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EFFECTS OF LIQUID NITROGEN IN HARDLY IMPREGNABLE FIR WOOD

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ABSTRACT

The main purpose of this study was to develop new methods to eliminate the problems encountered during the impregnation of wood material, and in this context, to improve the retention of wood material by using liquefied nitrogen. Uludağ Fir (*Abies nordmanniana* subsp. Bornmulleriana) was used as wood material impregnated with Tanalith-E, Immersol aqua and borax. The effects of liquid nitrogen and the amount of retention on the mechanical properties were investigated. Application of liquid nitrogen before impregnation has increased the retention in fir wood by an average of 150-200% in all impregnation methods, compared to the groups without liquid nitrogen application. Despite this increase in retention amounts, no significant changes were observed in mechanical properties due to the application of liquid nitrogen.

KEYWORDS: Uludağ fir, Tanalith-E, Immersol aqua, retention, nitrogen.

INTRODUCTION

Wood has played a major role throughout human history and has been used for millennia due to its numerous advantages include being widely distributed, multifunctional, strong, and easy to handle and process, aesthetic, sustainable and renewable (Hill 2006, Rowell 2005, Gecer et al. 2015). However, wood has some disadvantages related to its dimensional instability when wet and degradation occur due to abiotic agents including weathering, fire, erosion and mechanical-related damage and biotic agents including mold, fungi, decay and insects such as termites, beetles and marine borers (Gecer et al. 2015). In the recent years, there is some research about various methods on the preservation of wood (Jensen et al. 2002, Jensen and Schnell 2005, Jensen P. and Jensen J.B. 2006). Generally, these protection methods consist of impregnation, heat treatment, modification, drying and the upper surface treatment.

The impregnation of wood is one of wood preservation methods which is used to improve its material properties by altering its chemical nature in a broader sense. It is also a passive

process, where changes in properties also occur, but without an alteration of the chemistry of the material. Kurt et al. (2012) investigated the effect of liquid nitrogen on dimensional stability of Uludag fir (*Abies bornmülleriana* Mattf) wood after exposing to the steam test (2, 6, 12, 24, 48, and 96 hours). Samples were kept in a container filled with liquid nitrogen for 1, 4 and 10 hours, liquid nitrogen application was carried out in an open area and the liquid nitrogen was constantly filled in case it decreases. As a result, retention amounts were increased while liquid nitrogen and steam time are enhanced. Ors et al. (2006) investigated effects of impregnation with Imersol aqua on the modulus of elasticity in bending of oriental beech, oak, Scotch pine, Uludag fir, oriental spruce, and poplar. They found that the highest modulus of elasticity in bending was obtained in Oriental beech with short-term immersion (10720 $N \cdot mm^{-2}$) whereas the lowest was in poplar with long-term immersion (4597 $N \cdot mm^{-2}$). Simsek et al. (2010) studied some mechanical properties such as compression strength parallel to grain, modulus of rupture of wood impregnated with some environmentally-friendly borates (sodium tetra fluor borate, ammonium tetrafluoroborate, and ammonium pentaborate octahydrate and found that the higher concentration levels of borates, the lower mechanical properties of wood resulted. Villasante et al. (2013) determined the effect of preservatives (Vacsol Azure WR 2601 and Tanalith E 3492) on mechanical properties and to establish the relation between the penetration and compression strength for *Pinus sylvestris*. They observed that the treated wood (with either product) presents a statistically significant increase in static bending strength, modulus of elasticity and compression strength parallel to the grain. The purpose of this study was to determine air dry density, mechanical properties, and amount of retention in wood material applied with liquid nitrogen which has the potential to be a new method which can eliminate problems encountered in the impregnation of Uludag fir wood.

MATERIAL AND METHODS

Wood species

Uludag fir (*Abies nordmanniana* subsp. Bornmulleriana) was chosen randomly from timber suppliers in Ankara, Turkey. A special emphasis was put on the selection of the wood material. Accordingly, nondeficient, whole, knotless, normally grown (without zone-line, reaction wood, decay, and insect or fungal infection) wood materials were selected.

Impregnation materials

Tanalith E, Immersol aqua, borax (2.5% solution) supplied from Hemel Emp. San. and Tic. A.Ş. were used as impregnation chemicals. Tanalith E as the preservative used for this article is constitute of copper carbonate ($CuCO_3$), 2-aminoethanol, tebuconazole, boric acid (H_3BO_3) and di-2-ethylhexylphthalate. Tanalith-E impregnating agent was used in the form of a solution at a concentration of 2.36%. Imersol aqua was applied as a solution at 2.5% concentration. Borax was prepared in the laboratory in a way that they were at a concentration of 2.5%, after being completely dissolved.

Liquid nitrogen

Nitrogen is inert to most materials and its fluid is very cold. Due to these features, it is a safe freezer and cooler. Liquid nitrogen is inert, uncolored, odorless, noncorrosive, not support combustion, and extremely cold. Features of nitrogen are given in Tab. 1.

Tab. 1: Features of nitrogen.

Density	0.000808 $g \cdot cm^{-3}$
Freezing point 1 atm	- 210.0°C
Boiling point 1 atm	- 195.79°C

Density determination

Wood materials were kept in the room at 20 ± 2°C and 65 ± 3% relative humidity until their weight became stable. The air-dry densities of wood materials were determined according to TS 2472 (2005) before and after the impregnation process. Then, the dimensions of wood materials were measured with a compass of ± 0.001 sensitivity, and their volumes were determined by a stereometric method. The air-dry density (δ12) was calculated using the following Eq. 1:

$$\delta 12 = M12 / V12 \ (g \cdot cm^3) \quad (1)$$

where: M12 is the perfect air-dry weight (g), and V12 is the volume (cm^3) of the wood material.

Preparation of experimental samples

Air-dried samples were exposed to liquid nitrogen before impregnation in order to increase the retention amount of the impregnating agent. Samples prepared for each group were kept in liquid nitrogen for 15, 90 and 360 min. Then, the impregnation process was applied to the samples that were air dried, according to ASTM D 1413-76 (1976), TS 344 (1981) and TS 345 (1974) standards.

Before impregnation process, all samples except the control samples were kept under liquid nitrogen environment in the form of 15, 90 and 360 min, resp. Four different impregnation methods were used in each method in which the test samples were treated four different types of impregnation materials. First method, driving method with a brush, the samples were applied impregnation materials with the help of a brush. Second method, using the short term immersion method, the samples were dipped into the impregnation materials for 5 min. Third method, long-term immersion, the samples were dipped into the impregnation materials for 90 min. Fourth method, a pressure vacuuming method, which was equal to 760 mmHg, was applied to the samples. They were then dipped for 60 min in a impregnating tank which filled with impregnation materials to 8 –10 atm pressure. The above-mentioned four methods were applied separately for each impregnating agent (Tanalith-E, Imersol aqua, borax 2.5% solution). Before the impregnation process, all samples were weighed in an analytic balance with 0.01 g sensitivity. After the impregnation, the samples were kept until 3-4 days in a sunless environment. After cooling, all dried samples in the desiccator were weighed on the scale. The dry weight of the

samples was determined and recorded. The amount of retention (R, kg·m^{-3}) and ratio of retention (R, %) were calculated as follows:

$$R = \frac{G.C}{V} \cdot 10 \qquad (\text{kg}\cdot\text{m}^{-3}) \tag{2}$$

$$R(\%) = \frac{Moes - Moeö}{Moeö} \cdot 100 \qquad (\text{kg}\cdot\text{m}^{-3}) \tag{3}$$

$$G = M_{0es} - M_{0eo} \tag{4}$$

where: R - the weight gain percentage, G - amount of preservative solution absorbed by the sample (kg), C - the concentration of the impregnating material (%), *Moeo* - the weight of the oven-dried specimens before impregnation (kg), and *Moes* - the weight of oven-dried after impregnation (kg).

Application of the test

Before testing all samples were climatized until they were stable at 20 ± 2°C and 65 ± 3% relative humidity (RH) in climate room. The samples for bending test (MOR) and dynamic bending strength were cut as 2 x 2 x 32 cm according to TS 2474 (1976), TS 2477 (1976) respectively. Modulus of elasticity in bending (MOE) was conducted as compliance with TS EN 310 (1999). Bending strength and modulus of elasticity in bending were determined by using Universal testing machine. Impact strength was determined by using 10 kg·m^{-3} pendulum hammer tool. Compression strength in the parallel to the fibers was tested as compliance with TS 2474 (1976), TS 2595 (1976) resp. Specimens were 2 cm in thickness and width and 3 cm in length. Compressive strength in the parallel to the fibers was defined by using the universal testing machine.

Data analyses

By using four impregnation chemicals and one unimpregnated control sample, and four different impregnation methods were prepared using 10 replications for each combination. Multiple analyses of variances were used to determine the effect of liquid nitrogen in impregnation of the prepared samples.

RESULTS AND DISCUSSION

In this study, Uludag fir wood was impregnated by using Tanalith-E, borax and Imersol aqua. All of the samples (not control) before the impregnation process was subjected to liquid nitrogen treatment. The summary results of air dry density, retention rate and mechanical properties for each combination were given in Tabs. 2, 3 and 4.

Tab. 2: Summary of results related to air dry density of Uludag fir wood (g·cm^{-3}).

Impregnation materials	Impregnation method	Time of exposure in liquid nitrogen		
		15 min	90 min	360 min
Tanalith-E	Brush	0.428	0.445	0.446
	Short-term immersion	0.426	0.433	0.425
	Long-term immersion	0.430	0.424	0.467
	The pressure-vacuuming	0.415	0.442	0.445
Borax	Brush	0.428	0.438	0.442
	Short-term immersion	0.427	0.437	0.447
	Long-term immersion	0.437	0.428	0.435
	The pressure-vacuuming	0.433	0.435	0.436
Imersol aqua	Brush	0.443	0.442	0.421
	Short-term immersion	0.463	0.463	0.436
	Long-term immersion	0.455	0,456	0.452
	The pressure-vacuuming	0.422	0.427	0.434

The highest air dry density value was determined as 0.467 g·cm^{-3} on the samples impregnated with long-term immersion method in Tanalith-E after incubation in liquid nitrogen environment for 360 min and the lowest value was found as 0.415 g·cm^{-3} on the samples impregnated with the pressure-vacuuming method in Tanalith-E after waiting in liquid nitrogen environment for 15 min. Ors et al. (2006) determined that the increment with the increase in the impregnation period of air-dry densities of wood species impregnated with Imersol aqua. Air dry density is a measure of the proportion of cell wall material in the wood and is hence dependent on the ratio of cell wall thickness and cell diameter (Lundgren 2004).

Tab. 3 summarizes the mean values of the retention rate in Uludag fir wood. The highest change value of retention rate was 624% with the samples impregnated with the borax, applied by the brush method and exposed to liquid nitrogen for 90 min before impregnation method. In contrast, the lowest change was 18.9% in the samples impregnated with the Imersol aqua, applied by brush method and exposed to liquid nitrogen for 15 min before impregnation.

Tab. 3: The mean values of the retention rate in Uludag fir wood (%).

Impregnation material	Impregnation method	Time of exposure in liquid nitrogen			
		Uludag fir			
		15 min	90 min	360 min	Control
Tanalith-E	Brush	2.026 0.204* 57,07**	4.154 0.290* 222.11**	3.280 0.136* 154.34**	1.289 0.042*
	Short-term immersion	3.348 0.068* 108.91**	5.698 0.210* 255.54**	4.505 0.138* 181.07**	1.602 0.154*
	Long-term immersion	2.488 0.198* 51.01**	4.431 0.109* 168.94**	4.104 0.163* 149.12**	1.647 0.255*
	The pressure-vacuuming	4.295 0.311* 84.88**	5.323 0.376* 129.12**	4.343 0.257* 86.92**	2.323 0.143*
Borax	Brush	4.055 0.190*	4.994 0.191*	4.531 0.365*	0.689 0.201*

		488.40**	624.60**	557.37**	
	Short-term immersion	4.376 0.214* 263.86**	4.990 0.289* 314.93**	3.952 0.324* 228.62**	1.202 0.102*
	Long-term immersion	4.747 0.298* 144.29**	6.358 0.421* 227.22**	3.684 0.216* 89.58**	1.943 0.142*
	The pressure-vacuuming	6.134 0.258* 283.52**	8.441 0.462* 427.69**	5.172 0.260* 223.33**	1.599 0.125*
Imersol aqua	Brush	1.876 0.112* 18.94**	2.921 0.241* 85.14**	5.778 0.433* 266.23**	1.577 0.213*
	Short-term immersion	4.084 0.310* 97.79**	5.866 0.392* 184.12**	5.312 0.319* 157.30**	2.064 0.162*
	Long-term immersion	4.216 0.295* 93.75**	6.267 0.059* 187.99**	8.351 0.378* 283.72**	2.176 0.217*
	The pressure-vacuuming	5.866 0.417* 414.03**	6.166 0.459* 440.27**	5.394 0.318* 372.62**	1.141 0.112*

* Standard deviation.

** % Change in retention amount according to the samples without pre-impregnation liquid nitrogen application.

Generally, there was an increase in the amount of retention for 15 min and 90 min time of exposed in a nitrogen atmosphere of Uludag fir wood whereas the amount decreased in the time of exposure in nitrogen atmosphere for 360 min. Xu et al. (2015) and Poonia et al. (2016) determined that the retention rate increased by the treatment of the microwave method before the process of impregnation in wood material.

The increase of retention rate is dependent on permeability which increased due to change in cell structure because of high pressure generated by steam within the wood. Under high internal steam pressure, the pit membranes in cell walls, tyloses in vessels, and the weak ray cells rupture to form pathways for easy transportation of liquids and vapours (Vinden et al. 2011). After the treatment of microwave in wood, micro-checks were formed at the intercellular layer of ray cells, and the longitudinal tracheid and pit membranes were damaged (He et al. 2014). The amount of retention rate decreased because of more damage occurred in the cell of wood as a result of a certain period in the liquid nitrogen treatment.

Mechanical properties of Uludag fir wood is given in Tab. 4. The results indicated that the bending strength of samples treated by liquid nitrogen before impregnation process decreased significantly compared to of the corresponding ones in control samples. The minimum bending strength value was 50.23 $N \cdot mm^{-2}$ in the samples impregnated with Borax in short-time immersion method and in samples not exposed to liquid nitrogen before impregnation while the maximum bending strength value was 78.41 $N \cdot mm^{-2}$ for samples impregnated with Tanalith-E in applied by the brush method and exposed to liquid nitrogen for 90 min before impregnation method. The highest modulus of elasticity in bending value was at 9587.8 $N \cdot mm^{-2}$ for samples impregnated with Borax in applied by the vacuum pressure method and held in nitrogen for 360 min whereas the lowest was 7305.9 $N \cdot mm^{-2}$.

Tab. 4: Mechanical properties of Uludag fir wood ($N \cdot mm^{-2}$).

Exposure time in liquid nitrogen		Control			15 min			90 min			360 min		
Mechanical properties	Impregnated material / impregnated method	Tanalith-E	Borax	Imersol aqua	Tanalith-E	Borax	Imersol aqua	Tanalith-E	Borax	Imersol aqua	Tanalith-E	Borax	Imersol aqua
Bending strength	Brush	74.72 (2.95)*	69.62 (5.29)*	53.95 (4.57)*	72.03 (5.55)*	63.66 (4.16)*	59.57 (5.93)*	78.41 (5.17)*	63.34 (5.88)*	77.94 (7.55)*	64.46 (3.93)*	77.73 (5.48)*	75.45 (5.64)*
	Short-term immersion	64.13 (5.85)*	50.23 (1.34)*	60.40 (4.95)*	68.44 (4.88)*	67.05 (4.06)*	70.99 (5.92)*	73.39 (5.76)*	67.89 (3.90)*	70.13 (6.07)*	67.91 (6.17)*	70.94 (5.50)*	64.84 (5.88)*
	Long-term immersion	64.37 (5.94)*	54.69 (4.66)*	65.81 (0.59)*	74.11 (5.75)*	68.48 (5.42)*	67.66 (6.34)*	65.77 (5.14)*	72.93 (2.81)*	73.27 (1.10)*	75.13 (6.24)*	72.88 (5.81)*	75.76 (6.79)*
	The pressure - vacuuming	72.86 (3.49)*	64.44 (6.87)*	72.12 (4.01)*	77.94 (4.41)*	73.01 (4.80)*	71.76 (1.09)*	73.23 (6.36)*	72.29 (5.17)*	58.33 (4.84)*	61.82 (4.51)*	73.29 (2.06)*	64.39 (6.41)*
Modulus of elasticity in bending ($N \cdot mm^{-2}$)	Brush	7772.2 769.14*	7732.3 5.36*	7448.2 255.92*	7495.8 226.49*	8442.4 625.55*	7345.4 627.85*	9432.2 917.45*	7710.6 658,14*	9328.2 681.01*	8311.0 736.83*	9323.8 828.00*	9582.0 908.66*
	Short-term immersion	8007.3 797.22*	7492.6 159.38*	7305.9 89.34*	8435.4 182.34*	8147 644.58*	8504.8 772.36*	8998.8 627.27*	8134 473.41*	8545.2 705.00*	8364.8 804.44*	8455.4 768.46*	7561 670.93*
	Long-term immersion	8152.2 730.72*	7982 56.01*	8818.8 267.36*	8279.4 725.18*	8279.4 725.18*	8289.8 779.93*	8624.2 772.73*	8501.8 273.78*	9026.6 222.06*	8626.8 895.86*	8960.6 808.07*	8942.4 856.05*
	The pressure – vacuuming	8901.6 734,49*	7587.8 534.69*	8097.8 209.23*	9575.2 786.34*	9576.2 864.51*	9435 617.37*	8909.8 722.29*	9852.8 824.69*	7888.8 641.51*	7875.4 844.10*	9587.8 272.67*	7798.4 706,23*
Compression strength parallel to the fibers ($N \cdot mm^{-2}$)	Brush	46.43 (3.28)*	49.18 (3.22)*	49.55 (4.57)*	52.94 (5.37)*	47.21 (6,361)*	47.49 (3.18)*	53.72 (3.06)*	47.50 (3.66)*	53.19 (3.30)*	50.54 (4.79)*	51.28 (4.81)*	50.99 (4.33)*
	Short-term immersion	51.76 (5.35)*	46.03 (1.56)*	48.91 (3.70)*	50.91 (1.61)*	53.32 (4.05)*	52.16 (4.47)*	48.90 (2.93)*	50.77 (2.02)*	48.91 (4.45)*	50.85 (4.26)*	53.17 (5.20)*	50.09 (3.48)*
	Long-term immersion	51.324 (4.37)*	48.32 (1.66)*	49.73 (2.85)*	56.05 (4.21)*	49.24 (5.50)*	54.11 (4.10)*	56.01 (5.42)*	49.69 (4.65)*	48.04 (1.11)*	47.98 (2.11)*	51.91 (4.81)*	50.67 (3.21)*
	The pressure - vacuuming	44.27 (4.01)*	44.27 (3.01)*	51.94 (2.92)*	54.02 (5,29)*	58.25 (5.30)*	52.55 (5.03)*	53.37 (5.23)*	60.22 (2.88)*	51.22 (3.43)*	47.25 (3.57)*	52.90 (4.89)*	50.14 (1.82)*
Impact strength ($kN \cdot cm^{-2}$)	Brush	1.4 (0.14)*	2.4 (0.15)*	2.08 (0.08)*	1.44 (0.05)*	1.6 (0.03)*	1.48 (0.02)*	1.40 (0.55)*	1.9 (0.16)*	1.26 (0.05)*	2.04 (0.12)*	1.62 (0.08)*	2.27 (0.03)*
	Short-term immersion	1.28 (0.08)*	1.86 (0.05)*	2 (0.10)*	1.7 (0.02)*	1.78 (0.02)*	1.54 (0.03)*	1.58 (0.02)*	1.76 (0.17)*	1.6 (0.13)*	1.94 (0.07)*	1.4 (0.09)*	1.22 (0.07)*
	Long-term immersion	2,26 (0.11)*	1.48 (0.08)*	2.28 (0.08)*	1.06 (0.01)*	1.96 (0.02)*	1.7 (0.02)*	1.82 (0.02)*	1.78 (0.03)*	1.56 (0.02)*	1.8 (0.06)*	2.02 (0.12)*	1.82 (0.10)*
	The pressure - vacuuming	1.3 (0.10)*	2.06 (0.05)*	0.96 (0.05)*	1.56 (0.05)*	1.64 (0.05)*	1.9 0.03)*	1.96 (0.15)*	1.16 (0.08)*	1.7 (0.10)*	1.96 (0.05)*	1.72 (0.05)*	1.84 (0.11)*

Ors et al. (2006) reported that a decrease in the impregnation period increased the modulus of elasticity in bending. The highest compression strength parallel to the fibers value was 60.228 $N \cdot mm^{-2}$ in the samples impregnated with borax applied by the vacuum pressure method and held in nitrogen for 90 min and the lowest value was 44.274 $N \cdot mm^{-2}$ for control samples impregnated with borax applied by the vacuum pressure method. Akhtari et al. (2012) determined some mechanical properties, as bending strength (MOR), the modulus of elasticity in bending (MOE), compression strength parallel to grain of *Paulownia fortunei* wood impregnated with silver, copper and zinc oxide nanoparticles. They concluded that the impregnation treated samples of paulovnia wood with nanoparticles had no negative effect on MOR, MOE and compression strength parallel to grain. The highest impact strength value was 2.4 $kN \cdot cm^{-2}$ for samples impregnated with borax applied by the brush method and control samples.

The lowest impact strength was 1.3 $kN \cdot cm^{-2}$ for control samples impregnated with Tanalith-E applied by the vacuum pressure method. The effects of wood preservatives on mechanical properties are directly related to several keys such as preservative chemistry or chemical type, retention rate, post-treatment drying temperature and genus of material (Akhtari and Nicolas 2014).

Tab. 5: ANOVA results on mechanical properties in Uludag fir wood.

Mechanical properties	Variance resources	Sum of squares	Degrees of freedom	Mean square	F value	Significance ($P \leq 0.005$)
Bending strength	A: Time of exposure	1752.5	3	584.1	8.2	0.000
	B: Impregnation method	231.4	3	77.1	1.0	0.356
	C: Impregnation material	1932.8	2	644.2	9.053	0.000
	Interaction A*B	1889.3	9	209.9	2.95	0.002
	Interaction A*C	1525.6	6	169.5	2.382	0.013
	Interaction B*C	1059.2	6	117.6	1.654	0.101
	Interaction A*B*C	6019.5	18	222.9	3.133	0.000
	Error	18218.9	256	71.16		
	Total	1594520.1	320			
Modulus of elasticity in bending	A: Time of exposure	3.29E+07	3	1.10E+07	9.155	0.000
	B: Impregnation method	1.47E+07	3	4913585.4	4.105	0.007
	C: Impregnation material	3.52E+07	2	1.17E+07	9.799	0.000
	Interaction A*B	6.13E+07	9	6808080.5	5.688	0.000
	Interaction A*C	3.08E+07	6	3423824.9	2.86	0.003
	Interaction B*C	3.49E+07	6	3874941.5	3.237	0.001
	Interaction A*B*C	7.48E+07	18	2768923.1	2.313	0.000
	Error	3.06E+08	256	1197009.9		
	Total	2.39E+10	320			
Compression strength parallel to the fibers	A: Time of exposure	445.8	3	148.6	6.37	0.000
	B: Impregnation method	293.5	3	97.8	4.194	0.006
	C: Impregnation material	169.1	2	56.3	2.416	0.067
	Interaction A*B	487.6	9	54.1	2.322	0.016
	Interaction A*C	272.7	6	30.3	1.299	0.238
	Interaction B*C	540.8	6	60.0	2.576	0.007
	Interaction A*B*C	784.8	18	29.0	1.246	0.193
	Error	5972.6	256	23.3		
	Total	852675.3	320			
Impact strength	A: Time of exposure	0.72	3	0.242	1.254	0.291

	B: Impregnation method	2.1	3	0.7	3.621	0.014
	C: Impregnation material	0.54	2	0.181	0.934	0.425
	Interaction A*B	2.74	9	0.305	1.576	0.123
	Interaction A*C	5.76	6	0.641	3.315	0.001
	Interaction B*C	1.39	6	0.155	0.802	0.615
	Interaction A*B*C	19.17	18	0.71	3.675	0.000
	Error	49.47	256	0.193		
	Total	1024.8	320			

According Tab. 5; the effect of time of exposure in liquid nitrogen on all mechanical properties were found significant except the impact strength). The influence of impregnation method did not significantly affect the mechanical properties. The effect of impregnation material in the bending strength and modulus of elasticity in bending were found to be significant while the compression strength parallel to the fibers and impact strength were found to be insignificant.

CONCLUSIONS

Especially, the effect of the increase in retention amounts on the mechanical properties of Uludag fir wood, which is one of the hardly impregnable species, was investigated by liquid nitrogen exposure at different times before impregnation. In the samples where liquid nitrogen was applied before impregnation, according to the control group samples; on average, the retention amount was increased by 150-200% in all impregnating agents used in the study. In the studies conducted by Kurt (2006), Winandy and Rowell (1984), it was determined that the impregnation with water-soluble salts reduced the mechanical properties of wood material by 5-15%. In this study, it can be concluded that the application of liquid nitrogen before impregnation ought not to be seen as a reason for the decrease in mechanical properties, but this decrease may have been caused by impregnating materials and methods. However, a significant decrease is observed in the mechanical properties of wood material with the microwave method which is one of the alternative retentions enhancing methods (Hansson 2007).

The mechanical properties, retention amount and air-dry density of treated wood were determined. Results indicated that the air-dry density increased with longer time of exposure with the application of liquid nitrogen before impregnation of wood treated with Tanalith-E and borax while the impregnation with Imersol aqua decreased. Retention rate amount increased with increasing of the time of exposure at the liquid nitrogen treatment before impregnation process in wood, then decreased. The time of exposure at the liquid nitrogen applied before impregnation of wood influenced the mechanical properties such as bending strength, modulus of elasticity, compression strength from different directions. The bending strength of the samples held in liquid nitrogen decreased. The modulus of elasticity in bending strength values showed significant differences depending on the impregnation method and type of impregnation material. The compression strength parallel to the fibers increased with increases the time of exposure at the liquid nitrogen applied before impregnation of Uludag fir wood. Compared to control samples, impact strength of the samples held in liquid nitrogen is increased early and then decreased.

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