ghijklmn	86.42 klmnop	74.01 fghijklm
Beech	Sapwood	41.20 de	13.17 a	-	30.62 a	-	-	56.11 e	24.32 bc	-	77.65 fghijklmn	70.21 efghi	45.18 ab
	Impregnated	86.15 klm	88.94 lmn	77.29 ijk	79.47 hijk	82.81 jk	87.44 kl	80.29 jklm	91.46 mn	89.70 lmn	77.30 fghijklmn	87.62 lmnop	87.80 mnop
	Heartwood	21.93 ab	-	-	42.94 bc	-	-	54.82 e	9.59 a	-	64.25 def	35.58 a	49.87 bc
Common alder	Sapwood	25.73 bc	20.28 ab	15.69 a	65.44 defg	-	-	31.64 cd	17.57 ab	-	55.84 bcd	72.20 efghij	72.08 efghij
	Impregnated	74.84 ij	87.62 lmn	87.12 lm	71.41 efghij	75.68 fghijk	79.79 hijk	79.05 ijkl	84.75 jklm	82.03 jklm	65.36 defg	88.27 nop	80.15 hijklmno
	Heartwood	19.67 ab	27.58 bc	-	39.46 ab	-	-	-	-	-	76.83 fghijklmn	73.89 fghijkl	59.41 cde

Different letters in the same row indicate statistical difference ($p < 0.05$). Due to the very small size of the mean and Duncan homogeneity groups, the letters are placed on a separate line. * first year of exposure, ** second year of exposure, *** third (last) year of exposure

Table 2. Modulus of elasticity of wood samples exposed for 3 years (N/mm²)

Wood	Part	Trabzon 1	Trabzon 2	Trabzon 3	Muğla 1	Muğla 2	Muğla 3	Çanakkale 1	Çanakkale 2	Çanakkale 3	Elazığ 1	Elazığ 2	Elazığ 3
Scots pine	Sapwood	2543.82 a	4435.10 def	5229.82 ghij	5910.03 ghijk	5845.37 ghijk	5922.90 ghijk	5180.12 fg	5931.74 hijkl	-	6133.47 fghij	5822.12 efghi	4887.13 cde
	Impreg-nated	6477.32 mno	6972.33 no	6456.56 mno	6037.15 ijk	7170.96 m	6467.65 klm	6421.42 jkl	7143.94 m	6500.52 lm	6653.28 ij	6914.27 j	6736.32 ij
	Heart-wood	6013.05 klm	5822.30 jklm	4433.32 def	5652.20 efghijk	5691.42 efghijk	5145.56 cdefgh	5945.95 hijkl	5657.29 ghi	6499.58 lm	5506.97 defg	5839.50 efghi	5794.08 efghi
Cau-casian spruce	Sapwood	4972.98 fghi	2154.24 a	4127.79 cde	3711.99 a	6386.35 jklm	4876.43 cde	4657.01 ef	-	4088.14 cde	5445.50 defg	6391.55 ghij	6525.30 hij
	Impreg-nated	7021.77 o	6425.78 o	5862.38 mno	5770.16 fghijk	6899.76 lm	6334.79 jkl	5679.94 ghij	6379.24 ijkl	6057.80 hijkl	4247.31 bc	6471.87 fghij	6335.97 ghij
	Heart-wood	5455.31 hijk	4692.89 efg	3276.30 b	6053.16 ijk	5406.75 cdefghi	4790.90 cd	5547.71 gh	6348.82 ijkl	5542.48 gh	6021.85 fghij	6726.50 ij	6330.19 ghij
Euro-pean beech	Sapwood	4297.67 cdef	2505.15 a	-	3759.10 a	-	-	3603.03 bc	3403.19 b	-	5289.55 def	6047.43 fghij	5347.24 def
	Impreg-nated	5862.38 jklm	6501.52 mno	5562.28 ijkl	5806.36 ghijk	6107.52 ijkl	6259.60 ijkl	5728.94 ghijk	6589.18 lm	6140.09 hijkl	5788.55 efghi	6009.34 fghij	6327.23 ghij
	Heart-wood	3625.81 bc	-	-	4571.74 bc	-	-	5588.23 gh	2679.90 a	-	4627.60 cd	3472.65 b	4116.93 bc
Com-mon alder	Sapwood	3677.90 bcd	3344.32 b	2294.69 a	5109.65 cdefg	-	-	4415.35 de	2615.03 a	-	2468.08 a	5925.97 fghi	5781.72 efghi
	Impreg-nated	5574.40 ijkl	6359.87 mno	6230.51 klmn	5691.20 efghijk	6017.24 hijk	6021.95 hijk	6075.59 hijkl	6444.39 klm	5930.91 hijkl	5629.05 efgh	6517.94 hij	6640.60 ij
	Heart-wood	2600.53 a	4545.96 efg	-	3982.73ab	-	-	-	-	-	5240.27def	5780.52efghi	5792.04efghi

Different letters in the same row indicate statistical difference ($p < 0.05$). Due to the very small size of the mean and Duncan homogeneity groups, the letters are placed on a separate line

Table 3. Compression strength parallel to the grain of wood samples exposed for 3 years (above-ground parts) (N/mm^2)

Wood	Part	Trabzon			Muğla			Çanakkale			Elazığ		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Scots pine	Sapwood	51.16 jklm	49.92 ijkl	45.17 fghij	52.13 ijkl	50.68 hijkl	46.94 efghijk	53.12 jklmn	55.30 mno	44.10 defgh	53.80 lmnopr	47.76 fghijklmno	37.12 abcd
	Impregnated	5799 mn	59.69 n	43.64 fghij	53.74 kl	56.87 l	48.94 fghijkl	57.92 mno	60.38 o	47.00 fghij	54.67 nopr	52.75 klmnopr	47.49 efghijklmno
	Heartwood	48.25 hijk	47.39 hijk	41.57 efgh	48.02 efghijk	37.84 bcd	44.77 cdefghij	52.19 jklm	39.39 bcde	48.23 hijk	49.71 ghijklmnop	34.52 a	42.52 abcdefgh
Caucasian spruce	Sapwood	43.52 fghi	39.06 cdef	31.50 b	45.94 defghijk	52.16 ijkl	41.50 cdef	44.58 efghi	44.21 defgh	37.63 abcd	45.28 defghijkl	53.11 lmnopr	40.01 abcdef
	Impregnated	49.53 ijkl	56.47 lmn	46.75 ghij	52.25 jkl	47.59 efghijk	44.72 cdefghij	51.16 ijklm	55.09 lmno	43.67 cdefgh	51.95 jklmnopr	54.03 mnopr	46.67 efghijklmn
	Heartwood	43.86 fghij	46.90 hij	39.00 cdef	57.15 l	45.52 defghijk	40.51 cdef	52.78 jklmn	54.33 klmno	40.99 bcdefg	46.71 efghijklmn	52.78 klmnopr	41.60 abcdefg
European beech	Sapwood	54.25 klmn	44.73 fghij	35.50 bcde	50.26 ghijkl	52.05 ijkl	43.13 cdefgh	53.87 klmno	56.92 mno	42.52 cdefgh	55.52 opr	59.88 r	45.46 defghijklm
	Impregnated	56.21 lmn	57.61 mn	45.93 fghij	56.56 l	52.18 ijkl	45.21 defghij	57.20 mno	59.27 no	47.61 ghijk	53.96 lmnopr	56.60 pr	51.38 ijklmnop
	Heartwood	48.03 hijk	35.70 bcde	33.60 bcd	56.62 l	42.96 cdefgh	43.71 cdefghi	56.10 mno	48.45 hijkl	44.57 efghi	42.78 abcdefghi	45.91 efghijklm	39.05 abcde
Common alder	Sapwood	39.39 defg	31.35 b	17.05 a	42.82 cdefgh	46.36 defghijk	40.90 cdef	37.26 abc	40.04 bcde	32.77 a	39.94 abcdef	45.58 efghijklm	36.53 abc
	Impregnated	47.50 hijk	48.19 hijk	45.06 fghij	44.29 cdefghij	42.03 cdefg	40.03 cde	52.36 jklm	48.35 hijkl	38.75 abcde	48.90 ghijklmnop	51.38 ijklmnop	43.88 bcdefghij
	Heartwood	32.12 bc	43.28 fghi	20.77 a	22.74 a	36.67 bc	31.63 b	35.20 ab	43.12 cdefgh	-	48.72 ghijklmnop	48.97 ghijklmnop	35.66 ab

Different letters in the same row indicate statistical difference ($p < 0.05$). Due to the very small size of the mean and Duncan homogeneity groups, the letters are placed on a separate line

Table 4. Compression strength parallel to the grain of wood samples exposed for 3 years (underground parts) (N/mm²)

Wood	Part	Trabzon			Muğla			Çanakkale			Elazığ		
		1	2	3	1	2	3	1	2	3	1	2	3
Scots pine	Sapwood	44.51 ghij	42.91 ghi	30.19 cd	50.16 hijklmn	48.76 ghijklm	40.60 def	44.24 ij	47.82 ijklm	-	51.28 jklmnop	45.89 defghijkl	34.88 c
	Impregnated	59.05 n	60.42 n	47.26 hijk	56.61 no	61.86 o	48.67 ghijklm	55.80 nop	61.08 pr	50.91 jklmno	57.26 prs	60.71 rs	47.48 efghijklm
	Heartwood	43.32 ghi	47.35 hijk	34.31 cde	48.62 ghijklm	41.58 defg	37.58 de	49.31 ijklmn	47.50 ijkl	42.03 ghi	50.51 ijklmnop	41.58 cdefgh	45.22 defghijkl
Caucasian spruce	Sapwood	40.54 efgh	31.46 cd	27.52 bc	41.55 defg	45.62 fghij	34.53 d	36.90 fg	32.21 ef	29.30 e	40.99 cdefg	48.82 ghijklmnop	40.35 cdef
	Impregnated	54.34 n	57.81 mn	46.95 hijk	46.69 fghijk	51.24 ijklmn	47.92 ghijkl	51.73 klmno	57.71 op	43.87 hij	48.13 fghijklmn	56.10 noprs	48.84 ghijklmnop
	Heartwood	41.61 fghi	38.93 efg	28.17 bc	49.34 hijklmn	45.21 fghi	35.57 d	47.87 ijklm	50.81 jklmno	3736 fgh	49.65 hijklmnop	55.01 mnopr	39.85 cde
European beech	Sapwood	34.69 cde	34.35 cde	27.84 bc	5.93 a	-	-	36.62 fg	20.63 d	-	43.02 defghi	38.37 cd	13.25 a
	Impregnated	52.13 klm	50.61 jkl	45.18 ghijk	55.91 mno	54.60 lmn	47.83 fghijkl	54.98 mnop	64.39 r	49.25 ijklmn	56.35 oprs	63.00 s	55.41 mnoprs
	Heartwood	33.69 cde	-	-	22.08 c	12.94 b	-	34.48 ef	8.89 ab	-	34.03 c	17.27 ab	20.66 b
Common alder	Sapwood	29.52 bcd	-	-	42.87 efgh	-	-	15.81 cd	6.09 a	-	40.44 cdef	41.71 cdefgh	39.32 cde
	Impregnated	48.88 ijkl	58.50 mn	42.72 ghi	52.88 jklmn	53.18 klmn	48.34 ghijkl	54.59 lmnop	57.46 op	48.15 ijklm	51.78 klmnop	53.11 lmnopr	47.50 efghijklm
	Heartwood	23.11 ab	28.52 bcd	17.04 a	25.43 c	-	-	9.58 abc	-	-	23.99 b	34.98 c	20.48 b

Different letters in the same row indicate statistical difference ($p < 0.05$). Due to the very small size of the mean and Duncan homogeneity groups, the letters are placed on a separate line

and Çanakkale, Scots pine and Caucasian spruce; and in Elazığ, all wood species exhibited remarkably high modulus of elasticity values. In all impregnated samples, the modulus of elasticity values were found to be close to those of the control.

3. Compression strength parallel to grain (above-ground)

In Trabzon, the highest above-ground compression strength parallel to the grain was observed in Scots pine sapwood (45.17 N/mm^2), and the lowest in common alder sapwood (17.05 N/mm^2). Common alder heartwood and sapwood are in the same homogeneity group. At the end of the third year, the lowest resistance value in impregnated test samples was observed in Scots pine wood, and the highest in Caucasian spruce wood. Comparing compressive strength parallel to fibers with bending strength, differences are found. Wood rot is initially identified by a reduction in weight during outdoor assessments (Thaler et al., 2013). Rot diminishes compressive strength parallel to the fibers at a slower rate than bending strength (Witomski et al., 2016). A 30% reduction in weight from white rot in Scots pine wood diminishes compressive strength parallel to the fibers by 50%. A 50% reduction in compressive strength parallel to the fibers in the same test sample necessitates a 20% decrease in brown rot weight. Compressive strength was enhanced in impregnated samples. Decay and weight reduction are associated with this outcome. Rahman et al. (2010) impregnated tropical wood species with sodium metaperiodate, and tests showed an increase of up to 80% in compressive strength parallel to the fibers in impregnated samples compared with control samples. In Muğla, the highest above-ground compression strength parallel to the grain was observed in Scots pine sapwood (46.94 N/mm^2), and the lowest in common alder heartwood (31.63 N/mm^2). At the end of the third year, all unimpregnated samples, with the exception of common alder heartwood and sapwood, had compressive strength values in a range from 39.23 to 49.03 N/mm^2. In impregnated samples, the value could surpass 49.03 N/mm^2. In a prior study, wood samples of poplar (*Populus nigra*), both test and control, impregnated with boric acid, were exposed to the white rot fungus *Trametes versicolor*. After 14 weeks, the impregnated test samples had the highest compression strength parallel to the grain (22.59 N/mm^2), compared with only 10.42 N/mm^2 for the control samples (Hashemi et al., 2010). Jacobs et al. (2019) found that the middle section, which is exposed to soil and air, had the greatest prevalence of fungus in open field wood test specimens. In another study, beech (*Fagus orientalis*) was degraded by white rot fungus (*Coriolus versicolor*) in a laboratory for 14 weeks. At the end of the period, compressive strength parallel to the fibers decreased by 68% for heartwood and 60% for sapwood (Malakani et al., 2014). In the present study, which featured different testing conditions and durations, the compressive strength of European beech heartwood decreased by 48% and that of the sapwood by 43%. European beech heartwood and sapwood show low decay resistance when exposed to white rot fungi. Toxic extracts in beech heartwood have little or no effect against fungal decay (Malakani et al., 2014). In Çanakkale, the highest above-ground compression strength parallel to the grain was observed in Scots pine heartwood (48.23 N/mm^2). Test samples of common alder heartwood were excluded from the test due to intense rot. The lowest above-ground compression strength parallel to the grain after the exclusion of the common alder heartwood samples was found for common alder sapwood (32.77 N/mm^2). At the end of the third year, higher compression strength parallel to the grain was obtained in all heartwoods (except for common alder) compared with sapwood. Grabner et al. (2005) reported that heartwoods of larch (*Larix decidua* Mill.) gave higher results for compression strength parallel to the grain than sapwood. The reason for this is shown to be the extra strength provided by the extractives filling the heartwood tracheids. It was seen that the termite attacks in the underground part do not affect the compressive strength values above the soil. In the impregnated test samples, a compressive strength close to that of the heartwood was found. Among the samples treated with CCB, the lowest resistance value was obtained for common alder wood, and the highest for Scots pine wood. In the mixed climate, similar results were obtained to those for the Mediterranean climate. In Elazığ, the highest above-ground compression strength parallel to the grain was observed in European beech sapwood (45.46 N/mm^2), and the lowest in common alder heartwood (35.66 N/mm^2). At the end of the third year, the lowest resistance values in the impregnated test samples were obtained in Caucasian spruce and common alder wood, and the highest in European beech wood. It can be said that European beech wood, which initially exhibited low durability in contact with the soil, was quite durable and showed good resistance when impregnated. Common alder has the lowest parallel-to-grain compression strength in particular climates. Previous studies have shown that alder is not durable in outdoor conditions (Gürsu, 1967). In dry climates, the values of compression strength parallel to the grain for common alder heartwood and sapwood do not significantly differ, but in humid climates, this difference becomes evident. Species with low natural durability, such as European beech and common alder, have low contents of extractive substances. A study of gymnosperm woods found that species with low levels of chemical components in their sapwood also have low levels of chemical components in their heartwood (Meerts, 2002). Also, in some broad-leaved tree species, the strength decreases from the heartwood's edges to its middle part. This is because polyphenols polymerize, making extractive substances in the heartwood less effective (Nelson and Heather, 1972).

4. Compression strength parallel to grain (underground)

In Trabzon, the highest underground compression strength parallel to the grain was observed in Scots pine heartwood (34.31 N/mm^2), and the lowest in common alder heartwood (17.04 N/mm^2). Common alder heartwood and sapwood were in the same homogeneity group. The high humidity and acidic soil structure of the Black Sea climate facilitate the degradation of wood (Klinka et al., 1995). This situation is also noticeable in other woods. However, Scots pine showed better resistance than the others due to its high content of extractive substances. The compression strength parallel to the grain of the impregnated test samples, both above-ground and underground, were notably similar. Visual examinations showed no signs of degradation other than the color difference caused by soil residues. Impregnated Scots pine in Trabzon achieved 27% higher compressive strength than Scots pine heartwood. The equivalent percentages were 40% and 60% for Caucasian spruce and common alder, respectively. According to the results, it is certainly recommended to impregnate the wood in applications where there is a possibility of contact with the soil.

In Muğla, the highest underground compression strength parallel to the grain was observed in Scots pine sapwood (40.60 N/mm^2), while the test samples of European beech sapwood/heartwood and common alder sapwood/heartwood were excluded from the experiment during the measurements due to intense decay. The values of underground compression strength parallel to the grain for impregnated Scots pine, Caucasian spruce, European beech, and common alder test samples were 48.38 N/mm^2, 47.92 N/mm^2, 47.83 N/mm^2, and 48.34 N/mm^2, respectively. A study conducted by Akgül et al. (2017) revealed that Scots pine fibers combined with 2% nano CCB had a compressive strength of 58.00 N/mm^2. The control samples had a compressive strength of 42.86 N/mm^2. Given that the impregnated samples in this investigation were in contact with the soil in an open field for three years, it an be asserted that they exhibited superior compressive strength relative to the values reported in the existing literature. Temiz et al. (2004) utilized CCA impregnation solution on alder wood at different concentrations using a pressure method. The compressive strength values aligned with the fibers ranged from 36.06 N/mm^2 to 56.73 N/mm^2. In Çanakkale, the highest underground compression strength parallel to the grain was observed in Scots pine heartwood (42.03 N/mm^2), while Scots pine sapwood was excluded from the experiment due to termite damage, and common alder and European beech were excluded due to intense decay. Despite being buried, impregnated test samples showed no termite damage or decay. In Elazığ, the highest underground compression strength parallel to the grain was observed in Scots pine heartwood (45.22 N/mm^2), and the lowest in European beech sapwood (13.25 N/mm^2). Wood durability is affected by soil microorganisms, meteorological events, micro and macro flora, animal pests, and UV (Rahman and Chattopadhyay, 2007). Scots pine, European spruce, European beech, Douglas fir, and pedunculate oak were tested in six environments in Hannover, including normal soil, fertilized soil, peat–soil mixture, bark mulched soil, sandy and gravelly soil, and a concrete floor. Concrete was the slowest degradation environment as observed in 4.5-year-old field samples. Concrete lacks soil degradative microbes, which contributed to this outcome. After concrete, sand and gravelly soil also produced slow decay (Brischke et al., 2014).

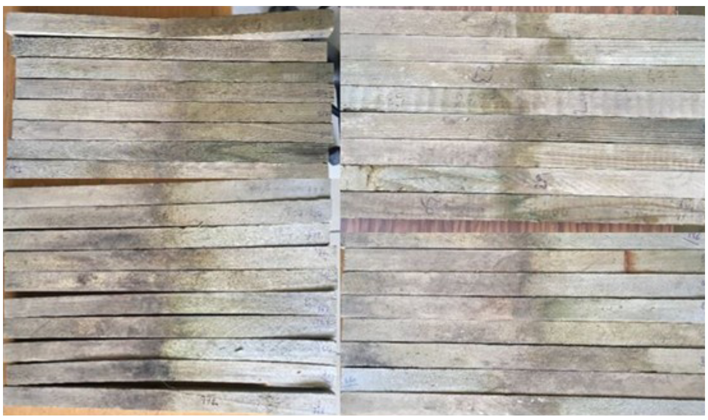

Fig. 5. Images of the above-ground and underground parts of the impregnated samples after three years in soil

Conclusion

For particular wood species, bending strengths were found to be highest in Elazığ, followed by Muğla and Çanakkale, with the lowest in Trabzon. The termite degradation observed in Scots pine and Caucasian spruce in Çanakkale reveals the durability of the heartwood. Within particular climate types, higher bending strength values were obtained for Scots pine and Caucasian spruce than for European beech and common alder. Although the bending strength values observed in Elazığ are much higher than in the other locations, the results for Scots pine and Caucasian spruce woods are remarkable. The bending strength values of European beech and common alder were lower. It was observed that the bending strength of beech wood was lower than that of common alder. The bending strength values of impregnated samples were found to be close to those of the unimpregnated control samples. For particular wood species, modulus of elasticity was highest in Elazığ and lowest in Trabzon and Çanakkale. The relation between heartwood and sapwood was similar as in the case of the bending strength results. Within particular climate types, Scots pine and Caucasian spruce had higher modulus of elasticity than European beech and common alder. While the modulus of elasticity in Elazığ was higher than in other regions, the results for common alder and Caucasian spruce wood were also remarkable. European beech had a lower modulus of elasticity. Impregnated samples had similar modulus of elasticity to the control samples. Elazığ had the highest values for above-ground and underground compression strength parallel to the grain, whereas Trabzon and Çanakkale had the lowest, for particular tree species. Compressive strength differed between heartwood and sapwood. Within particular climate types, common alder wood had the lowest above-ground and underground compressive strength. The compressive strengths obtained for other wood species were similar, although that of Scots pine was superior. Evaluation of impregnated samples revealed that common alder wood had the lowest above-ground and underground compressive strength, while Scots pine wood had the highest. A significant difference in durability was detected between the above-ground and underground sections. The results indicated that all wood types could be utilized in contact with soil for a limited duration in a terrestrial climate. In other climate types, the utilization of deciduous tree woods without impregnation should be discouraged, particularly in uses requiring direct contact with the soil. Field trials were shown to be crucial for assessing the service life of timber products intended for outdoor usage. It was indicated that varying climates and soil structures significantly influence wood strength.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

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