POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

Effects of impregnation and heat treatment on some physical and mechanical properties of wood material

Emprenye ve ısıl işlemin ahşap malzemenin bazı fiziksel ve mekanik özelliklerine etkileri

***Yazar(lar) (Author(s))**: Osman PERÇİN[1], Şemsettin DORUK[2], Mustafa ALTUNOK[3]*

ORCID[1]: 0000-0003-0033-0918

ORCID[2]: 0000-0002-9492-0881

ORCID[3]: 0000-0002-2048-1994

To cite to this article: Perçin O., Doruk Ş. ve Altunok M., "Effects of Impregnation and Heat Treatment on Some Physical and Mechanical Properties of Wood Material", ***Journal of Polytechnic***, 26(4): 1421-1429, (2023).

Bu makaleye şu şekilde atıfta bulunabilirsiniz: Perçin O., Doruk Ş. ve Altunok M., "Emprenye ve ısıl işlemin ahşap malzemenin bazı fiziksel ve mekanik özelliklerine etkileri", ***Politeknik Dergisi***, 26(4): 1421-1429, (2023).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.1120778

Effects of Impregnation and Heat Treatment on Some Physical and Mechanical Properties of Wood Material

Highlights

- *Thermal modification affected the technological properties of wood material.*
- *Thermal modification had limited effect at low temperature.*
- *The improving effect of plant extracts was occured at different rates.*
- *Mechanical strength losses at high temperature are greater than at low temperature.*

Graphical Abstract

Wood is one of the oldest building materials and is still commonly used today. In this study, test samples were impregnated with environmentally friendly wood preservatives and their effect on mechanical strength was investigated after heat treatment.

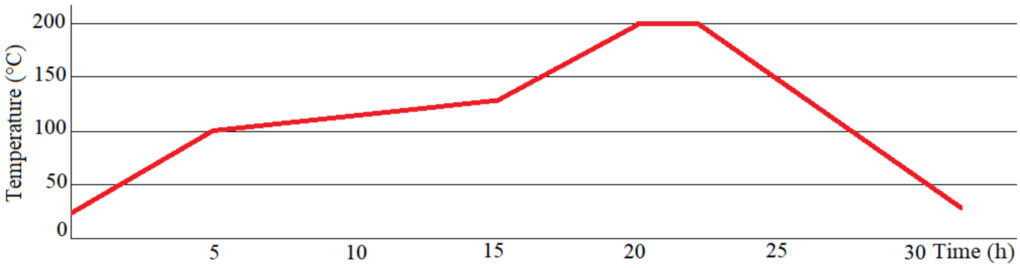

Figure. Heat treatment method used in study

Aim

The aim of this study is to determine the effect of heat treatment on some mechanical properties of spruce (Picea orientalis) samples impregnated with tannin solutions obtained from valonia (the extract of Quercus ithaburensis), gallnut powder (Quercus infectoria Oliver) and pine bark powder (Pinus brutia Ten.).

Design & Methodology

The test samples were impregnated with plant extracts in 10% solution and then heat treated at 150, 175 and 200 °C.

Originality

Samples were impregnated with 10% plant extracts, 760 mm Hg after applying vacuum for 30 minutes by subjecting to diffusion in the solution and left at the atmospheric pressure for 30 minutes according to ASTM D 1413-76 standart.

Findings

The effect of impregnation solution and heat treatment on physical and mechanical properties was occured at different rates.

Conclusion

Impregnation solutions limited the mechanical strength losses of wood material at lower temperature.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Effects of Impregnation and Heat Treatment on Some Physical and Mechanical Properties of Wood Material

Araştırma Makalesi / Research Article

Osman PERÇİN[1*], Şemsettin DORUK[2], Mustafa ALTUNOK[3]

[1]Necmettin Erbakan University, Faculty of Fine Arts ans Architecture, Department of Interior Architecture and Environmental Design, Konya-Turkey

[2] Karabük University, Faculty of Forestry, Department of Forest Industrial Engineering, Karabuk-Turkey

[3]Gazi University, Faculty of Technology, Department of Wood Products Industry Engineering, Ankara-Turkey

(Geliş/Received : 24.05.2022 ; Kabul/Accepted : 27.06.2022 ; Erken Görünüm/Early View : 25.07.2022)

ABSTRACT

The aim of this study was to determine some physical and mechanical properties of spruce (*Picea orientalis*) wood, which was impregnated with aqueous solutions of valonia (valex) (the extract of *Quercus ithaburensis*), pine bark powder (pinex) (*Pinus brutia* Ten.) and gallnut powder (galex) (*Quercus infectoria* Oliver) as a pre-treatment and then heat treated. Test specimens were prepared from sapwood of spruce wood and impregnated with 10% tannin solutions before heat treatment base on ASTM D 1413-76. After pre-impregnation processs, specimens subjected to heat treatment at 150 °C, 175 °C and 200 °C for 2 h. The effect of impregnation process and heat treatment temperature on the air-dried density, compressive strength paralell to the grain (CS), bending strength (MOR) and modulus of elasticity in bending (MOE) were analyzed. As results, impregnation solutions showed positive effects on mechanical strength in unheat-treated samples and determined that mecnaical strength loses due to heat treatment slightly limited at low temperatures. However, strength loses increased with increasing temperature. The highest strength loses were also determined in impregnated samples with galex extract and heat-treated samples at 200 °C.

Keywords: Heat treatment, plant extracts, wood material, impregnation.

Emprenye ve Isıl İşlemin Ahşap Malzemenin Bazı Fiziksel ve Mekanik Özelliklerine Etkileri

ÖZ

Bu çalışmanın amacı, ön işlem olarak meşe palamudu (valex) (*Quercus ithaburensis*), kızılçam kabuğu (pinex) (*Pinus brutia* Ten.) ve meşe mazısı (galex) (*Quercus infectoria* Oliver) ekstraktlarının sulu çözeltileri ile emprenye edildikten sonra ısıl işleme tabi tutulan ladin (Picea orientalis) odunun bazı fiziksel ve mekanik özelliklerinin belirlenmesidir. Test örnekleri, ladin ağacının diri odun kısmından hazırlanmış ve ısıl işlemden önce ASTM D 1413-76'ya göre %10 tanen çözeltileri ile emprenye edilmiştir. Ön emprenye işlemlerinden sonra, test örnekleri 150 °C, 175 °C ve 200 °C'de 2 saat süreyle ısıl işleme tabi tutulmuştur. Emprenye ve ısıl işlemin hava kurusu yoğunluk, liflere paralel basınç direnci (CS), eğilme direnci (MOR) ve eğilmede elastikiyet modülüne (MOE) etkileri analiz edilmiştir. Sonuç olarak, emprenye çözeltilerinin ısıl işlem uygulanmamış örneklerinde mekanik özellikleri olumlu etkilediği ve düşük sıcaklıklarda ısıl işlemden kaynaklanan direnç kayıplarını bir miktar sınırladığı tespit edilmiştir. Ancak artan sıcaklıkla beraber direnç kayıpları da artmıştır. En yüksek direnç kayıpları, galex ile emprenye edilmiş ve 200 °C'de ısıl işlem uygulanmış örneklerde tespit edilmiştir.

Anahtar Kelimeler: Isıl işlem, bitki ekstraktları, ahşap malzeme, emprenye.

1. INTRODUCTION

Wood is one of the oldest building material used by mankind throughout history. Compared to other building materials, it is used continuously due to its superior properties such as high strength properties, insulating electricity and heat, nailing and joining properties, easy processing and flexibility compared to its weight [1]. Although wood material has positive properties, its flammability due to being an organic material, its ability to be destroyed by insects and fungi, its ability to change its dimensions depending on the temperature and relative humidity of the air, and its discoloration due to the effect of sun rays are evaluated as its negative properties [2]. Impregnation of wood material and wood modifications made by various methods are among the most important of these. Thanks to these methods, the negative properties of wood material are could be improved [3-5].

Wood material has met the needs of humanity in most areas since the earliest times and has become an industrial product with more usage areas with the technological advances in recent years. With the increase in new usage areas and human population, the demand

*Sorumlu Yazar (Corresponding Author)
e-posta : opercin@erbakan.edu.tr

for wood materials increases, and it causes the forest resources to decrease day by day. This situation necessitates the use of wood resources in a much more efficient way, its use in various industries with the modification of wood species with low strength properties and to create different materials such as wood composite materials [6].

In order to prevent this losses and increase the service life of the wood material, it should be made resistant to various chemicals, biological, physical and chemical factors. A lot wood preservative are more commonly using in industry to protect wood from deterioration in the field of use. The most prefered components are CCA (chromated copper arsenate), CCB (copper chrome boron), ACZA (ammoniacal copper zinc arsenate), CC (ammoniacal copper citrate), CBA (copper azole), CDDC (copper dimethyldithiocarbamate), creosetes, pentachlorophenols and other copper - based wood preservative such as ACQ (alkaline copper quat), CA (copper azole) for many years. Some of these solutions are harmful to environmental healths and some of them more expensives [7-10]. In recent years, due to increasing importance of natural environment, human health and depending on new laws for protect of woods, the importance of developing more environmentally friendly preservatives has emerged [11-12].

Regarding the improvement of the properties of wood material, it would be beneficial to focus on alternative environmentally friendly solutions that are not harmful to humans and the environments instead of chemicals in the protection of wood materials by impregnation [13]. Plant extracts or tannins are among the environmentally friendly wood modifiers that have been widely used in recent years. In many scientific studies, it has been reported that wood materials impregnated with plant extracts provide resistance against biological organisms [14].

Increased environmental awareness has raised the demand for more environmentally friendly wood modification methods. Another wood modification method that gaining in popularity over the last decades is heat treatment. Heat treatment is an environmentally friendly method applied without using any chemicals to improve the properties of wood material [5, 15]. When wood is heated, generally chemical changes start to take place inside the wood structure depending on some conditions (treatment temperature, treatment time, atmosphere, etc.), wood type, and its features, or the initial moisture content of the wood [16]. Chemical changes due to heat treatment conditions, invariably lead to the alteration of various properties of woods [17-18]. Thermal treatments applied at higher temperatures considerably reduce the mechanical stregths of the wood material and makes it more brittle depend on treatment conditions and treatment intensities [19-21]. The decrease in strength properties of limits the use of heat-treated wood material in load-bearing systems in structural applications [22-24].

Regarding the impregnation with tannin solution, a previous study by Kasap Okut and Altınok (2020) studied decay properties of some wood materials. The tannin solution was applied to the wood material with brush and dipping technique and the decay properties of the test samples in the soil were investigated. As a result, it has been reported that the walnut tannin solution prevented the wood decay [25]. In another work, Yaşar and Altınok (2019) investigated effect of natural tannin solutions (pine, acorn) and and chemical impregnation (imersol aqua, timbercare aqua) on characteristic of woods. As a result, they reported that natural tannin solutions could be an alternative to chemical impregnation materials in wood samples exposed to outdoor conditions [26]. Tondi et al. (2012) analyzed the changes in mechanical and fire properties of Scotch pine and European beech samples after impregnation with tannin-based chemicals. They found that the mechanical properties of the impregnated samples improved by an average of 20% [27].

Heat-treated wood material has an increasing use interior and exterior application such as hard wood flooring, siding, claddings, decking, saunas, wall panelling, windows, doors, and garden furnitures [28]. In addition, heat treatment reduces the equilibrium moisture content of wood material [29], enhances its dimensional stability [30] and it also decreases mechanical properties of wood with the increasing severity of the heat treatment [31-32], heat treatment also increases weathering resistance as regards colour stability [33].

Impregnation of wood with some chemical before heat treatment may be reduce the severity of strength losses due to heat treatment [34]. Awoyemi and Westermark (2005) suggested that impregnation of wood material with boron solutions before heat treatment may reduce the severity of mechanical strength loss during heat treatment [35]. Winandy (1997) also determined that addition of borate-based buffers to the fire retardant solutions was found to significantly mitigate subsequent thermal degradation [36]. In the another study, Gündüz et al (2011) studied the effects of tannin and heat treatment on features of Anatolian chestnut (*Castanea sativa* Mill.) wood. They repoted that after removal of tannin and heat treatment, technological feature such as bending property, module of elasticity in bending and compression strength decreased [37]. In a similar study by Verly Lopes et al. (2020) southern yellow pine (*Pinus* spp.) and yellow-poplar (*Liriodendrum tulipifera*) woods were impregnated with a mixture of condensed tannin and disodium octaborate tetrahydrate. After impregnation process test samples were heat-treated under N_2 atmosphere at 190 °C for four hours and boron depletion and wood durability were investigated. They declared tannin restricted boron leaching and with heat treatment showed better results to termites [38].

The use of plant-based tannins and heat treatment of wood represents a relatively environmentally friendly approach to the wood preservation industry [38]. While there are many studies with the effect of tannin chemicals on rot fungis and wood decay organisms, but its effect on mechanical properties is very limited with heat treatment. The aim of this paper was to research the effects of pine barks powders (*Pinus brutia* Ten.), valonia (the extracts of *Quercus ithaburensis*) and gallnuts (*Quercuss infectoria* Oliver) tannins on resulting changes in mechanical properties of heat-treated spruce (*Picea orientalis*) wood samples.

2. MATERIAL and METHOD

2.1. Material

The spruce (*Picea orientalis*) wood beams (density 0.45 g/cm^3) were used which obtained from a local sawmill Ankara, Turkey. Because the spruce wood is widely use in wood working industry and it is naturally grown in Turkey. Wood beams (96 x 295 x 3000 mm) (radial, tangential, longitudinal) free of visible defects and sapwod were chosen for the experiments. The moisture content of the oversized boards ranged from 11-14%. All the beams were stored in a lumber yard so that they reach to equilibrium moisture content.

Three natural extract solutions were used in this study. For this reason, 10% pine bark extracts (pinex) (*Pinus brutia* Ten.), valonia extracts (valex) (the extract of *Quercus ithaburensis*) and gallnuts (galex) (*Quercuss infectoria* Oliver) extracts used for impregnations process. The extracts were obtained from a commercial company in the form of a granulated powder in Manisa, Turkey. These tannins are widely produced in Turkey and have an important commercial value. Tannins are polyphenols that can be divided into two groups: hydrolyzable tannins and condensed tannins found in various plants. Tannins can be obtained from the bark of mimosa, acorn, chestnut, sumac, tara, and bark of various pine species. Tannins are used in many different fields such as leather manufacturing, adhesives, additives to beverages, and medical applications [14, 25, 26, 37]. In this study, tannins were dissolve in distille water at 80 °C to a concentration of 10%.

2.2. Method

Atotal of 160 test specimens were prepared for each test in accordance with the standard TS 2470 (1976) [39]. Samples were divided into smaller pieces in accordance with the relevant standards, and specimens were divided into four groups. The first group consist of non-impregnated (control) and heat-treaded samples, the second group pinex impregnated and heat-treaded specimens, the third group valex impregnated and heat-treated samples and finally the fourth group consists of galex impregnated and heat-treated samples. All samples were conditioned at 20 °C and 65% moisture content for three weeks before the impregnation and heat treatment process.

For the MOR and MOE, test samples of size 20mm x 20mm x 360mm (radial x tangential x longitudinal) and for the density and compressive strength parallel to grains 20mm x 20mm x 30mm (radial x tangential x longitudinal) were prepared. The experiments were done MOR according to TS 2474 (1976) standard [40], MOE according to TS 2478 (1976) [41] standard and compressive strength parallel to grains according to TS 2595 (1977) [42]. Density of test samples were determined according to TS 2472 (1976) [43]. Then, the prepared specimens were conditioned at 20°C and 65% relative humidity until they reach to equilibrium moisture contents. Samples for each test were equally divided into four groups including a set of unimpregnated control specimens while the other sets were impregnated with tannin solutions. Before the impregnation process, the average moisture content of the samples was about 12%. The conditioned test specimens were impregnated based on ASTM-D-1413-76 (1976) [44]. Test specimens were weighed before impregnation process. The pressure-vacuum method was used for impregnation process. The impregnation process was carried out in a vacuum and pressure impregnation device in Gazi university, Faculty of Technology, Woodworking Industrial Engineering Department. The test specimens were exposed to 760 mm/Hg pre-vacuum for 30 minutes and then examples were hold in tannin solutions to diffuse in solution under normal atmospheric pressure for 30 minutes. After impregnation process weight of test samples were again determined and dry at ambient temperatures.

The test samples were first impregnated with the studied solutions and then the impregnated samples were heat treated. Heat treatment was carried out at three different temperatures: 150 °C, 175 °C and 200 °C in a programmablelogic controlles (PLC) laboratory oven under the protection of hot water vapor. In this process heat treatment was carried out in three continuous phase for each treatment. In the first phase, after test specimens were placed into the heat treatment oven, the temperature was increased to 100°C for 5 h and then 130°C for 10 h. The water vapor was injected into the oven at 1 bar, time of 5 sec. at intervals of 200 sec. during the heat treatment. In the second phase, temperature of oven increased from 130 °C to target temperatures of 150 °C, 175 °C and 200 °C for 2 h. Specimens were kept at these temperatures for 2h. In the final phase temperature was reduced to 25 °C for 10 h and test samples conditioned. The heat-treatment process is described in Figure 1.

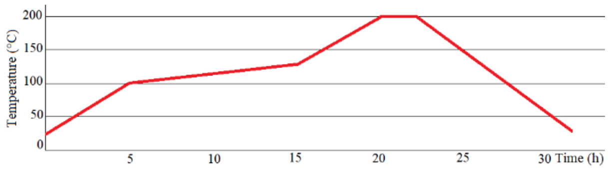

Figure 1. Heat treatment method used in study(200 °C)

After the heat treatment, the weights and dimensions of all test samples were determined and recorded. Before the experimental tests the specimens were conditioned in a climate cabinet with a relative humidity of 65% and a temperatures of 20 °C (standard atmosphere) until they reach the EMC.

2.3. Data Evaluation

Data obtained from the tests were evaluated statistically by MSTAT-C (Version1.42, Michigan State University, East Lansing, MI) statistic computer package program. In the data analysis, the effects factors of impregnation solutions and heat treatment temperature were determined using the analysis of variance (ANOVA). Differences among the average values were compared using the least significant difference(LSD) test.

3. RESULT AND DISCUSSIONS

The air-dried density and EMC and also standard deviations for the impregnated spruce wood at the three temperature levels is presented in Table 1. The values in Table 1 are average values of ten replicates. Density values of impregnated samples higher than those of control groups. This increase in density may be due to extract solutions uptake during the impregnation. It can be observed that the air-dried density values were decreased with increasing temperature. The highest decreasing rate on the showed as 13.66%, 11.30%, 10.84% and 9.05% at the 200 °C in impregnated samples with galex, valex, pinex and unimregnated samples, respectively. The change of densities was not uniform. Heat treatment has influences on physical properties of wood material. The weight of wood after heat treatment decreased according to increase of treatment temperature and its time [45]. Esteves et al. (2007) decleared that wood density reduce due to the removal of wood components by heat treatment at higher temperature and moisture desorption [46]. Similar results were also reported by Alén et al. (2002) for spruce (*Picea abies*) wood samples[47]. Heat treatment caused a decrease in the EMC values of all test samples. Treatment at 200 °C was resulted the lowest values for the EMC.

Table 2 shows the retention values (kg/m^3) of wood samples having 10% concentration level along with standard deviations.

Table 1. Air-dried density and EMC of impregnated and heat-treated specimens

Impregnation solutions	Heat treatment (°C)	EMC (%)	Density (g/cm^3)
Unimpregnated	Control	13.96 (0.3677)	0.453 (0.0218)
	150	12.32 (0.3547)	0.441 (0.0288)
	175	10.49 (0.2937)	0.427 (0.0176)
	200	8.96 (0.3856)	0.412 (0.0134)
Pinex	Unheated	14.17 (0.3485)	0.464 (0.0151)
	150	12.57 (0.4735)	0.449 (0.0160)
	175	10.58 (0.3185)	0.434 (0.0181)
	200	9.39 (0.2459)	0.411 (0.0138)
Valex	Unheated	14.53 (0.3681)	0.469 (0.0116)
	150	12.98 (0.5839)	0.446 (0.0114)
	175	10.83 (0.4057)	0.431 (0.0182)
	200	9.77 (0.1739)	0.416 (0.0120)
Galex	Unheated	14.04 (0.3909)	0.461 (0.0125)
	150	12.42 (0.8617)	0.451 (0.0131)
	175	10.29 (0.3152)	0.435 (0.0151)
	200	9.11 (0.3559)	0.398 (0.0134)

The data in parentheses represent the standard deviation.

Table2. Retention levels of spruce wood samples treated with solutions

Extract species	Retention level (kg/m^3)
Pinex *(Pinus brutia)*	25.16 (0.84)
Valex*(Quercus ithaburensis)*	24.42 (0.54)
Galex *(Quercus infectoria)*	17.11 (0.46)

The data in parentheses represent the standard deviation.

As can be seen from Table 2, retentions of samples were found to be 25.16 kg/m^3, 24.42 kg/m^{3}and 17.11 kg/m^3 after *Pinus brutia*, *Quercus ithaburensis* and *Quercus infectoria* solutions, respectively. Uptake of solutions inside wood was similar for the *Quercus ithaburensis* and *Pinus brutia*. However, *Quercus infectoria* wood preservative showed some difference in retention that it showed the least retention value. The retention level of extract solutions was the highest in *Pinus brutia*. Generally, bark contains polyphenolic substances and more extractive compound compare to wood and its due to the structure of bark with a well water-holding capacity [48], so could be possible reasons for the high retention for *Pinus brutia*. A difference in retention has been reported by Sen et al. (2009) and explained by the structure of valex, sumex and pinex extracts [49].

The result of the analysis of variances of the effects of impregnation solution and heat treatment temperature on compressive strengths parallel to the grains, bending strengths and modulus of elasticity in bending are summarize in Table 3.

Table3. Results of the analysis of variances

Properties	Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Signature (P<0.05)
Compressive Strength	Factor A	3	623.959	207.986	84.6590	0.0000
	Factor B	3	4615.045	1538.348	626.1708	0.0000
	AxB	9	190.132	21.126	8.5990	0.0000
	Error	144	353.773	2.457		
	Total	159	5782.908			
Bending Strength	Factor A	3	187.243	62.414	7.7657	0.0001
	Factor B	3	22700.760	7566.920	941.4951	0.0000
	AxB	9	66.855	7.428	0.9243	*
	Error	144	1157.347	8.037		
	Total	159	24112.205			
Modulus of Elasticity	Factor A	3	8084656.875	2694885.625	68.7532	0.0000
	Factor B	3	22531681.875	7510560.625	191.6130	0.0000
	AxB	9	84031.625	933681.736	23.8205	0.0000
	Error	144	5644298.000	39196.514		
	Total	159	44663772.375			

Facror A: Extract solutions; Factor B: Heat treatment temperatures; *Statistically not significant

Table 3 indicated that the effects of the extract solutions, heat treatment temperatures and their interactions were found to be statistically significants (P≤0.05) on mechanical strength, except for interaction on bending strength. The results of compressive strengths, bending strengths and modulus of elasticity in bending for impregnated and heat-treated specimens are show in Table 4. Differences between all test groups were statistically significant at the 0.05 confidence level.

Table 4. The results of CS, MOR and MOE for impregnated and heat-treated specimens

Process type	CS	MOR	MOE
Extract Solutions*	X(N/mm²)	X(N/mm²)	X(N/mm²)
Unimpregnated	43.96 D	57.08 B	8194 C
Pinex	49.13 A	59.56 A	8467 A
Valex	47.04 B	58.39 A	8305 B
Galex	45.05 C	56.88 B	7854 D
Heat Treatment**			
Unheated	48.98 B	69.78 A	8091 C
150 °C	51.15 A	67.07 B	8453 B
175 °C	47.82 C	55.51 C	8575 A
200 °C	37.22 D	39.56 D	7601 D
LSD	*0.6922; **0.6922	*1.252; **1.252	*87.43; **87.43

Note: Different letters show which values are statistically different at the 0.05 level; LSD: Least significant difference

According to the Table 4, pinex solution was given the highest CS value, valex and galex followed the pinex, respectively. As can seen this results, extract solutions were performed higher performance than unimpregnated samples and extract solutions had significant effect on CS. As seen in Table 4, heat treatment affected MOR of spruce wood. It was observed that the highest and lowest CS were found as 51.15 N/mm² at 150 °C and 37.22 N/mm² at 200 °C. When compared the this results the MOR increased as 4.4% at 150 °C, however decreased as 24% at 220 °C.

The lowest MOR value was found in impregnated samples with galex solutions. The other solutions were higher than unimpregnated samples. This result can be explained by relatively low retention of galex solution compared to the pinex and valex solutions. Also it was determined that as be in CS, the bending strength increased at the initial stage of the heat treatment and decreased later. This highest reduction was determined as 43% at 200 °C.

Table 4 shows the effect of extract solutions and heating in differen ttemperatures on MOE as compared to unimpregnated and unheated groups. According to this, galex solutions had the lowest value compared to the others. In addition, the lowest MOE was found at 200 °C. As can be seen from Table 4, the modulus of elasticity values in bending a little increased at 150 °C and 175 °C compared to unheated groups. Table 5 shows the results of Duncan Test and changes in the CS, MOR, and MOE of impregnated and heat-treated spruce wood.

Table 5. The effect of extract solutions and heat treatment on CS, MOR and MOE of spruce wood

Treatment Type	CS (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)
Control	47.16 F	68.16 BC	7912 E
150 °C	49.11 DE	65.49 D	8336 C
175 °C	43.13 G	54.42 E	7843 EF
200 °C	36.43 I	40.27 F	7683 FG
Pinex	50.58 BC	72.13 A	8443 C
Pinex+150 °C	54.22 A	68.48 BC	8665 B
Pinex+175 °C	50.81 BC	56.87 E	8947 A
Pinex+200 °C	40.89 H	40.78 F	7811 EF
Valex	49.43 CDE	70.46 AB	8299 C
Valex+150 °C	51.13 B	67.43 CD	8398 C
Valex+175 °C	50.44 BCD	55.93 E	8913 A
Valex+200 °C	37.16 I	39.73 FG	7611 G
Galex	48.74 E	68.88 BC	8109 D
Galex+150 °C	50.14 BCD	66.89 CD	8411 C
Galex+175 °C	46.89 F	54.83 E	7596 G
Galex+200 °C	34.42 J	37.44 G	7298 H
LSD	1.384	2.504	174.9

Note: Different letters show which values are statistically different at the 0.05 level; LSD: Least significant difference.

According to the Table 5, CS, MOR and MOE values of all impregnated samples higher than control groups. Compressive strength values ranged from 54.22 N/mm^2 to 34.42 N/mm^2 for impregnated and heat-treated samples. The lowest CS value was obtained at impregnated with galex and heat-treated at 200 °C samples. In terms of reducing resistance losses in CS, pinex solutions had more advantage than other solutions. The highest CS loss was obtained for heat-treated specimens at 200 °C as 29.4% that was pre-treated with galex. As can be seen on Table 5, CS values a slightly increased in applied heat treatment at low temperatures, however applied at higher temperatures reduced their values. Losses in compresive strength of heat-treated wood is mainly due to the degradation of hemicelluloses, cellulose and lignin, which hemicellulos is less stable to heat treatment than cellulose and lignin [50]. In the another study Sweet and Winandy (1999) reported that hemicellulose compound of cell wall play important role on wood strength [51].

The MOR strengths presented in Table 5 showed that only impregnated specimens have a higher MOR value with an increased ranged from 1% to 6% compared to the control group. In each experiment group aslo determined that MOR values decreased with increasing heat treatment temperature. The highest loss of MOR was observed at 200 °C for impregnated samples with galex. The highest MOR value was observed in only impregnated samples with pinex solution. This may be due to the retention of test samples that the highest retention value was found in pinex and the lowest galex solution. Also determined that MOR values of impregneted samples higher than control group. As seen in Table 5, tannin impregnation positive affected MOR value of wood. Grabner et al. (2005) examined the extractives on mechanical properties of larch wood. The results showed that extractives of wood have significant effect on mechanical properties of wood. Increasing extractive content in heartwood showed better mechanical properties in the transverse direction [52].

Results of the Table 5 indicated that impregnated samples with pinex and heat-treated at 175 °C had the highest MOE value 8947 N/mm^2 which was 13% higher than control samples. The specimens that were only impregnated showed a small increase in MOE compared to the control group. This stuation clearly show that extract solutions had a significant and positive effect on the wood's MOE values. According to the this results, the effect on MOE might differ from different extract solutions. On the other hand, MOE values were increased clearly at 150 °C, while at 200 °C a reduction was noticed in the each group. The initial increase of MOE can be explained by an increase in the crystallinity of cellulose and in the relative content of lignin [53]. Also determined that during the mechanical tests, the samples of treatments at 200 °C showed more abrupt rupture than the other heat treatment temperatures which can lead to considerably different failure behavior after mechanical tests.

4. CONCLUSIONS

Based on the findings of this study, the impregnation with extract solutions and heat treatment affected significantly mechanical properties of spruce (*Picea orientalis*) wood. The results showed that impregnation process before heat treatment increased density, CS, MOR and MOE values. The CS, MOR and MOE slightly increased in the initial stages of heat treatment, however at higher temperatures reduced their values. According to extract solutions, the retention value was the highest in pinex and the lowes tin galex. The extract solutions showed a different response to the heat treatment which pinex was more advantage than other extractives in terms of reducing strength losses. Accordingto the results, it can be concluded that impregnation of spruce wood with extract buffering solutions before heat treatment could mitigate the loses in mechanical strengths at lower temperature.

Consequently the use of wood material as a natural contruction material in interior design has increasing importance. Different wood materials can be used in various parts of the interior of building and there are differences their usage. Especially it is used in interiors as wall covering material, floors and ceilings, doors, windows, furniture, stairs, in features and decorations, etc. Heat-treated wood has higher aesthetic appearance and environment-friendly renewable material. One of the negative properties of heat-treated wood material is the lower mechanical strength. In the literature impregnation of wood material with some chemicals before heat treatment has decreased its thermal degradation. The impregnation of wood with natural extract solutions before heat treatment should be further investigated in future studies. In addition, it can be suggested to use different tannin solutions and different heat treatment temperatures in the protection of wood materials, so that the role of the binary interaction of tannin solutions and heat treatment temperatures in the preservation of wood material can be investigated in more detail.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Osman PERÇİN: Performed the experiments, analyse the results, wrote the manuscript.

Şemsettin DORUK: Performed the experiments, analyse the results, wrote the manuscript.

Mustafa ALTUNOK: Performed the experiments, analyse the results, wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Usta İ . "Depictions on wood: Acceptation and internalization of wood, which is an ıntercultural ınteraction tool, as "a valuable objec" (wood is valuable)", ***Journal of Science and Technology***, 2(2): 139-144, (2016).

[2] Kurtoğlu, A. "Ağaç malzeme yüzey işlemleri" 1. Cilt: Genel Bilgiler, İ.Ü. Orman Fakültesi, Orman Endüstri Mühendisliği Bölümü, Üniversite Yayın No: 4262, Fakülte Yayın No: 463, ISBN 975-404-590-9, İstanbul, 2000.

[3] Freeman M. H., Shupe T. F., Vlosky, R. P., and Barnes H. M., "Past, present, and future of the wood preservation industry", ***Forest Products Journal***, 53(10): 8-15, (2003).

[4] Hill C. A. S. "Wood modification - chemical, thermal and other processes", Wiley Series in Renewable Resources, *Wiley and Sons*, Chichester, UK, (2006).

[5] Sandberg D., Kutnar A. and Mantanis G. "Wood modification Technologies: a review", ***Iforest-Biogeosciences and Forestry***, 10(6): 895-908, (2017).

[6] Pelit H., "The effects of densification and heat treatment on finishing process with some technological properties of eastern beech and scots pine", *Ph.D. Thesis*, Gazi University, Institute of Science, Ankara (2014).

[7] Venmalar D. and Nagaveni, H. C., "Evaluation of copperised cashew nut shell liquid and neem oil as wood preservatives", *Institute of Wood Science and Technology*. Malleswaram. Bangalore, India. IRG/WP 05-05-0368368, (2005).

[8] Temiz A., Alfredsen, G., Yildiz U. C., Gezer E. D., Kose G., Akbas S. and Yildiz S. "Leaching and decay resistance of alder and pine wood treated with copper based wood preservatives", ***Maderas. Ciencia y tecnologia***, 16(1): 63-76, (2014).

[9] Özdemir T., Temiz A. and Aydin, I. "Effect of wood preservatives on surface properties of coated wood", ***Advances in Materials Science and Engineering***, 2015, Article ID 631835, 1-6. (2015).

[10] Şen S. and Yalçın M. "Threats on human and environment health of impregnated wood material completed service life and their recycling processes", ***Düzce University Faculty of Forestry Journal of Forestry***, 5(1): 91-106, (2009).

[11] Yildiz U. C. Temiz A., Gezer E. D. and Yildiz, S. "Effects of the wood preservatives on mechanical properties of yellow pine (*Pinus sylvestris* L.) wood", ***Building and Environment***, 39(9): 1071-1075, (2004).

[12] Aşçı T. and Keskin H. "Strengthening the retention amount and leaching resistance of boron compounds used as impregnation material", ***Journal of Polytechnic***, 24(1): 103-112, (2021).

[13] Fidan M. S. and Adanur H., "Physical and mechanical properties of wood impregnated with quebracho and boron compounds", ***Forestist***, 69(1): 68-80 (2019).

[14] Yalcin M., Pelit H., Akcay, C. and Cakicier, N. "Surface properties of tannin-impregnated and varnished beech wood after exposure to accelerated weathering", ***Coloration Technology***, 133(4): 334-340, (2017).

[15] Czajkowski Ł., Olek W. and Weres J. "Effects of heat treatment on thermal properties of European beech wood", ***European Journal of Wood and Wood Products***, 78(3): 425-431, (2020).

[16] Poncsák S., Kocaefe D., Bouazara M. and Pichette A. "Effect of high temperature treatment on the mechanical properties of birch (*Betula papyrifera*)", ***Wood Science and Technology***, 40(8): 647-663, (2006).

[17] Shukla S. R. "Evaluation of dimensional stability, surface roughness, colour, flexural properties and decay resistance of thermally modified *Acacia auriculiformis*", ***Maderas. Ciencia y tecnología***, 21(4): 433-446, (2019).

[18] Ali M., Abdullah U. H., Ashaari Z., Hamid N. H. and Hua L. S. "Hydrothermal modification of wood: a review", ***Polymers***, 13(16): 2612, (2021).

[19] Hannouz S., Collet R., Buteaud J. C., Bléron L. and Candelier K. "Mechanical characterization of heat treated ash wood in relation with structural timber standards", ***Pro Ligno***, 11: 3-10, (2015).

[20] Chen C., Tu D., Zhao X., Zhou Q., Cherdchim B. and Hu C. "Influence of cooling rate on the physical properties, chemical composition, and mechanical properties of heat-treated rubberwood", ***Holzforschung***, 74(11): 1033-1042, (2020).

[21] Roszyk E., Stachowska E., Majka J., Mania P. and Broda M. "Moisture-dependent strength properties of thermally-modified *fraxinus excelsior* wood in compression", ***Materials***, 13(7): 1647, (2020).

[22] Boonstra M. J., Rijsdijk J., Sander C., Kegel E., Tjeerdsma B., Militz H., Van Acker J. and Stevens M. "Microstructural and physical aspects of heat treated wood: Part 2", ***Maderas. Ciencia y tecnología***, 8: 209-217, (2006).

[23] Kocaefe D., Poncsak S. and Boluk Y. "Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen", ***BioResources***, 3(2): 517-537, (2008).

[24] Dilik T. and Hiziroglu S. "Bonding strength of heat treated compressed Eastern red cedar wood", ***Materials and Design***, 42: 317-320, (2012).

[25] Kasap Okut, G. and Altınok, M. "Investigation on the decay of some wood type modified with natural wood tannin", ***Journal of Polytechnic***, 23(2): 343-350, (2020).

[26] Yaşar M. and Altunok M. "Some physical and mechanical properties of impregnated chestnut wood with natural and chemical agent exposed to outdoor conditions", ***Journal of Polytechnic***, 22(2): 399-406, (2019).

[27] Tondi G., Wieland S., Wimmer T., Thevenon M. F., Pizzi, A. and Petutschnigg A. "Tannin-boron preservatives for wood buildings: Mechanical and fire properties", ***European Journal of Wood and Wood Products***, 70(5): 689-696, (2012).

[28] Jirouš-Rajković, V. and Miklečić J. "Heat-treated wood as a substrate for coatings, weathering of heat-treated wood, and coating performance on heat-treated wood", ***Advances in Materials Science and Engineering***, 2019, Article ID 8621486, 1-9, (2019).

[29] Kariz M., Kuzman M. K., Sernek M., Hughes M., Rautkari L., Kamke F.A. and Kutnar A. "Influence of temperature of thermal treatment on surface densification of spruce", ***European Journal of Wood and Wood Products***, 75(1): 113-123, (2017).

[30] Živković V., Prša I., Turkulin H., Sinković, T. and Jirouš-Rajković V. "Dimensional stability of heat treated wood floorings", ***Drvna Industrija***, 59(2): 69-73, (2008).

[31] Tomak E. D., Ustaomer D., Yildiz S. and Peşman E. "Changes in surface and mechanical properties of heat treated wood during natural weathering", ***Measurement***, 53: 30-39, (2014).

[32] Chotikhun A., Kittijaruwattana J., Salca E. A. and Hiziroglu S. "Selected physical and mechanical properties of microwave heat treated rubberwood (*Hevea brasiliensis*)", ***Applied Sciences***, 10(18): 6273, (2020).

[33] Garcia R. A., de Oliveira Lopes J., do Nascimento A. M., de Figueiredo Latorraca J. V. "Color stability of weathered heat-treated teak wood", ***Maderas. Ciencia y tecnología***, 16(4): 453-462, (2014).

[34] Wang W., Cao J., Cui F. and Wang X. "Effect of pH on chemical components and mechanical properties of thermally modified wood", ***Wood and Fiber Science***, 44(1): 46-53, (2012).

[35] Awoyemi L. and Westermark U. "Effects of borate impregnation on the response of wood strength to heat treatment", ***Wood Science and Technology***, 39(6): 484-491, (2005).

[36] Winandy J. E. "Effects of fire retardant retention, borate buffers, and redrying temperature after treatment on thermal-induced degradation", ***Forest Products Journal***, 47(6): 79-86, (1997).

[37] Gündüz G., Aydemir D., Onat S. M. and Akgün K. "The effects of tannin and thermal treatment on physical and mechanical properties of laminated chestnut wood composites", ***BioResources***, 6(2), 1543-1555, (2011).

[38] Verly Lopes D. J., Barnes H. M. and dos Santos Bobadilha G. "Influence of heat treatment and tannin impregnation on boron depletion and wood durability", ***Forests***, 11(2): 201, (2020).

[39] TS 2470. "Wood - sampling methods and general requirements for physical and mechanical tests", Turkish Standardization Institute, Ankara, Turkey, (1976).

[40] TS 2474. "Wood determination of ultimate strength in static bending", Turkish Standard Institute, Ankara: Turkey, 1976.

[41] TS 2478. "Wood determination of modulus of elasticity in static bending", Turkish Standard Institute, Ankara, Turkey, 1976.

[42] TS 2595. "Wood testing in compression parallel to grain", Turkish Standard Institute, Ankara, Turkey, 1977.

[43] TS 2472. "Wood - determination of density for physical and mechanical tests", Turkish Standard Institute, Ankara, Turkey, 1976.

[44] ASTM-D 1413-76. "Standart test methods of testing wood preservatives by laboratory soilblock cultures", Annual Book of Astm Standarts. USA, 452-460, (1976).

[45] Yıldız S. "Physical, mechanical, technologic and chemical properties of Fagus orientalis and Picea orientalis wood treated by heating", *Ph.D. Thesis*, Karadeniz Technical University, Institute of Science, Trabzon, (2002).

[46] Esteves B., Marques A. V., Domingos I. and Pereira H. "Influence of steam heating on the properties of pine (*Pinus Pinaster*) and eucalypt (*Eucalypus globulus*) wood", ***Wood Science and Technology***, 41(3): 193-207, (2007).

[47] Alén A., Kotilainen R., and Zaman A. "Thermochemical behavior of Norway spruce (*Picea abies*) at 180-225°C", ***Wood Science and Technology***, 36: 163-171, (2002).

[48] Dönmez I. E. and Dönmez S. "Structure of tree bark and possibility of utilization", ***SDU Faculty of Forestry Journal***, 14: 156-162. 2013.

[49] Sen S. Tascıoglu, C. and Tırak K. "Fixation, leachability, and decay resistance of wood treated with some commercial extracts and wood preservative salts", ***International Biodeterioration and Biodegradation***, 63(2): 135-143, (2009)

[50] Yildiz S., Gezer E. D. and Yildiz, U. C. "Mechanical and chemical behaviour of spruce wood modified by heat", ***Building and Environment***, 41(12):1762-1766, (2006).

[51] Sweet M. S. and Winandy J. E. "Influence of degree of polymerization of cellulose and hemicellulose on strength loss in fire-retardant-treated southern pine", ***Holzforschung***, 53: 311-317, (1999).

[52] Grabner M., Muller U., Gierlinger N. and Wimmer R. "Effects of heartwood extractives on mechanical properties of larch", ***IAWA Journal***, 26(2): 211-220, (2005).

[53] Silva M. R., Machado G. D. O., Brito J.O. and Calil Junior C. "Strength and stiffness of thermally rectified eucalyptus wood under compression", ***Materials Research***, 16(5): 1077-1083, (2013).

.