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Investigation of the Effect of Wood Type, Drying Time and Impregnation Type on Evaporation Speed in Wooden Material

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ABSTRACT

In this study, the sapwoods of black pine (*Pinus nigra*), Oak (*Quercus ithaburensis*), Beech (*Fagus orientalis*), Spruce (*Picea orientalis*) and Larex (*Larix decidua*) woods, which are the most preferred in the timber and furniture sector in experimental studies, were used. All wood samples used were purchased from local timber operators operating in Simav district of Kütahya province. Prepared wood samples were impregnated by using three different.impregnation materials at Semitaş A.Ş located in Banaz district of Uşak province. These impregnations are Protim Wr 265, Celcure C4 ve Celbronze 150 Ac Dye. According to the result obtained, the highest absorption of impregnation meterial was observed in Larch and Beech wood samples treated with Celcure C4 impregnation meterial. The least impregnation absorption was observed in Larex wood samples where Protim Wr 265 impregnation material was applied. When we investigate at the evaporation rate results, the lowest evaporation rate was seen in the Spruce wood samples for all three impregnation materials. The samples with the highest evaporation rate were Larex wood samples. The highest evaporation was observed when the Larex wood sample impregnated with Celcure C4 was incubated for 36 hours (0.02032 kg/m^2.hour).

Keywords: Celbronze; Celcure C4; Drying Time; Evaporation Rate; Protim Wr 265; Beech; Oak; Spruce; Larex; Impregnated.

1. Introduction

Wood has long been recognized as one of the oldest and most widely utilized natural materials in human history, serving various functional and structural needs [1]. Due to its abundance, lightweight nature, high durability, and ease of processing, wood remains a preferred material across multiple industries [2]. Its aesthetic qualities and organic structure make it particularly suitable for the production of furniture and decorative items [3,4]. Despite these advantageous properties, wood is inherently susceptible to environmental factors and biological degradation caused by microorganisms such as fungi, bacteria, and insects. Consequently, protective measures are necessary to enhance the longevity and performance of wooden furniture and decorative products [5]. Various defects, including surface and internal cracks, can arise in wood due to exposure to environmental conditions such as moisture and temperature fluctuations. Furthermore, biological deterioration manifested as decay, discoloration (bluing), and staining commonly occurs due to fungal infestations [6]. The overarching goal of wood protection methods is to inhibit the colonization and activity of biological pests by creating unfavorable living conditions within the wood structure [7]. To improve resistance against biological, chemical, and physical degradation, a range of preservation techniques such as controlled drying, impregnation, and surface treatments are applied based on the intended use of the material [8]. Among these, impregnation is a widely used method whereby chemical materials are introduced into the porous structure of the wood to protect it against biological pests (e.g., fungi, insects, termites, and marine borers), fire hazards, and dimensional instability [6]. Impregnation materials are generally categorized into three types: water-based, organic solvent-based, and oil-based preservatives. These substances are particularly recommended for wooden elements that come into direct contact with soil, are exposed to open air, or are used in aquatic environments [9]. Water-soluble preservatives either chemically react with the wood components or become fixed within the structure through precipitation reactions during the impregnation process, thereby increasing resistance to leaching a process known as fixation [10]. Given that these preservatives leave a dry and coatable surface upon application, they are also utilized in architectural and landscaping applications such as flooring and fencing, in addition to their use in structural timber, poles, and marine environments [11].

Proper drying is another essential step that significantly affects the final quality and durability of wood. Drying refers to the removal of excess moisture not suitable for the wood's intended purpose, and it plays a critical role in preventing dimensional changes and microbial degradation [12]. Moisture loss in wood-based materials often leads to structural deformations such as joint separations in furniture, opening at frame corners, warping of window sashes and doors, longitudinal shrinkage in shelves, surface cupping, and gaps between flooring components [13]. To prevent such defects and maintain the quality of wood, the drying process must be carefully managed to reduce moisture content to a level appropriate for the intended application [14].

Wood can be dried naturally by stacking it in shaded or open areas, allowing it to be exposed to ambient climatic conditions this method is known as natural drying [15]. In contrast, technical drying is conducted in specially designed chambers with controlled environmental parameters, including temperature, relative humidity, and air circulation [16]. When wood is dried under suitable conditions and its moisture level is properly maintained, the risk of fungal decay is significantly reduced. Fungal activity, which is the primary cause of wood decay, requires the presence of moisture, heat, and oxygen. Therefore, controlling any of these factors can effectively inhibit the colonization of decay fungi.

Bülbül and Keskin [17] the impacts of impregnation with Tanalith-E on surface roughness of solid wood materials determine the impacts of impregnation with Tanalith-E on surface roughness of solid wood materials. For this purpose, Oriental beech (Fagus orientalis Lipsky), Scotchpine (*Pinus sylvestris* Lipsky), European oak (*Quercus petraea* Liebl.) and Uludag fir (*Abies nordmanniana* subsp. Bornmüllerana Mattf.) woods widely used in Turkey are impregnated with Tanalith-E impregnation solution for short term (10 minutes) and medium term (2 hours) immersion method according to ASTM D 1413 standard.

1.1. Objectives of the Scientific Study

1) Determination of the weight differences in wood materials after impregnation absorption with Protim Wr 265 impregnation material.

2) Determination of the weight differences in wood materials after impregnation absorption with Celcure C4 impregnation material.

3) Determination of the weight differences in wood materials after impregnation absorption with Celbronze AC 150 Dye 4 impregnation material.

4) Determination of the evaporation rate in wood materials after impregnation absorption with protim wr 265 impregnation material.

5) Determination of the evaporation rate in wood materials after impregnation absorption with celcure c4 impregnation material.

6) Determination of the evaporation rate in wood materials after impregnation absorption with Celbronze AC 150 Dye 4 impregnation material.

7) The objective of this study is to investigate the effects of wood species, drying temperature, and drying duration on the evaporation rate of moisture in wood.

2. Materials and Methods

2.1. Materials

2.1.1. Wood materials

In this study, the sapwoods of black pine (*Pinus nigra* Arnold), Oak (*Quercus ithaburensis* Decne), Beech (*Fagus orientalis* Lipsky), Spruce (*Picea orientalis* Lipsky) and Larex (*Larix decidua* Mill.) woods, which are the most preferred in the timber and furniture sector in experimental studies, were used.All wood samples used were purchased from local timber operators operating in Simav district of Kütahya province. In the selection of wood samples, care was taken to ensure that it had smooth fibers, no backings, no knots, regular annual rings, and was not exposed to fungal or insect damage.

2.1.2. Impregnation materials

Protim Wr 265, Celcure C4, and Celbronze 150 Ac Dye were used as impregnation materials. These materials were supplied from Semitaş A.Ş. located in Banaz district of Uşak province. The physical and chemical properties of impregnation materials are given in Table 1.

Table 1. Physical and chemical properties of impregnation materials used in this study

Properties	Protim Wr 265	Celcure C4	Celbronze 150Ac Dye
Situation	Liquid	Liquid	Liquid
Colour	Transparent	Blue	Brown
Smell	Detectable	Amine	Detectable
Solubility in water	Immiscible	Miscible	Miscible
Viscosity	Second	-	-
Flash point	75 °C	n/a	n/a
pH	5-6	10-12	6-7
Relative Density	0.75-0.85	1.1-1.3	1.16
Flammability	Flammable	None Flammable	Flammable

2.2. Preparation of Test Samples

Wood specimens intended for the experiments were precisely machined to final dimensions of 19 × 40 × 25 mm (radial × tangential × longitudinal). From each wood species, twelve specimens exhibiting the closest initial weights were selected to ensure uniformity, resulting in a total of 60 samples. All specimens were individually coded, and their initial masses were determined using a precision analytical balance (±0.001 g accuracy) and recorded for subsequent analysis.

For the experiments, twelve wood specimens were prepared from each wood species. The specimens were then divided into four subgroups within each species, with each subgroup consisting of three samples. Subsequently, three samples from each species were combined to form composite batches containing a total of fifteen specimens, which were subjected to the impregnation process. All numbered and grouped specimens were impregnated using the full-cell (Bethell) method at the Semitaş Impregnation and Industry Facility located in Banaz, Uşak, Turkey. Three different impregnation chemicals were used during the treatment process: Protim Wr 265, Celcure C4, and Celbronze 150 AC Dye.

To evaluate the effectiveness of different preservative treatments on wood performance, the specimens were divided into three experimental groups. Group 1 (samples 4–6) was impregnated with a preservative referred to as Natural Preservative (Protim Wr 265). The specimens were exposed to Protim Wr 265 under a pressure of 12 atmosfe basıncı (atm) for a duration of 3 hours. Group 2 (samples 7–9) was treated with Green Preservative (Celcure C4), prepared as a 2.5% concentration solution and applied to the specimens under 12 atm pressure for 4 hours. Depending on the prevailing environmental conditions, the treatment duration could be extended to ensure complete impregnation. Group 3 (samples 10–12) was impregnated with Brown Preservative (Celbronze AC 150 Dye). For this treatment, Celbronze AC 150 Dye was mixed with Celcure C4 to obtain a 2.5% concentration solution, which was then applied to the wood specimens under 12 atm pressure for 4 hours.

Following the impregnation process, all specimens were left to rest for 2–3 days to allow the preservative solution to drain completely, after which their initial weights were recorded. Subsequently, the specimens were conditioned in a climate chamber for two weeks to achieve an appropriate moisture content. After conditioning, the weights of all test specimens were measured using a precision balance and documented. The specimens were then grouped and subjected to oven-drying at 60 °C for 36 h and 72 h, respectively. The weights of the specimens were measured individually after each drying interval. Following this stage, the specimens were oven-dried again at 80 °C under the same conditions (36 h and 72 h), and their weights were recorded after each drying period. Upon completion of all drying procedures, the final weights of the specimens were measured and systematically documented.

2.3. Density

The oven-dry density values of the wood materials were determined using air-dried specimens, in compliance with the principles outlined in TS 2472. For this purpose, the specimens in air-dry condition were subjected to drying in a ventilated oven at 103 ± 2 °C until a constant weight was achieved, ensuring the complete removal of moisture. After drying, the specimens were cooled in a desiccator containing $CaCl_2$ to prevent re-absorption of atmospheric humidity and subsequently weighed with an analytical balance having a precision of 0.01 g. Dimensional measurements were conducted with a digital caliper accurate to ± 0.01 mm, and specimen volumes were determined using the stereometric method. Based on these measurements, the oven-dry density (δ_0) of the specimens was calculated as the ratio of oven-dry weight (M_0) to oven-dry volume (V_0). This procedure ensures accurate and reproducible determination of the fundamental physical property of wood materials, which is critical for characterizing their mechanical performance and dimensional stability in engineering applications.

The oven-dry density of the wood samples was calculated by using Equation 1:

$$\delta_0 = \frac{M_0}{V_0} \qquad (1)$$

where δ_0 is oven-dry density (kg/m^3), and M_0 is the oven-dry weight of the material (kg), and V_0 is the oven-dry volume of the material (m^3).

2.4. Evaporation Rate

The evaporation rate was calculated using the formulas given in Equations (2) and (3):

$$U_k = \frac{mr_s - mr_b}{S.D_z} \qquad (2)$$

where U_k: evaporation rate (kg/m^2.hour), mr_b: the initial weights (kg), mr_s: final weights (kg), S: evaporation surface area (m^2), D_z: Time (hour).

$$S = \frac{V_d}{e} \qquad (3)$$

where S: evaporation surface area (m^2), V_d: saturated volume (m^3), e: thickness (m).

3. Results

The results concerning the weight differences of wood materials impregnated with various groups of impregnation materials after the impregnation absorption process are presented in Table 2.

Table 2. Weight differences in wood materials after impregnation absorption with different impregnation materials

Impregnation materials	Test of Samples	Initial Weight (kg)	Impregnated weight (kg)	Difference (kg)
Control	Black pine 1	0.02048	-	-
	Black pine 2	0.02067	-	-
	Black pine 3	0.02036	-	-
	Beech 1	0.02738	-	-
	Beech 2	0.02762	-	-
	Beech 3	0.02788	-	-
	Oak 1	0.02826	-	-
	Oak 2	0.02843	-	-
	Oak 3	0.02828	-	-
	Spruce 1	0.01846	-	-
	Spruce 2	0.01851	-	-
	Spruce 3	0.01827	-	-
	Larex 1	0.02680	-	-
	Larex 2	0.02674	-	-
	Larex 3	0.02704	-	-
Protim Wr 265	Black pine 4	0.02059	0.022981	0.002393
	Black pine 5	0.02085	0.023427	0.002578
	Black pine 6	0.02089	0.023120	0.002229
	Beech 4	0.02814	0.032423	0.004282

	Beech 5	0.02805	0.033149	0.005103
	Beech 6	0.02756	0.033357	0.005800
	Oak 4	0.02927	0.030314	0.001049
	Oak 5	0.02767	0.029328	0.001663
	Oak 6	0.02766	0.029658	0.001999
	Spruce 4	0.01877	0.019776	0.001007
	Spruce 5	0.01891	0.019930	0.001010
	Spruce 6	0.01939	0.020333	0.000946
	Larex 4	0.02735	0.028225	0.000877
	Larex 5	0.02715	0.027957	0.000811
	Larex 6	0.02680	0.027635	0.000834
Celcure C4	Black pine 7	0.02059	0.030434	0.009848
	Black pine 8	0.02041	0.029848	0.009435
	Black pine 9	0.02071	0.029727	0.009018
	Beech 7	0.02835	0.037988	0.009635
	Beech 8	0.02843	0.039746	0.011320
	Beech 9	0.02722	0.035682	0.008460
	Oak 7	0.02718	0.034671	0.007496
	Oak 8	0.02799	0.032346	0.004353
	Oak 9	0.02896	0.033091	0.004130
	Spruce 7	0.01818	0.022992	0.004809
	Spruce 8	0.01832	0.025447	0.007124
	Spruce 9	0.01877	0.023766	0.004996
	Larex 7	0.02707	0.035685	0.008615
	Larex 8	0.02630	0.037429	0.011126
	Larex 9	0.02735	0.035504	0.008154
Celbronze AC 150 Dye	Black pine 10	0.02077	0.030297	0.009523
	Black pine 11	0.02084	0.030066	0.009231
	Black pine 12	0.02030	0.028822	0.008526
	Beech 10	0.02791	0.036644	0.008736
	Beech 11	0.02756	0.037072	0.009509
	Beech 12	0.02802	0.036959	0.008944
	Oak 10	0.03011	0.031955	0.001848
	Oak 11	0.02797	0.031436	0.003462
	Oak 12	0.02828	0.033091	0.004812
	Spruce 10	0.01876	0.021733	0.002976
	Spruce 11	0.01841	0.021916	0.003506
	Spruce 12	0.01910	0.022209	0.003113
	Larex 10	0.02726	0.031124	0.003868
	Larex 11	0.02719	0.032364	0.005173
	Larex 12	0.02770	0.030852	0.003155

According to Table 2, among all tested samples, the greatest weight gain following impregnation absorption was found in Beech group 8 specimens treated with Celcure 4, indicating a high level of chemical retention. In contrast, the lowest weight difference was observed in Larex group 4 specimens impregnated with Protim Wr 265, suggesting a comparatively lower uptake of the treatment solution. When the impregnation material groups were compared, the highest post-impregnation weight gain was observed in specimens treated with Celcure 4, followed by those treated with Clebronze AC 150 Dye and Protim Wr 265, respectively.

Upon examination of the test specimens treated with the Protim Wr 265 impregnation material, the highest absorption was observed in the Beech 6 samples (0.005800 kg), while the lowest absorption was recorded in the Larex 5 samples (0.000811 kg). For the specimens treated with the Celcure 4 impregnation material, the Beech 8 samples exhibited the highest impregnation uptake (0.011320 kg), whereas the lowest uptake was found in the Oak 9 samples (0.004130 kg). In the case of specimens treated with the Celbronze AC 150 Dye impregnation material, the highest absorption was again measured in the Black Pine 10 samples (0.009523 kg), with the lowest value observed in the Oak 10 samples (0.001848 kg). These variations in evaporation rates are attributed to differences in wood species' anatomical structures, permeability characteristics, and interactions with the specific chemical formulations used.

These findings reflect the degree of chemical uptake by the wood specimens, which is a critical parameter for assessing the effectiveness and penetration capacity of the impregnation treatment. The observed weight changes serve as an indirect indicator of the retention levels of the treatment solutions and are essential for evaluating the potential improvement in the wood's durability and resistance against biological or environmental degradation.

Evaporation rate results for wood materials impregnated with various impregnating materials are given in Table 3.

Table 3. Evaporation rate results for wood materials impregnated with various impregnating materials

Impregnation materials	Wood Type	Temperature (^{0}C)	Time (Hour)	Evaporation Rate (kg/m^{2}hour)
Control	Black pine	60	36	0.01100
			72	0.00630
		80	36	0.01440
			72	0.00740
	Beech	60	36	0.01150
			72	0.00650
		80	36	0.01490
			72	0.00760
	Oak	60	36	0.01160
			72	0.00700
		80	36	0.01573
			72	0.00822
	Spruce	60	36	0.00960
			72	0.00558
		80	36	0.01210
			72	0.00620

	Larex	60	36	0.01351
			72	0.00774
		80	36	0.01738
			72	0.00904
Protim Wr 265	Black pine	60	36	0.01320
			72	0.00930
		80	36	0.01662
			72	0.00883
	Beech	60	36	0.01330
			72	0.00810
		80	36	0.01850
			72	0.00960
	Oak	60	36	0.01210
			72	0.00760
		80	36	0.01718
			72	0.00890
	Spruce	60	36	0.01087
			72	0.00620
		80	36	0.01390
			72	0.00719
	Larex	60	36	0.01434
			72	0.00831
		80	36	0.01811
			72	0.00932
Celcure C4	Black pine	60	36	0.01410
			72	0.00780
		80	36	0.01741
			72	0.00891
	Beech	60	36	0.01710
			72	0.00970
		80	36	0.01980
			72	0.01000
	Oak	60	36	0.01500
			72	0.00880
		80	36	0.01927
			72	0.01000
	Spruce	60	36	0.01164
			72	0.00660
		80	36	0.01185
			72	0.00610
	Larex	60	36	0.01562
			72	0.00905
		80	36	0.02032
			72	0.01057

Celbronze AC 150 Dye	Black pine	60	36	0.01400
			72	0.00790
		80	36	0.01681
			72	0.00863
	Beech	60	36	0.01640
			72	0.00930
		80	36	0.02000
			72	0.01000
	Oak	60	36	0.01500
			72	0.00880
		80	36	0.01815
			72	0.00942
	Spruce	60	36	0.01150
			72	0.00660
		80	36	0.01445
			72	0.00740
	Larex	60	36	0.01579
			72	0.00921
		80	36	0.01952
			72	0.01023

As presented in Table 3, the highest evaporation rate following the impregnation process was recorded in the Larex wood specimens treated with Celcure C4 were subjected to a conditioning process at 80 °C for 36 hours. Conversely, the lowest evaporation rate was observed in the in the Spruce wood specimens treated with non-impregnated (Control) were subjected to a conditioning process at 60 °C for 72 hours, suggesting limited chemical uptake and lower subsequent moisture loss.

When comparing the average evaporation rates across different impregnation materials, specimens treated with Celcure 4 exhibited significantly higher values, followed by those treated with Celbronze AC 150 Dye and Protim Wr 265, respectively. These findings clearly demonstrate that the type of preservative material has a substantial effect on post-treatment evaporation behavior.

The evaluation of the specimens treated with the Protim Wr 265 preservative revealed that the highest evaporation rate was measured in the Oak wood with a conditioning process at 80 °C for 36 hours, whereas the lowest evaporation rate was recorded in the Spruce wood with a conditioning process at 80 °C for 36 hours. The evaluation of the specimens treated with the Celcure C4 preservative revealed that the highest evaporation rate was measured in the Larex wood with a conditioning process at 80 °C for 36 hours, whereas the lowest evaporation rate was recorded in the Spruce wood with a conditioning process at 60 °C for 72 hours. The evaluation of the specimens treated with the Celbronze AC 150 Dye preservative revealed that the highest evaporation rate was measured in the Beech wood with a conditioning process at 80 °C for 36 hours, whereas the lowest evaporation rate was recorded in the Spruce wood with a conditioning process at 60 °C for 72 hours.

4. Conclusions

As a result of the conducted analyses, it was observed that the Protim Wr 265 preservative exhibited the highest penetration into Beech (*Fagus orientalis* L.) wood samples when comparing the initial weights before treatment and the final weights after impregnation. In contrast, the lowest penetration of this preservative was recorded in Larex (*Larix decidua*) wood samples. For the samples treated with Celcure C4, although the weight differences were not significantly distinct, Black pine (*Pinus nigra*) samples showed higher absorption levels, whereas the lowest uptake was again observed in Larex wood samples.

In the case of samples treated with Celbronze, the highest preservative retention was observed in Scots Pine and Beech wood specimens, based on weight measurements. Larex wood samples showed the lowest absorption in this group as well.

According to the evaporation rate data, the highest evaporation rate was observed in the Larex wood samples treated with Celcure C4, which were conditioned at 80 °C for 36 hours (0.02032 $kg/m^2 \cdot hour$). Conversely, the lowest evaporation rate was recorded in untreated Spruce control samples conditioned at 60 °C for 72 hours (0.00558 $kg/m^2 \cdot hour$). In general, the highest evaporation rates (excluding Spruce samples) were recorded in all wood species treated with Celcure C4 and conditioned at 80 °C for 36 hours. For Spruce, however, the highest evaporation rate was observed in the samples treated with Celbronze AC 150. The lowest evaporation rates across all wood species were consistently found in the untreated control samples conditioned at 60 °C for 72 hours.

5. Future Recommendations

In future scientific studies on wood-based sandwich panels, the following may be recommended:

1- CCA (Copper/Chromium/Arsenate), ACC (Acid/Copper/Chromate), CCB (Copper/Chromium/Boron), FCAP (Fluorine/Chromium/Arsenate/Phenol, CCP (Copper/Chromium/Phosphorus) 2- Epoxy and polyvinyl acetate adhesives as impregnation material.

2- As an impregnation method, the full cell method and the empty cell method can be applied, among the pressure-applied methods.

3- Additionally, the bending strength, modulus of elasticity, and dowel tensile strength of wood-based sandwich panels produced using the above materials may be investigated.

6. Limitations

Due to some limitations such as insufficient lab-server facilities and lack of financial support, the real data can't be applied for this analysis. However, the methodological process and the features of the results would be similar if the real data set were used.

Declarations

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Competing Interests Statement

The authors have declared that no competing financial, professional, or personal interests exist.

Consent for publication

All the authors contributed to the manuscript and consented to the publication of this research work.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

Availability of data and materials

Supplementary information is available from the authors upon reasonable request.

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Informed Consent

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