Bartın Orman Fakültesi Dergisi | Journal of Bartin Faculty of Forestry
2023, 25(1): 43–57 | DOI: 10.24011/barofd.1154796
BAROFD

The Impact of a Water Repellent Chemical (Ruco-DryEco®) Used in Textile Industry on Certain Physical Properties of Wood

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Article History
Received: 03.08.2022
Accepted: 28.12.2022
Published: 15.04.2023

Research Article

Abstract − This study investigated the impact of a water repellent chemical used in the textile industry on certain physical properties of wood materials. Uludağ fir (*Abies bornmülleriana* Mattf) and Oriental beech wood (*Fagus orientalis* Lipsky) were used as wood materials and Ruco-DryEco®, a water-based, fluorine-free product for textile industry, was used as chemical material. This product is used at a concentration of 3% in the treatment of textiles. In the impregnation of wood material samples, 3 different concentrations of solution were used. After the impregnation with 5% and 10% concentrations, the study was repeated at 50% concentration because the expected water repellency was not achieved. Weight percent gain (WPG), bulking effect (BE), water uptake rate (WU), water repellent efficiency (WRE), volumetric swelling (S) and anti-swelling efficiency (ASE) values of the samples treated with this chemical were determined. The results obtained were compared with the control group samples. According to the data obtained, WPG and BE values increased as the solution concentration increased. In addition, the increase in impregnation time and the use of crosslinker also caused a relatively small increase in WPG values. The study revealed that impregnation time did not have much effect on BE. The WU of the samples decreased slightly compared to the control group. As the amount of water repellent adhering to the material increased, WU also decreased. S values of all treatment groups decreased compared to the control group. However, impregnation with low concentration solutions did not provide a significant ASE. For both wood species, higher ASE values were obtained as the solution concentration increased.

Keywords − *Water repellent efficiency, volumetric swelling, anti-swelling efficiency, dimensional stability, wood preservation*

Tekstil Sektöründe Kullanılan Bir Su İtici Kimyasalın (Ruco-DryEco®) Ahşap Malzemenin Bazı Fiziksel Özelliklerine Etkisi

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Makale Tarihçesi
Gönderim: 03.08.2022
Kabul: 28.12.2022
Yayım: 15.04.2023

Araştırma Makalesi

Öz − Bu çalışmada, tekstil sektöründe kullanılan bir su itici kimyasalın ağaç malzemenin bazı fiziksel özelliklerine etkisi araştırılmıştır. Ağaç malzeme olarak Uludağ göknarı (*Abies bornmülleriana* Mattf) ve Doğu kayını odunu (*Fagus Orientalis* Lipsky), kimyasal malzeme olarak tekstil sektöründe kullanılan, florokarbon içermeyen su bazlı bir ürün olan Ruco-DryEco® ticari isimli kimyasal kullanılmıştır. Bu ürün tekstil ürünlerinin işleminde %3 derişimde kullanılmaktadır. Ağaç malzeme örneklerinin emprenyesinde 3 farklı derişimde çözelti kullanılmıştır. % 5 ve % 10 derişimde çözeltiler ile yapılan emprenye sonrası beklenen su iticiliğin sağlanamaması nedeni ile çalışma %50 derişimde tekrarlanmıştır. Bu kimyasal ile muamele edilen numunelerin yüzde ağırlık artışı (YAA), şişirme etkisi (ŞE), su alma oranı (SAO), su itici etkinlik (SİE), hacimsel genişleme (HG) ve genişlemeyi önleyici etkinlik (GÖE) değerleri tespit edilmiştir. Elde edilen sonuçlar kontrol grubu örneklerine göre kıyaslanmıştır. Elde edilen verilere göre, çözelti derişimi arttıkça YAA ve ŞE değerleri artmıştır. Ayrıca emprenye süresinin artışı ve bağlayıcı kullanımı da YAA değerlerinde nispeten az da olsa artışa neden olmuştur. ŞE üzerinde ise emprenye süresinin çok fazla etkili olmadığı görülmüştür. Örneklerin SAO kontrol grubuna kıyasla bir miktar düşmüştür. Malzemeye tutunan su itici madde miktarı arttıkça SAO da azalmıştır. Tüm işlem gruplarının HG değerlerinin kontrol grubuna oranla azaldığı görülmüştür. Ancak düşük derişimli çözeltilerle emprenye önemli bir GÖE sağlamamıştır. Her iki odun türü için de çözelti derişimi arttıkça daha yüksek GÖE değerleri elde edilmiştir.

Anahtar Kelimeler – *Su itici etkinlik, hacimsel genişleme, genişlemeyi önleyici etkinlik, boyutsal kararlılık, odun koruma*

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1. Introduction

Wood will always maintain its importance and value as it is an environment, nature and human-friendly material. It is also an important industrial raw material due to its physical and aesthetic properties as well as its low processing cost. However, wood has some disadvantages such as moisture exchange, biodegradation and dimensional change that limit its use (Kumar 1994; Galperin *et al.*, 1995).

Showing a hygroscopic feature as a structure, wood material shrink or swell by absorbing or desorbing water depending on the relative humidity and temperature of the environment. In order to reduce this undesirable tendency of wood to change size, there are two basic processes: treatment with water repellents and dimensional stabilization. Although these two concepts are used interchangeably, they are actually completely different approaches to controlling moisture in wood. Water repellent treatment can be defined as the ability to prevent or control the rate of liquid water uptake of wood, while dimensional stability can be defined as the ability to prevent or reduce swelling and shrinkage caused by moisture uptake. Dimensional stability depends on the dimensions of the material rather than the rate of water uptake (Rowel and Banks, 1985). At the same time, the mechanical properties of the wood material decrease with increasing moisture content below the fiber saturation point (Gerhards, 1982).

Since water repellents do not form a chemical bond with wood, they are applied to wood by dipping and vacuum impregnation methods. As a result of these processes, weak Van Der Waals bonds are formed between water repellents and wood (Koski, 2008; Can, 2018). Immersion in wax, linseed oil, solid paraffin, petrolatum or silicone oil are the most common examples of water repellent treatment applications (Rowel and Banks, 1985; Var, 2001; Pelit *et al.*, 2017). It has been reported that the water repellent effect decreases with the extension of the soaking time in samples treated with such water repellents (Var, 2001; Can, 2018). Sivrikaya *et al.* (2020) stated that impregnation with tallow also significantly slows down the water uptake of wood, but cannot completely prevent it.

There are also chemical methods using vinyl momomers such as styrene, vinyl chloride, methyl methacrylate, acrylonitrile and t-butyl styrene to give water repellent properties to wood. These monomer groups do not bond with hydroxyl groups in the cell wall, they only fill the cell cavities and polymerize in these areas (Küsefoğlu, 1988). Reducing the use of such chemicals would be beneficial for environmental health.

One of the main components of wood material is cellulose and the most important reason for the expansion of wood material is the water molecules that settle in the amorphous regions of cellulose chains. A significant portion of the fabrics used in the textile industry are cotton-based fabrics and the main ingredient of cotton is cellulose. Therefore, it is considered that water repellent chemicals used in the production of cotton fabrics in the textile sector can also be used for wood materials. In the textile industry, water repellent properties are mostly given to fabric surfaces by conventional methods using fluorinated compounds, but due to the harmful effects of these compounds on human and environmental health, fluorine-free alternative chemicals and methods have been investigated (Bahners *et al.*, 2008). For this purpose, studies have been carried out on the water repellency properties of chemicals such as super hydrophobic mixtures containing silicagelnano particles, perfluoro oxylate, fluorine-free durable nanosilane mixtures in cotton fabrics (Ağıran *et al.*, 2008). Due to its relatively low cost and good results, dimethylol dihydroxyethylene urea (DMDHEU) is also widely used as an anti-wrinkle agent in the textile industry. However, due to the generation of free formaldehyde during this process, studies have been intensified on alternatives that cause less harmful emissions (Huang *et al.*, 2007). Wood modification with DMDHEU has also been studied. DMDHEU treatment has been proven to increase the dimensional stability of wood and reduce water uptake (Sandberg *et al.*, 2017; Emmerich *et al.*, 2019, Sivrikaya and Can, 2022). However, it is also noted that this treatment has disadvantages such as brittleness, cracking tendency and high formaldehyde emission from the product (Sandberg *et al.*, 2017).

In this study, the possibilities of using a water repellent chemical used in the textile industry for wood materials were investigated. Ruco-DryEco®, which does not contain fluorine and can be used as an aqueous solution, was chosen as a water repellent textile chemical, taking into account that it is an environmentally friendly product. This chemical can be used alone or in combination with a special crosslinking chemical. The study samples were treated using 6 different solutions, taking into account the effect of solution concentration and cross-linker usage, and it was aimed to determine the effect of this treatment on the water uptake, water repellent efficiency, volumetric swelling and anti-swelling efficiency values of the wood material.

2. Material and Method

2.1. Wood Material

In this study, Uludağ fir (*Abies bornmülleriana* Mattf) and Oriental beech (*Fagus Orientalis* Lipsky) woods, which are widely preferred in furniture and woodworking industries, were used as wood materials. Wood materials were procured from timber enterprises located in Balıkesir - Dursunbey district. The timbers obtained with a thickness of approximately 10 cm were stacked and left for natural drying for 4 months. Then, small test samples were prepared in accordance with TS 2470 (Turkish Standards Institute [TSE], 1975a). In addition, care was taken to ensure that the samples were free of defects such as cracks, knots, fiber curl, fungus and mold growth.

2.2. Chemicals

Ruco-DryEco®, a fluorocarbon-free water-based product available in the textile industry, and Ruco-Link® Bew, a solvent-free crosslinking agent provided by the manufacturer for this chemical, were used as water repellent materials. These chemicals were obtained from Rudolf Duraner GMbH Bursa, Turkey. Product information was provided by the manufacturer (Rudolf Duraner GMbH). The chemical is a white emulsion with a density of 1.1 g/cm^3 at 20˚C and a pH value of approximately 3.0-7.0 and can be easily diluted with cold water. The product, which has a cationic structure with a mixture of dendrimers and polymers in a super branched structure, is defined as a fluorine-free water repellency chemical for fabrics made from all kinds of textile fibers (Ruco-DryEco, 2017).

2.3. Preparation of Test Samples

Test and control samples were cut from air-dried timber into draft pieces measuring 25x90x600 mm. These drafts were kept for 3 weeks at 20±3 ˚C temperature and 65±5% relative humidity until they reached constant weight. Samples with dimensions of 20x20x100 mm were prepared from the drafts that reached equilibrium moisture of content. Before the impregnation process, the test and control samples were kept in an oven at 103 ± 2 ˚C in accordance with TS 2472 (TSE, 1975c) until they reached constant weight, their weights were measured with a sensitivity of 0.01 g and their oven dry weights were determined. The dimensions of the samples were also measured with a digital caliper with a precision of 0.01 mm and a digital comparator with a precision of 0.01 and their oven dry volumes and densities were calculated.

Three different concentrations were used in the impregnation of the test samples. According to the information provided by the manufacturer, the water repellent chemical is used as an aqueous solution at a concentration of 3% in the impregnation of cotton-based textile products. Based on this information, the study was repeated at 50% concentration since the expected water repellency was not achieved after impregnation with 5% and 10% concentration solutions. The water repellent chemical used can be used both with crosslinker and alone. Accordingly, in order to determine the effect of crosslinker, both water repellent chemical solutions only and solutions containing 50% crosslinker compared to water repellent chemical were used in 6 different ways (Table 1). In order to determine the effect of the impregnation time on the penetration of the water repellent chemical in the dipping method, 2 different times, 2 and 4 hours, were applied. A total of 26 groups of samples were prepared, including 2 wood species, 6 solutions for each wood, 2 impregnation times and 1 control group. 10 samples were used for each group.

Table 1
Properties of impregnation solutions

Solution code	RucoDry	Crosslinker	Distilled water
5%RD	5 %	-	95 %
5%RD+C	5 %	2.5 %	92.5 %
10%RD	10 %	-	90 %
10%RD+C	10 %	5 %	85 %
50%RD	50 %		50 %
50%RD+C	50 %	25 %	25 %

RD: RucoDry Eco, C: Crosslinker

2.4. Impregnation

After the oven dry samples were impregnated for 2 and 4 hours separately according to the dipping method, their wet weights were determined by weighing with a precision of 0.01g. For the polymerization of the water repellent chemical, the samples were treated in an oven at 150 °C for 10 minutes. The samples were then kept under normal conditions for 24 hours and then dried in an oven at 103 ± 2 ˚C until they reached constant weight and their oven dry weights after impregnation were determined by weighing again with the same precision. The post-treatment volumes of the samples were also calculated by measuring their dimensions with an accuracy of 0.01 mm.

Air dry and oven dry densities of the test samples before impregnation were determined according to TS 2472 (TSE, 1975c) and moisture content was determined according to TS 2471 (TSE, 1975b).

2.5. Determination of Physical Properties

Weight percent gain (WPG) and bulking effect (BE) values after impregnation were determined according to the following equations.

$$WPG = \frac{m_{i0}-m_0}{m_0} x100 \tag{2.1}$$

$$BE = \frac{V_{i0}-V_0}{V_0} x100 \tag{2.2}$$

m_0: oven dry weight before treatment (g)
V_0 :oven dry volume before treatment (cm^3)
m_{i0} :oven dry weight after treatment (g)
V_{i0} :oven dry volume after treatment (cm^3)

Water uptake (WU) and volumetric swelling (S) values of the samples were determined in accordance with TS 4086 (TSE, 1982). After treatment, the samples with known dry volume and weight were immersed in distilled water at room temperature so that they were completely submerged. Then, every 24 hours, the samples were taken out of the water and the excess water was removed with tissue paper and the weights and volumes were determined. The procedure was terminated at the end of the 7th day when it was determined that the volume of the samples did not increase. The WU and water repellent efficiency (WRE) values of the samples were calculated according to the following equations:

$$WU = \frac{m_{is}-m_{i0}}{m_{i0}} x100 \tag{2.3}$$

$$WRE = \frac{WU_t - WU_c}{WU_c} x100 \quad (2.4)$$

m_{is} : weight of soaked samples (g)
m_{i0} : oven dry weight after treatment (g)
WU_c : water uptake of the control samples (%)
WU_t : water uptake of treated samples (%)

In determining the S value, the principles specified in TS 4086 (TSE, 1982) were followed and the calculation was made on the samples used in the water uptake tests. The radial, tangential and longidituonal dimensions of the treated and control samples used in the aforementioned experiments were measured with an accuracy of 0.01 mm in the oven dry state. Subsequently, the dimensions of the control and treated samples in the swelled state were determined by measurements from the same points. S and anti-swelling efficiency (ASE) values were calculated according to the following equations.

$$S = \frac{V_{is} - V_{i0}}{V_{i0}} x100 \quad (2.5)$$

$$ASE = \frac{S_i - S_c}{S_c} x100 \quad (2.6)$$

V_{i0} : oven dry volume after impregnation (cm^3)
V_{is} : volume after immersing in water (cm^3)
S_c : volumetric swelling of the control samples (%)
S_t : volumetric swelling of treated samples (%)

2.6. Statistical Analysis

Statistical analysis of the experimental data was carried out using analysis of variance (ANOVA) and Duncan's multiple range test. ANOVA was used to determine whether the effect of water repellent chemical treatment on the physical properties of Oriental beech and Uludağ fir wood was significant. Duncan's test was used to compare the groups, to determine the significant differences between these groups and to determine which group or groups these differences originated from.

3. Findings and Discussion

3.1. Weight Percent Gain

The WPG values and Duncan test results of the wood materials after impregnation with Ruco-DryEco are given in Figure 1 and Table 2, respectively. According to these data, as the solution concentration increases, WPG also increases. In addition, the increase in impregnation time and the use of crosslinkers also cause a relatively small increase in WPG values. In the use of crosslinkers, there was binding between the chemical molecules in the cell cavities and therefore the amount of retention increased. It is seen that the most important factor in WPG is the concentration of the solution. Approximately 9% WPG was detected in samples with 50% concentration and using crosslinker. Similarly, Li *et al.* (2020) obtained 9.5% WPG in bamboo wood impregnated with 50% DMDHEU, a chemical used in the textile industry. Sivrikaya and Can (2022) stated that WPG values ranging from 15% to 30% were obtained in direct proportion to the solution concentration in impregnation processes of poplar wood with DMDHEU at different concentrations with 5 bar pressure, and similar results were found in the literature. Since the pressure between 5-15 bar was used in impregnation with DMDHEU, it was possible to obtain higher WPG values.

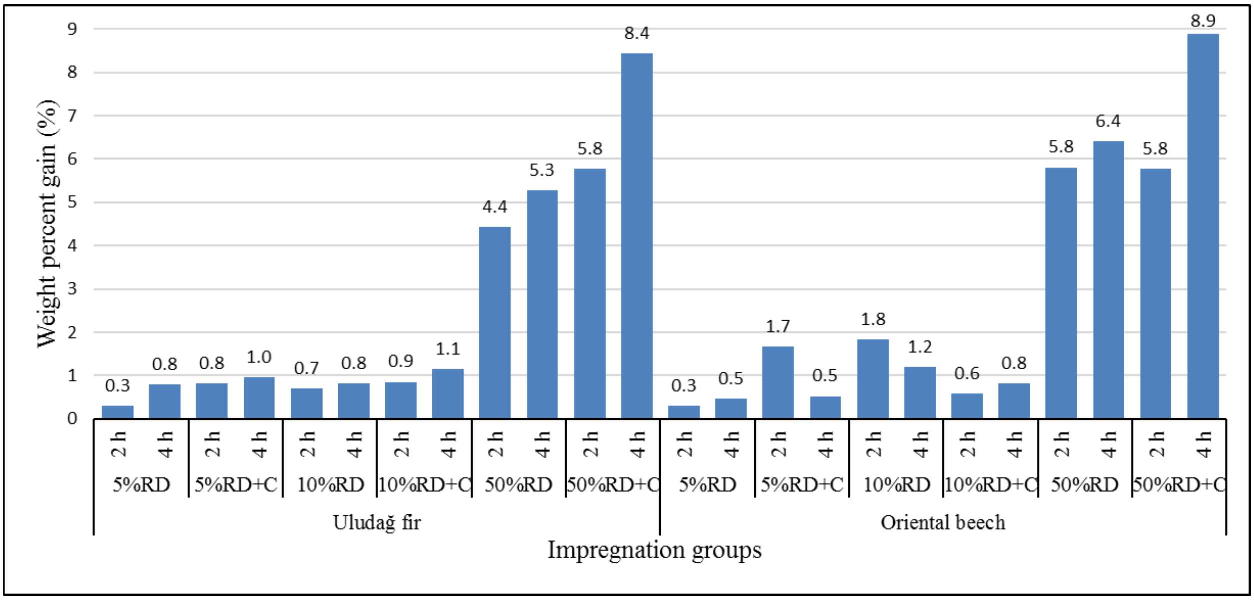

Figure 1. Effect of Ruco-DryEco treatment on WPG in Uludağ fir and Oriental beech wood

The study revealed that the effects of wood species, solution and impregnation time factors on WPG value were statistically significant. When evaluated in terms of wood species and impregnation time, higher WPG occurred in Oriental beech and 4 hours treatment. According to the results of Table 2, there is no statistically significant difference between 5% RD+C and 10% RD+C groups and between 5% RD+C and 10%RD groups in terms of WPG. The difference between all other groups was statistically significant. The highest WPG was obtained in the 50% RD+C group. It was determined that the use of crosslinker significantly increased the WPG values.

Table 2
Duncan test results for the effect of solution concentration on WPG

Impregnation solution	**WPG (%)**		
	X	**(SD)**	**HG**
5%RD	0.47	(0.07)	a
10%RD+C	0.85	(0.09)	b
5%RD+C	0.99	(0.24)	bc
10%RD	1.14	(0.21)	c
50%RD	5.48	(0.41)	d
50%RD+C	7.21	(0.42)	e

RD: RucoDry Eco, C: Crosslinker, X: Mean, SD: Standart deviation, HG: Homogeneity group, different letters denote significant difference, statistically

3.2. Bulking Effect

The volume increase that occurs in wood materials during impregnation or chemical modification, i.e. the bulking effect (BE), is used as an indicator of whether the chemical penetrates into the cell wall. The change in BE after impregnation with Ruco-DryEco is given in Figure 2. As expected, BE values show a parallel change with WPG values. It was determined that the effect of impregnation time on BE values was not significant, especially at 5% and 10% concentrations, both time and crosslinker effect did not cause a significant change. The highest BE values were found as 4.1% in Uludağ fir and 6.1% in Oriental beech impregnated with 50% RD+C. Sivrikaya and Can (2022) obtained 6.44% BE in the impregnation of poplar wood with DMDHEU at 30% concentration. Although the materials and chemicals used are different, we can say that almost the same amount of impregnation solution penetrates the cell wall.

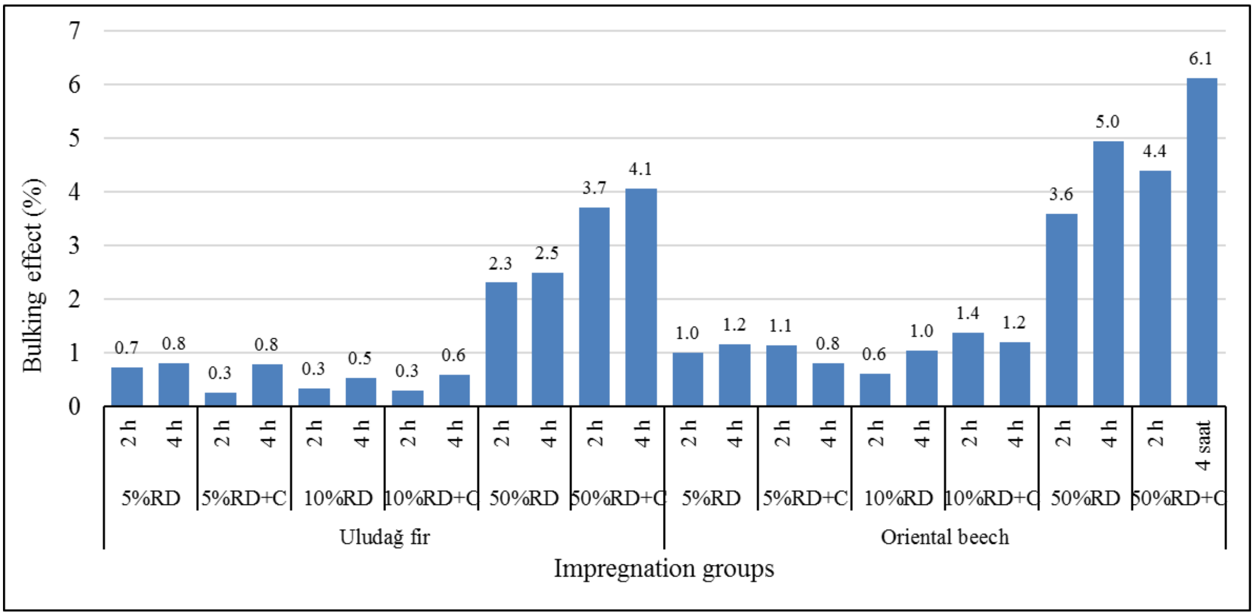

Figure 2. BE values of Ruco-DryEco treatment on Uludağ fir and Oriental beech wood

According to the results of analysis of variance for the effect of wood species, solution and impregnation time factors on BE value, while the factors were effective individually, other binary and ternary interactions did not show a statistically significant effect on BE value except for the binary interaction of wood type x solution. The result of Duncan test for the effect of solution concentration on BE is given in Table 3. According to this, there is no statistically significant difference between the groups at 5% and 10% concentration with or without crosslinker. The highest BE value was found in the 50%RD+C group. It can be said that the use of crosslinker only shows its effect significantly in impregnation with high concentrations of solution. As the solution concentration increases, and therefore the crosslinker ratio increases, the amount of chemicals entering the cell wall and crosslinker there also increases. The BE determined in Oriental beech is higher than that obtained in Uludağ fir. In Oriental beech, which has a higher density, the chemical penetrated more into the cell wall and caused more volumetric swelling.

Table 3
Duncan test results for the effect of solution concentration on BE

Impregnation solution	Bulking effect (%)		
	X	(SD)	HG
10%RD	0.63	(0.18)	a
5%RD+C	0.75	(0.25)	a
10%RD+C	0.87	(0.29)	a
5%RD	0.93	(0.25)	a
50%RD	3.34	(0.90)	b
50%RD+C	4.58	(0.95)	c

RD: RucoDry Eco, C: Crosslinker, X: Mean, SD: Standart deviation, HG: Homogeneity group, different letters denote significant difference, statistically.

3.3. Water Uptake

The WU change of the samples impregnated with Ruco-DryEco is given in Figure 3 for Uludağ fir and Figure 4 for Oriental beech. The WU of the samples decreases slightly compared to the control group. This decrease is inversely proportional to the solution concentration and thus WPG values, and as the WPG increases, the water uptake rate decreases. At the end of 168 hours, the lowest WU values were found in the samples impregnated with 50%RD+C with approximately 45% in Uludağ fir and 57% in Oriental beech.

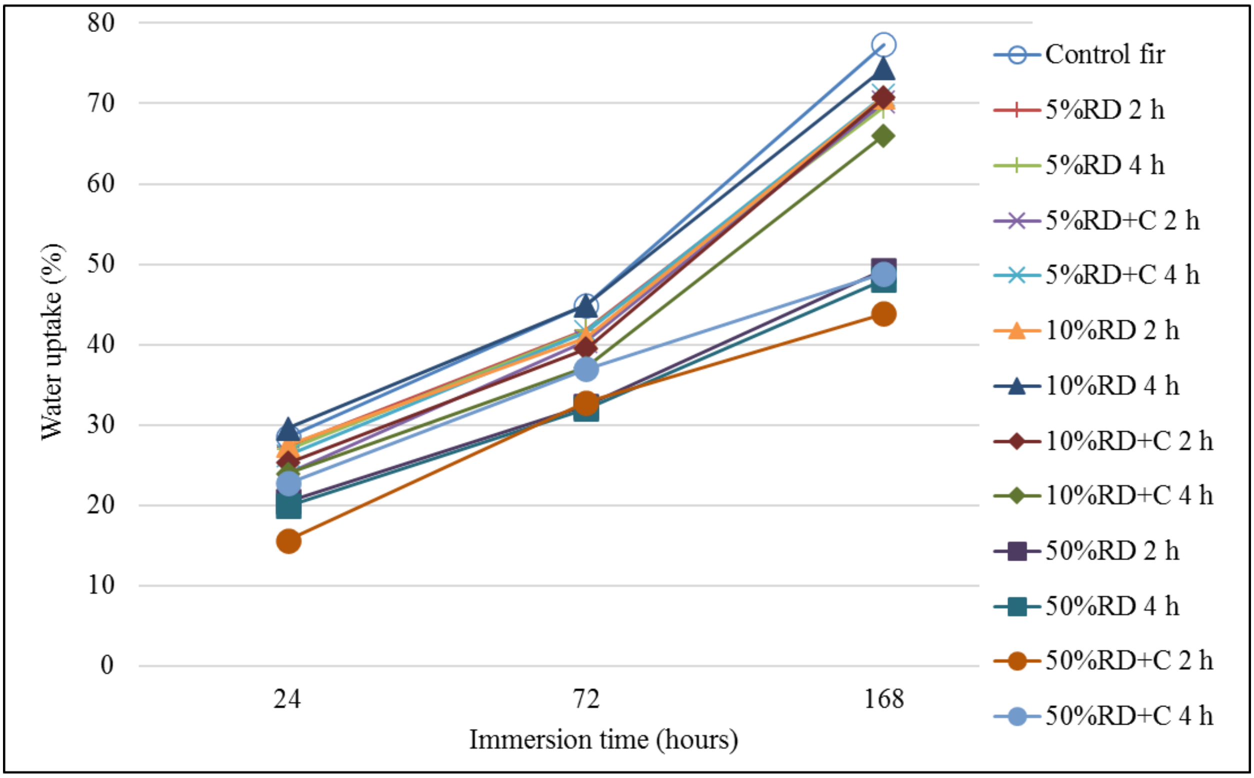

Figure 3. WU values of Uludağ fir samples impregnated with Ruco-DryEco

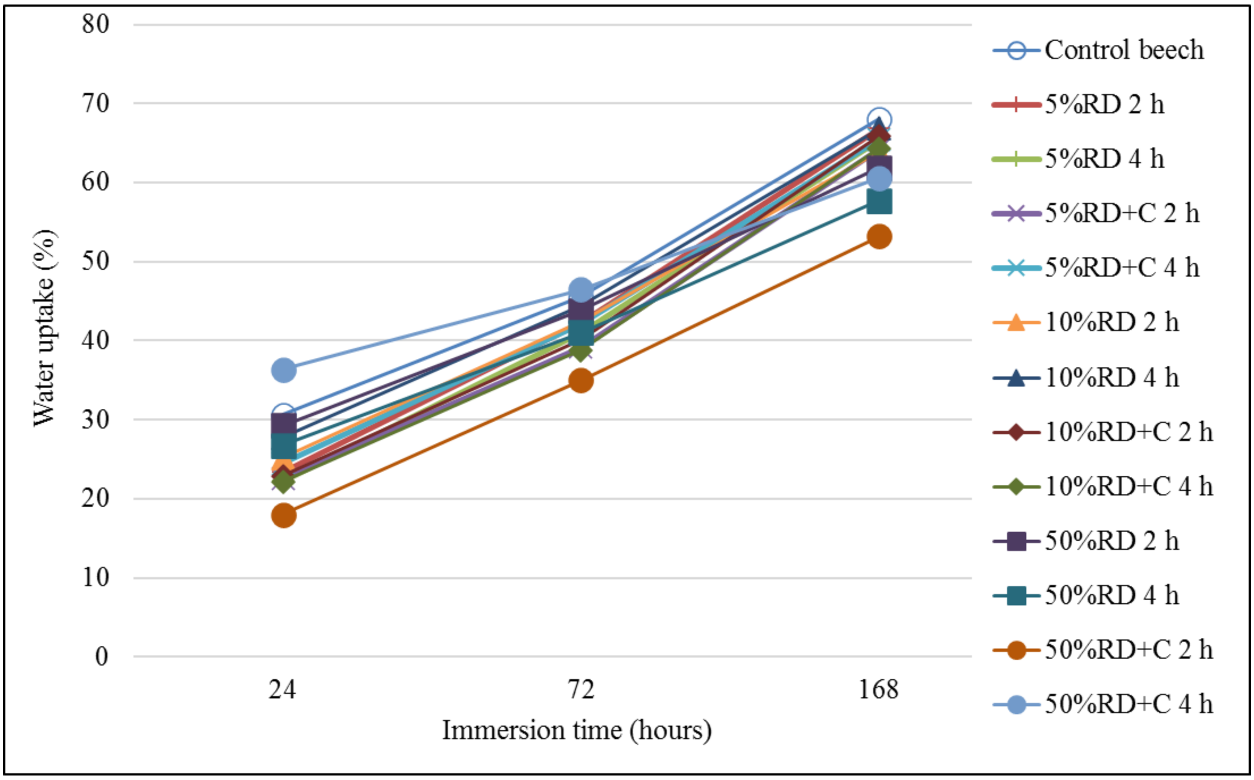

Figure 4. WU values of Oriental beech samples impregnated with Ruco-DryEco

According to the results of analysis of variance, wood species and solution concentration had a significant effect on WU at 24, 72 and 168 hours, while impregnation time had no statistically significant effect ($p=0.191$)

on WU at 168 hours. Duncan test results for the effect of solution concentration on WU are given in Table 4. In all solution concentrations, WU decreased statistically significantly compared to the control group. At 24 hours, there was no significant difference between the solution groups with different concentrations, but as the exposure time to water increased, the difference between the values increased, and at the end of 168 hours, the water uptake of the low concentration groups approached the control group, while the water uptake of the 50% concentration solution groups was statistically significantly less. It was determined that the use of crosslinker was effective in reducing the water uptake, but the most important factor was the solution concentration.

Table 4
Duncan test results for the effect of solution concentration on WU

WU at 24 hours			**WU at 72 hours**			**WU at 168 hours**		
Solution	**X (SD)**	**HG**	**Solution**	**X (SD)**	**HG**	**Solution**	**X (SD)**	**HG**
50%RD+C	23.16 (8.33)	a	50%RD	37.30 (7.02)	a	50%RD+C	51.64 (6.86)	a
10%RD+C	23.54 (1.61)	a	50%RD+C	37.80 (6.11)	a	50%RD	54.25 (7.09)	b
50%RD	24.10 (5.23)	b	10%RD+C	38.89 (2.43)	a	10%RD+C	66.76 (3.98)	c
5%RD+C	24.31 (2.04)	b	5%RD+C	40.81 (2.81)	b	5%RD+C	67.70 (4.32)	cd
5%RD	24.98 (2.64)	b	5%RD	41.74 (2.03)	bc	5%RD	68.05 (4.07)	cd
10%RD	27.48 (3.50)	c	10%RD	43.13 (4.66)	c	10%RD	68.99 (4.87)	d
Control	29.54 (5.13)	d	Control	45.23 (4.27)	d	Control	72.72 (6.31)	e

RD: RucoDry Eco, C: Crosslinker, X: Mean, SD: Standart deviation, HG: Homogeneity group, different letters denote significant difference, statistically.,

Similarly, Krause (2006) determined that impregnation with DMDHEU, which closes the water conduction pathways by settling in the cell wall and cavities of the wood, decreased the WU value of the wood, slowed the rate of water uptake in the short term in the water uptake experiment, but increased it in the long term (Emmerich *et al.*, 2019). A similar result was determined in bamboo wood treated with DMDHEU (Li *et al.*, 2020). Gökmen and Sivrikaya (2021) obtained approximately 90% WU in fir impregnated with 20% tall oil at the end of 168 hours; Can and Sivrikaya (2016) stated that the lowest WU value at the end of 72 hours in Uludağ fir impregnated with different solvents and concentrations of tall oil was obtained in 20% tall oil impregnation dissolved in methanol with 62%, and that this process slowed down the water absorption rate of the wood but did not completely prevent it. In impregnation with Ruco-Dry Eco, the chemical settles in the cell wall and cavities, thus slowing the water uptake of the wood, but it does not bond to the cell wall and therefore loses its effect over time.

WRE values obtained in impregnation with Ruco-Dry Eco are given in Figure 5. It is seen that the highest WRE value with 40.1% was obtained in the impregnation of Uludağ fir with 50%RD+C. The WRE values calculated in 24 hours were mostly higher in impregnation with low concentration solutions. In the impregnation of both Uludağ fir and Oriental beech with 50% concentration solutions, the WRE values calculated at 168 hours were higher. The higher WRE value calculated at 24 hours in the lower concentration groups indicates that the treatment with water repellent chemical slows down the entry of water into the material, but loses its effect as the exposure time to water increases. It can be interpreted that the chemical used does not bond with the wood material and is exposed to leaching over time and therefore loses its effect. Considering the swelling effect of the chemical in the groups with high concentrations, it can be said that the gaps where water can enter are also reduced, the chemical takes longer to leach out and therefore the WRE values are higher than the other groups.

In accordance with these results, Var (2001), in his study in which he impregnated beech, alder, spruce and scots pine woods with paraffin, wax and linseed oil using the dipping method, stated that the water uptake rate decreased by 50%, the water repellency effect increased with the extension of the impregnation period, but the water repellency effect decreased with the extension of the soaking time of the samples in water after the impregnation process. This was interpreted as the water repellent effect was inversely proportional to the water exposure time.

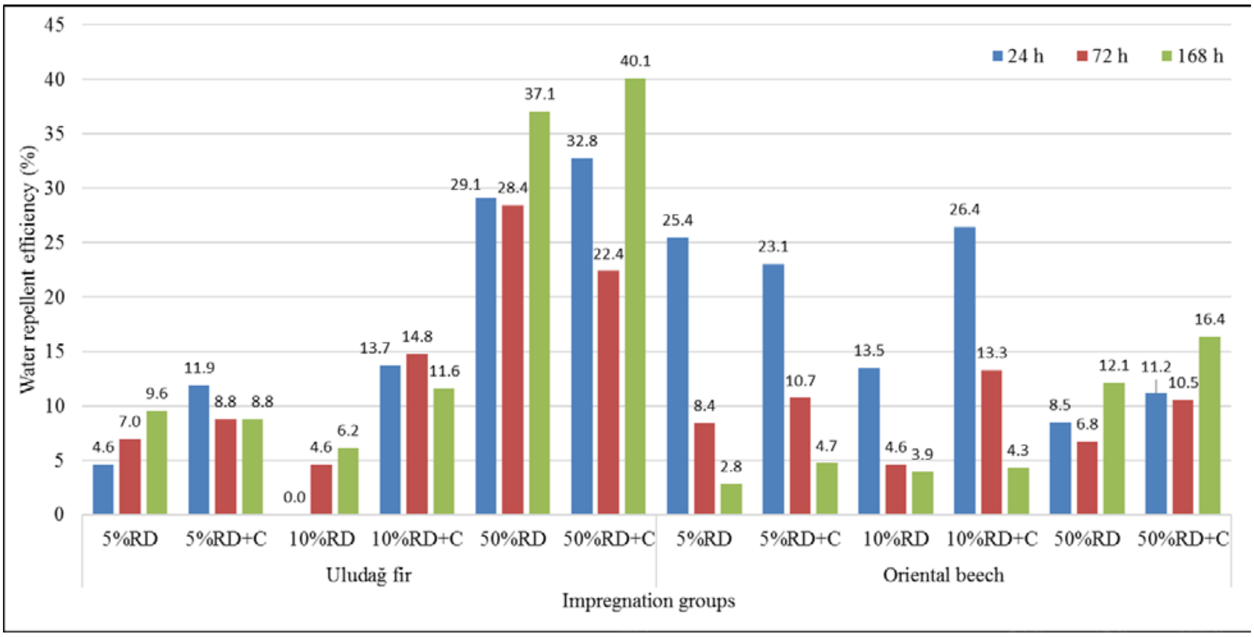

Figure 5. WRE values of impregnation with Ruco-Dry Eco

3.4. Volumetric Swelling

The S values of Uludağ fir impregnated with Ruco-Dry Eco are given in Figure 6 and the change in S values of Oriental beech is given in Figure 7. For both woods, lower S values were obtained with impregnation with 50% concentration solutions. At the end of 168 hours, the lowest S values were determined as 10.4% in Uludağ fir and 12.1% in Oriental beech impregnated with 50% RD+C.

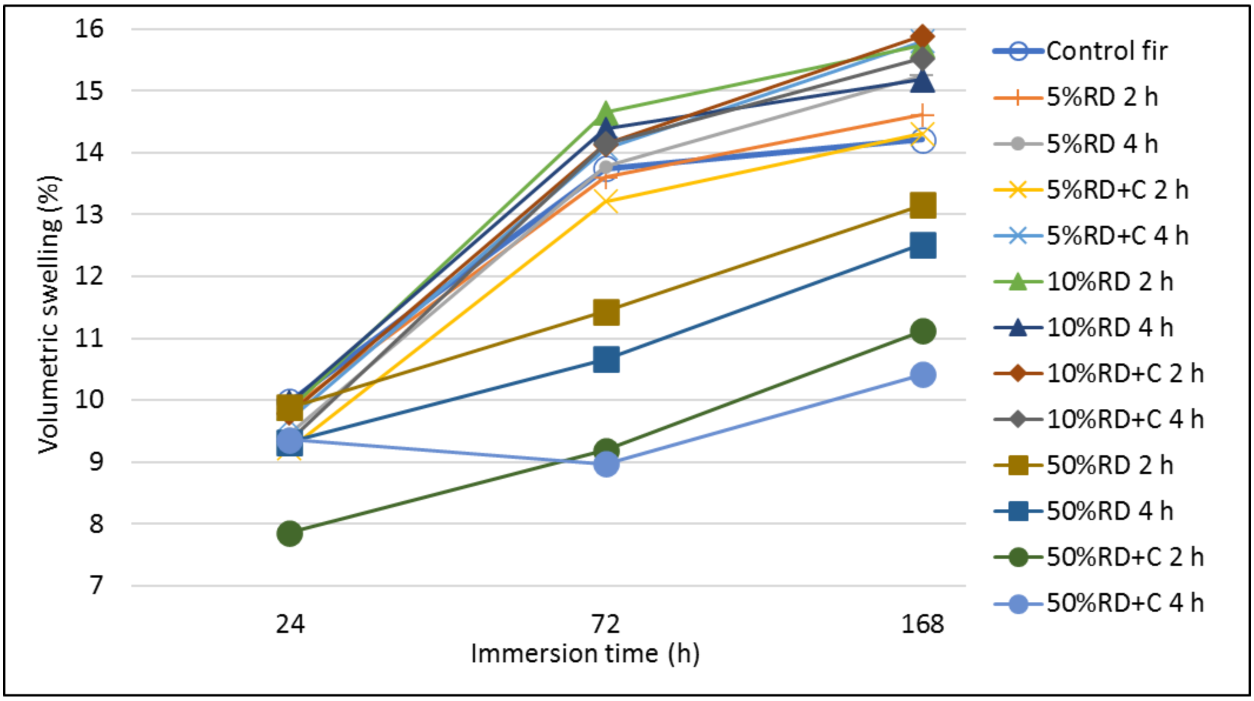

Figure 6. Swelling values of Uludağ fir samples impregnated with Ruco-Dry Eco

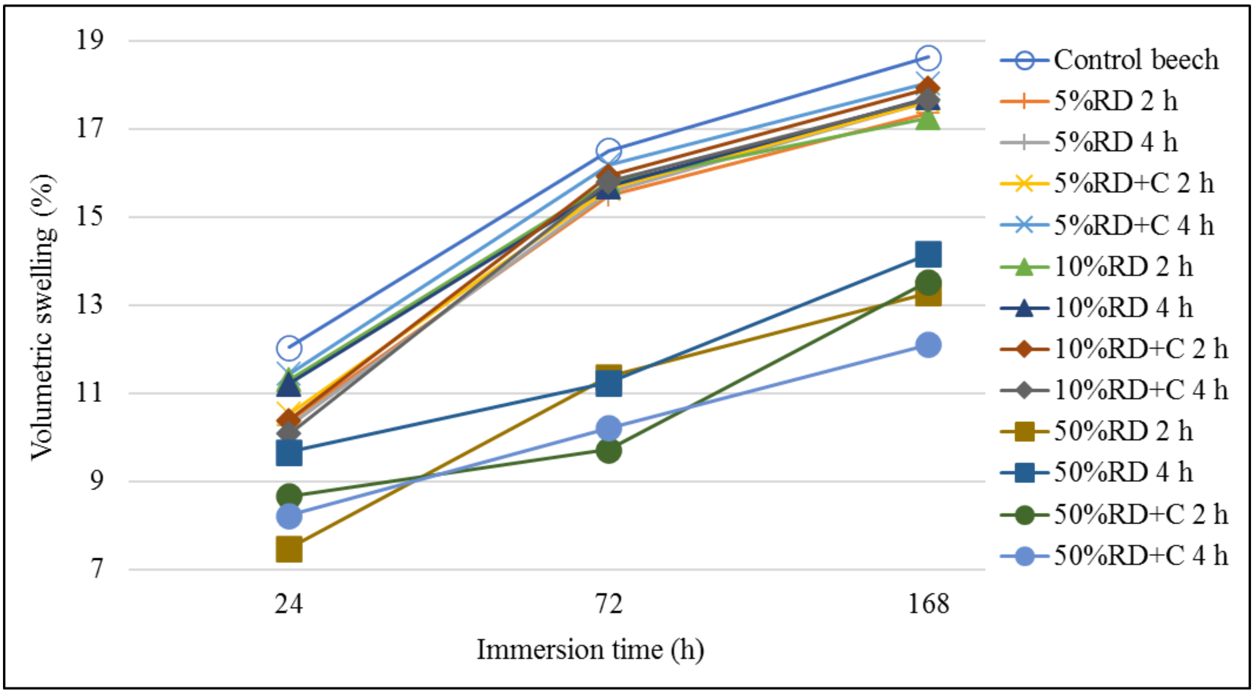

Figure 7. Swelling values of Oriental beech samples impregnated with Ruco-Dry Eco

The results of the analysis of variance showed that the effect of wood type and solution concentration on S was statistically significant, but the effect of impregnation time was not significant (p=0.190 for 24 hours; p=0.833 for 72 hours; p=0.923 for 168 hours). Therefore, impregnation time was not taken into account in the calculation of the mean ASE values. Duncan's test results for the effect of solution concentration on S are given in Table 5.

Table 5
Duncan test results for the effect of solution concentration on swelling

Swelling (%) 24 hours			**Swelling (%) 72 hours**			**Swelling (%) 168 hours**		
Solution	**X (SD)**	**HG**	**Solution**	**X (SD)**	**HG**	**Solution**	**X (SD)**	**HG**
50%RD+C	8.53 (2.21)	a	50%RD+C	9.52 (2.92)	a	50%RD+C	11.79 (1.83)	a
50%RD	9.08 (2.12)	a	505RD	11.18 (2.14)	b	50%RD	13.28 (1.66)	b
10%RD+C	9.90 (0.81)	b	5%RD	14.61 (1.25)	c	5%RD	16.21 (1.58)	c
5%RD	9.98 (0.95)	b	5%RD+C	14.78 (1.86)	c	Kontrol	16.42 (2.65)	c
5%RD+C	10.22 (1.15)	b	10%RD+C	15.01 (1.32)	c	5%RD+C	16.44 (2.57)	c
10%RD	10.58 (1.34)	bc	10%RD	15.12 (1.09)	c	10%RD	16.47 (1.30)	c
Control	11.01 (1.32)	c	Control	15.13 (1.54)	c	10%RD+C	16.75 (1.45)	c

RD: RucoDry Eco, C: Crosslinker, X: Mean, SD: Standart deviation, HG: Homogeneity group, different letters denote significant difference, statistically.

At the end of 24 hours, there is no significant difference between the S values of the samples impregnated with 50% RD and 50% RD+C and between the S values of the samples impregnated with 5% and 10% concentration solutions. When the S values determined at 72 hours and 168 hours were examined, it was determined that there was no statistically significant difference between the other treatment groups and the control group except for the 50% concentration groups, while there was a statistically significant difference between the 50%RD and 50%RD+C groups both among themselves and with all other treatment groups. The use of crosslinker seems to be effective on S only in high concentration solutions. In impregnation with Ruco-Dry Eco, it is seen that only 50% concentration solution can be effective on S, while low concentration treatments have no effect as the water exposure time is prolonged.

ASE values of the samples impregnated with Ruco-Dry Eco are given in Figure 8. For both woods, lower ASE values were obtained for impregnation with low concentration solutions. Even in Uludağ fir, ASE values at 72 and 168 hours were close to zero or negative. However, since there is no statistically significant difference between the S values of these groups, negative values have no meaning. ASE values at 24 hours were higher in these groups. This result shows that impregnation with low concentrations of Ruco-Dry Eco only reduces water uptake and thus S for a short time, but has no effect on ASE in the long term. The highest ASE values of 34% for Uludağ fir and 39.6% for Oriental beech were obtained at 72 hours when impregnated with 50% RD+C. However, at the end of 168 hours, ASE decreases to 24.3% and 31.2%, respectively. It was evaluated that the impregnating agent does not chemically bind to the material and loses its effect as the exposure time to water increases (Var, 2001), and even some of it dissolves and mixes with water and its swelling effect on the material decreases (Can, 2018). Therefore, the ASE values calculated at 168 hours may have been lower than those calculated at 72 hours. The use of crosslinker also resulted in an average ASE increase of 13% in Uludağ fir and 4.7% in Oriental beech.

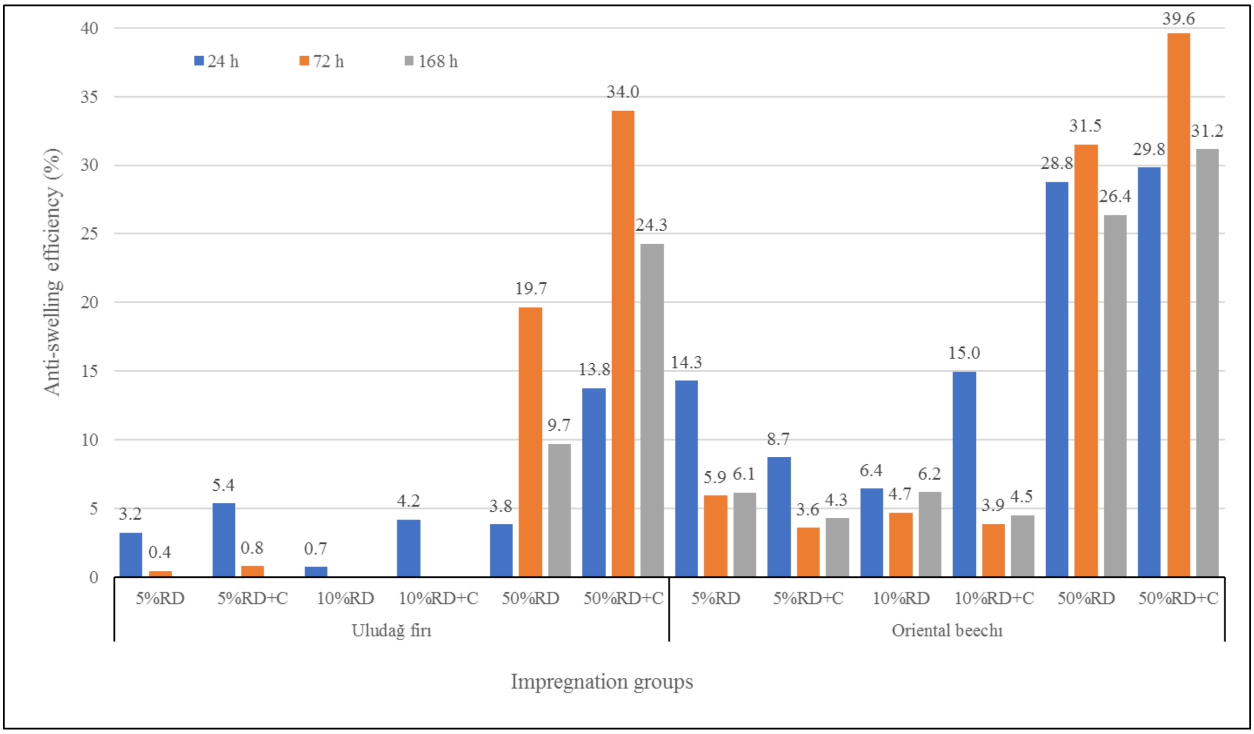

Figure 8. ASE values of samples impregnated with Ruco-Dry Eco

Chen *et al.* (2020) reported the highest 15.3% ASE at the end of 192 hours in poplar wood impregnated with epoxidized linseed oil/carnauba wax suspension. In a similar study, Demirel *et al.* (2018) obtained approximately 70% ASE in scots pine impregnated with epoxidized soybean oil, which is effective by binding to the cell wall of the wood. As a result of heat treatment with the Thermowood method, ASE values of up to 50% can be obtained in wood material (Sefil, 2010). Although ASE values up to 70% were determined in wood treated with DMDHEU, this value is generally in the range of 30-40% (Sandberg *et al.*, 2017), and 30-35% ASE values were obtained in beech (Bollmus, 2011). ASE value can reach 80% in chemical modification such as acetylation (Çetin *et al.*, 2005; Temiz *et al.*, 2006). But all these methods require significant machinery and equipment investment, and chemical modification also releases harmful chemical by-products and uses a very difficult and laborious process.

4. Results and Recommendations

This study investigated the impact of impregnation with Ruco-Dry Eco, an environmentally friendly water repellent chemical used in the textile industry, on the water absorption and volumetric swelling properties of Uludağ fir and Oriental beech and the results obtained are summarized below.

- In impregnation with Ruco-Dry Eco, WPG and BE values were obtained in direct proportion to the solution concentration. The use of crosslinker in the solutions also caused an increase in the WPG and BE values obtained.
- WU values of Uludağ fir and Oriental beech impregnated with Ruco-Dry Eco vary inversely with WPG and BE values.
- No significant WRE and ASE could be obtained with Ruco-Dry Eco impregnated with 5% and 10% concentration solutions. With 50% solution concentration and crosslinker usage, 40.1% WRE and 34% ASE were obtained in Uludağ fir and 16.4% WRE and 39% ASE were obtained in Oriental beech after 168 hours.
- The use of crosslinker in impregnation with Ruco-Dry Eco increased both WRE and ASE values.
- The ASE values of impregnation with Ruco-Dry Eco decreased as the water exposure time of the materials increased. These results showed that the chemical does not adhere to the material and some of it is washed away, thus reducing its effect.
- Although impregnation with Ruco-Dry Eco does not provide very high water repellency and dimensional stability compared to chemical modification, it can be preferred due to its environmentally friendly nature. It is recommended to use a 50% concentration of solution and crosslinker to achieve sufficient water repellency.
- Since the WRE and ASE values of impregnation with Ruco-Dry Eco decrease with longer exposure to water and are therefore likely to be washed out of the material, it is recommended for use in indoor environments with high humidity rather than in outdoor environments where there is direct contact with water.

Acknowledgement

In this study, data from the master's thesis prepared by Veysel Kapçak at the Karabuk University Institute of Science and Technology were used. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author Contributions

Suat Altun: Designed the study, analyzed the data and drafted the manuscript and revisions.

Veysel Kapçak: Carried out the experiments, data collection, and reporting.

Conflict of Interest

No potential conflict of interest was reported by the authors.

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