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Influence of Thermal Treatment on the Hygroscopicity and Dimensional Stability of Oak Wood

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The influence of thermal treatment on moisture exchange between wood and natural environment with variable air parameters as well as on dimensional stability of wood samples was investigated. The experiments were carried out with oak wood samples indoors and outside. The thickness of samples was 30 mm, width was 30 mm and length was 20 mm; conventional density varied from 500 kg/m^3 to 580 kg/m^3. Initially, the wood was air-dried down to 7 % – 9 % of moisture content. In order to decrease possibility of the both moisture absorption and evaporation during wood application thermal treatment must be applied. Due to that the samples were heated at temperature of 60, 80, 100 and 120 ºC for 24, 48, 72 and 96 hours. The moisture content of wood and its variations after thermal treatment depends on the both heating temperature and duration. The higher temperature and the longer heating duration, the lower wood hygroscopicity can be achieved. The effect of thermal treatment on the moisture content and its changes were observed for wood samples stored indoor and outside. In dependence of thermal treatment conditions moisture content in wood samples independently on storing conditions (indoor or outside) can decrease down to 30 % compare to the untreated ones. The change of moisture content during various seasons after 24 hours of storing indoor decreases down to 60 %, while outside that is only 39 %. Dimensional stability of wood samples also depends on the both thermal treatment temperature and duration. The higher treatment temperature and the longer duration, the higher dimensional stability can be obtained. The heat treatment of oak wood samples at selected regimes allows to decrease values of shrinkage and swelling coefficients down to 40 %.
Keywords: wood, sorption, moisture content, thermal treatment, dimensional stability.

INTRODUCTION

Wood is one of strongest organic natural materials and is widely used in various fields of application. Wooden constructions is light in weight and resistant to various external factors. Wood has high mechanical strength, is durable and has low mass. In some constructions hardwood can replace metal elements [1].

Wood can be easily processed, has good isolation properties. Due to this wood is widely used in building and furniture industry. On the other hand, disadvantage of wood is high hygroscopicity. During exploitation it absorbs humidity from environment and evaporate it out. That influences dimensions and shape of assortments. Besides, moisture content in the wood influences its physical and mechanical properties [2 – 4].

There are different modes to decrease hygroscopicity of the wood. Most popular is wood coating, thermal treatment, impregnation using paraffin, acetylation, etc. [5 – 7]. Wood is ideal structural system and artificial structural modification can improve some properties, but other after modification can be decreased [8].

Wood thermal treatment or heating – is good and environmental safe alternative method compared with impregnation using chemicals. After thermal treatment biological durability can be significantly improved, resistance to biological vermin and increased dimensional stability of product [9 – 11]. Such kind of treated wood is widely used for producing garden, kitchen, sauna furniture, floors, ceilings, windows frames, doors, etc. [12]. Equilibrium moisture content of thermally treated wood is fully dependent on the treatment temperature and duration. The more intensive treatment regimes, the lower moisture content in the wood is reached. For example, after 2 hours treatment equilibrium moisture content of oak wood at heating temperature of 130 ºC decreases by 10.1 %, at temperature of 180 ºC that is 20.2 % and at temperature of 230 ºC it decreases down to 50 %. Equilibrium moisture content for other kinds of wood, such as chestnut, calabrian pine, black pine and fir changes according to the same law [10, 11]. On the other hand, after thermal treatment some properties of the wood samples decreases [9 – 11]. After thermal treatment of pinewood at temperature of 120 ºC for 10 hours compression strength parallel to grain decreases by 6 %, bending strength and impact bending strength decreases by 10 %, modulus of elasticity during bending decreases down to 14 %, janka-hardness – 10 % – 18 %, tension strength perpendicular to grain even 23 % [9]. The higher heating temperature, the more intensive decrease of properties was found [9, 13,14].

It was shown that wood changes appear at lower temperatures close to those of drying [15]. However, results of investigations related to the wood properties after treatment at lower than 80 ºC were not observed. Besides, investigation usually are performed at constant environmental parameters [3, 8 – 12].

In order to determine and compare sorption properties of pine wood in Lithuanian climatic conditions only moisture changes of pine wood dried in atmospheric and chamber conditions were determined [16]. While

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investigation of thermal treatment on the hygroscopicity changes under variable condition was not investigated.

Assuming that decrease of sorption properties is in high dependence on the wood type, the aim of this investigation was to determine and evaluate the influence of thermal treatment parameters on the oak wood hygroscopicity and dimensional stability under the various climatic conditions during different seasons in Lithuania.

EXPERIMENTAL

Oak wood, widely used in furniture production and construction industry, was investigated. Initially, the wood was air-dried down to (7 – 9) % of moisture content. Before thermal treatment samples from air-dried wood with thickness of 30 mm, width of 30 mm, and length of 20 mm were prepared. Conventional density of samples was (500 – 580) kg/m^3. Totally 16 groups for thermal treatment and one control group (untreated wood samples) containing of 30 samples in each of them were prepared and tested.

Thermal treatment in drying chamber SNOL 350 was performed at following regimes: temperature was T = 60, 80, 100 and 120 ºC, duration was τ = 12, 24, 48, and 96 hours.

The density of samples was determined according to ISO 3131-1975 [17], moisture content of samples was determined according to ISO 3130–1975 [18], and coefficients of shrinkage and swelling were measured according to ISO 4469–1981 [19] and ISO 4859-1982 [20].

The change of oak samples moisture content was studied in premises and outside. Outside the samples were kept in the meteorological boxes, protected against direct precipitation, sunlight and wind. The changes of moisture content was evaluated by comparing weight of wood samples measured during each 10 days in spring (04.19 – 04.28), 10 days in summer (06.16 – 06.25), 10 days in autumn (09.17-09.26) and 10 days in winter (02.12 – 02.21). Environmental parameters were fixed using Asman‘s psichrometer (Table 1).

Table 1. Environmental parameters

Period	Temperature T,ºC			Relative humidity ψ, %		
	T_{av}	T_{min}	T_{max}	ψ_{av}	ψ_{min}	ψ_{max}
Inside						
Spring	17.5	17.0	19.0	44.0	36.0	53.0
Summer	25.2	24.0	27.5	50.5	45.0	54.0
Autumn	20.0	18.0	23.5	49.5	49.0	52.0
Winter	14.6	11.0	17.8	43.0	38.0	47.0
Outside						
Spring	9.3	6.3	12.3	59.3	44.0	80.0
Summer	19.5	17.1	23.7	67.7	54.0	80.0
Autumn	14.4	11.6	15.6	82.0	72.0	88.0
Winter	–2.5	–6.2	1.3	85.0	76.0	90.0

Experimental results have revealed following tolerance of statistical parameters: for moisture content inside the group standard deviation was S = (0.35 – 0.7) %, variation was V = (5.3 – 7.2) %, precision index of an average value was P = (3.9 – 4.8) %. For moisture content outside statistical parameters varied as follows: S = (0.7 – 1.1) %, V = (3.8 – 8.4) %, and P = (3.2 – 4.5) %.

RESULTS AND DISCUSSION

In order to evaluate influence of environmental conditions, i. e. and thermal treatment temperature and duration on the dimensional stability and hygroscopicity, the variation of actual moisture and averaged moisture changes per 24 hours during 10 days of each season have been evaluated. The average of actual moisture content of oak wood samples is presented in Table 2, Fig. 1 and Fig. 2.

Table 2. Actual moisture content of samples during various seasons, %

Treatment temperature$T$, ºC	Treatment duration τ, h	Actual moisture content of oak wood samples ω, %							
		Spring		Summer		Autumn		Winter	
		Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
60	12	6.28	13.04	7.98	12.85	10.16	19.28	6.39	20.37
	24	6.21	12.95	7.85	12.14	9.95	18.40	6.31	20.25
	48	6.16	12.90	7.78	12.11	9.71	18.08	6.09	19.43
	96	6.14	12.28	7.70	12.01	9.32	16.61	5.96	19.39
80	12	6.12	12.26	7.50	11.95	9.30	15.57	5.82	19.27
	24	6.07	12.19	7.27	11.87	9.26	15.29	5.75	19.22
	48	6.05	12.02	7.27	11.76	9.13	15.13	5.67	19.16
	96	6.03	11.83	7.12	11.71	9.08	14.99	5.61	19.00
100	12	6.03	11.74	7.08	11.70	9.01	14.98	5.56	18.89
	24	5.99	11.73	6.97	11.68	9.00	14.90	5.36	18.82
	48	5.87	11.65	6.82	11.65	8.96	14.85	5.22	18.76
	96	5.75	11.64	6.59	11.59	8.96	14.84	5.21	18.70
120	12	5.71	11.57	6.26	11.53	8.91	14.75	5.18	18.60
	24	5.68	11.66	6.13	11.51	8.82	14.69	5.11	18.45
	48	5.08	11.43	6.09	11.46	8.68	14.63	5.03	18.30
	96	5.00	10.98	5.97	11.32	8.18	14.23	5.02	18.30
Untreated samples		6.58	13.50	8.79	12.88	10.67	19.49	6.60	20.68

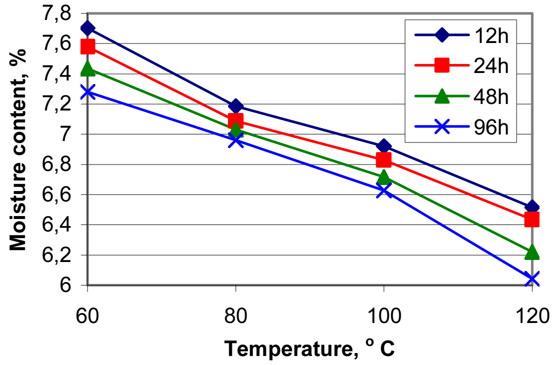


Fig. 1. Relation between the average actual moisture content per year vs thermal treatment temperature and duration inside

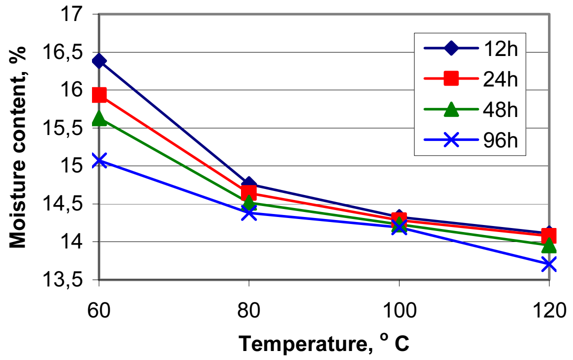


Fig. 2. Relation between the average actual moisture content per year vs thermal treatment temperature and duration outside

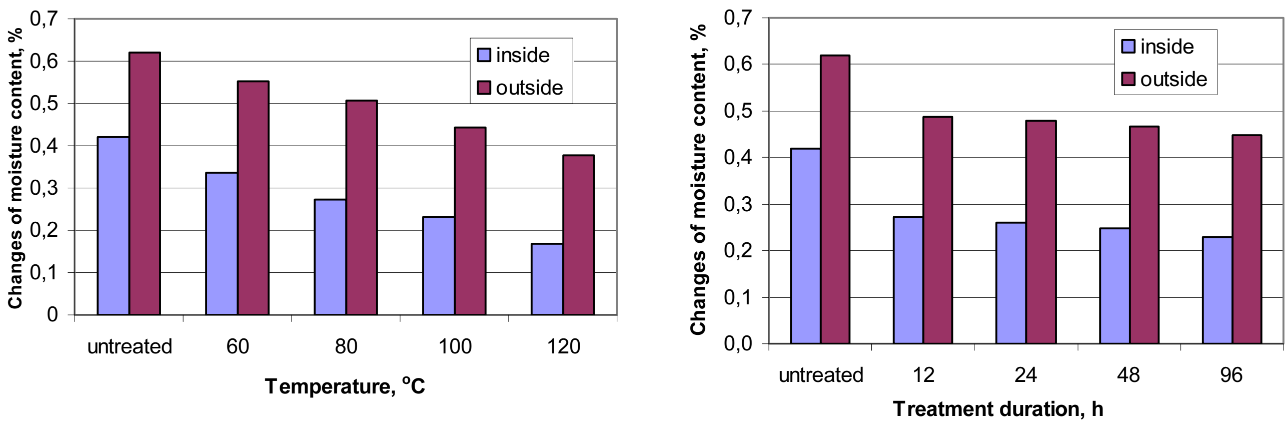
The increase of heating temperature from 60 ºC up to 120 ºC, decreases moisture content in wood samples from 1.1 times outside in summer and winter and down to 1.3 times in summer inside (Table 2.). The moisture content of samples heated for 96 hours at temperature of 120 ºC was found lower compare to those untreated: inside it was lower 1.3 times in spring, autumn and winter. In summer period it was 1.5 lower compare to the control one. For samples kept outside moisture content decreased 1.2 times in summer and spring, 1.4 times in autumn and 1.1 times in winter. Actual wood moisture after heating for 96 hours at temperature of 120 ºC in various atmospheric periods inside can decrease from 24 % down to 32 % (Fig. 1.) and outside that is from 12 % down to 27 % (Fig. 2.). Influence of heating temperature on wood moisture changes can be expressed according to the following ratio 1:0.91:0.87:0.84:0.8 (1 is control group (untreated, only air-dried sample) and other represents respectively treated at temperature of 60, 80, 100 and 120 ºC). After heating duration of 24, 48, 72, 96 hours this ratio for actual moisture is 1:0.89:0.87:0.86:0.85. As it can be seen, the influence of heat treatment temperature is more effective compare to those of heating duration.

Actual average moisture content of wood samples outside in winter was 3.4 higher than those inside.

The limits of moisture variation also decreased hours when heating temperature and duration increased (Fig. 3).

In Fig. 3, a, is presented variation of moisture content in dependence of treatment temperature. The result in column represents average result of total durations, i. e. all evaluated values independently on heat treatment duration at selected temperature are summarized and average of them is calculated. As it can be seen, the variation of moisture content of the samples compare to untreated ones inside was decreased from 18 % down to 60 % and outside that was from 11 % to 39 %. In this case influence of treatment temperature on the variation of moisture content can be expressed according to the ratio 1:0.85:0.73:0.63:0.5 (1 is for untreated sample ant other ones respectively for samples treated at temperature of 60, 80, 100, and 120 ºC). Effect of treatment duration is presented in Fig. 3, b. At heating duration of 24, 48, 72, 96 hours the ratio of actual moisture content changes was 1:0.72:0.7:0.67:0.63. Evident that the higher heat treatment duration, the lower actual moisture of wood samples and narrower variation limits were found (confirmation for that also is presented in Table 2). Comparison of the above presented results indicates that the influence of heat treatment temperature is more significant than heating duration.

Obtained decrease of hygroscopicity can be related initially to the monomolecular and later to the poly-molecular adsorption [16]. This can be explained by the fact that during thermal treatment at high temperatures part of free hydroxyl groups of cellulose molecule creates constant links. In this case these groups can not act as



a b

Fig. 3. The influence of treatment temperature (a) and duration (b) on the variation of average moisture content during 24 hours

potential sorption centres and capillary condensation process does not obtain changes [5].

If thermal treatment results on the decrease of hydroscopicity, follows that can result on the dimensional stability of wood samples, i. e. swelling and shrinkage of wood. In order to evaluate dimensional stability after thermal treatment part of thermally treated oak samples at temperature of 60, 80, 100 and 120 ºC and duration for 24, 48, 72 and 96 hours were dried up to absolutely dry mass and its dimensions in tangential and radial directions were determined. In order to eliminate effect of moisture sorption all treated samples of each group were divided in two groups. In first group samples were soaked until moisture content above 30 % will be reached and measures of the samples were determined. The second group of samples was initially soaked and after that dried and only after that dimensions in radial and tangential directions were determined. As result of this test average value of both groups for each treatment regime was assumed.

The average values of dimensional changes are presented in Fig. 4 and the coefficients of swelling and shrinkage are presented in Table 3.

The higher treatment temperature and duration the lower limits of dimensional changes. As it can be seen, the drying of samples at temperature from 60 ºC up to 120 ºC for 12 hours is unwarranted regimes for increase measurements stability (Fig. 4, a). In this case higher treatment duration is required (Fig. 4, b). This suggestion confirms and values of shrinkage and swelling coefficients presented in Table 3. The coefficients obtained for samples heated at 60 °C for 12 hours in radial and tangential direction is the same as for untreated samples. The increase of treatment temperature and duration results on the decrease of values of these coefficients. That indicates on

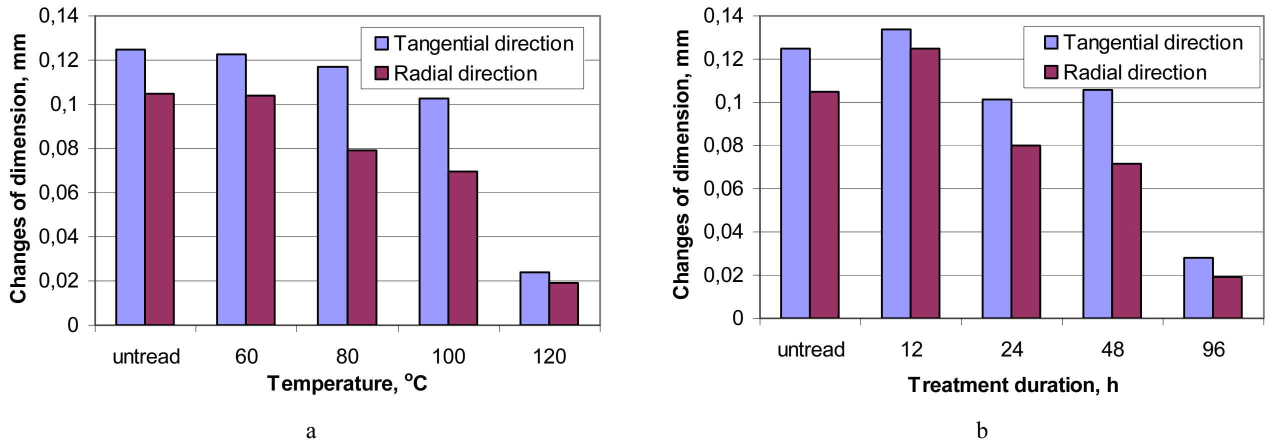


Fig. 4. The influence of treatment temperature (a) and duration (b) on the samples measures after 24 hours of treatment

Table 3. Coefficients of shrinkage and swelling of samples, %

Treatment temperature, ºC	Treatment duration, h	Coefficient of tangential shrinkage, %	Coefficient of radial shrinkage, %	Coefficient of volumetric shrinkage, %	Coefficient of tangential swelling, %	Coefficient of radial swelling, %	Coefficient of volumetric swelling, %
60	12	0.33	0.24	0.56	0.11	0.04	0.16
	24	0.32	0.22	0.55	0.11	0.04	0.15
	48	0.31	0.23	0.55	0.10	0.03	0.15
	96	0.31	0.23	0.55	0.11	0.05	0.15
80	12	0.31	0.22	0.54	0.10	0.04	0.14
	24	0.30	0.21	0.52	0.10	0.04	0.14
	48	0.30	0.22	0.53	0.10	0.04	0.14
	96	0.30	0.22	0.52	0.09	0.04	0.14
100	12	0.30	0.22	0.52	0.10	0.03	0.14
	24	0.29	0.22	0.50	0,09	0.03	0.13
	48	0.28	0.22	0.49	0.11	0.03	0.14
	96	0.28	0.19	0.47	0.09	0.04	0.14
120	12	0.25	0.19	0.44	0.09	0.04	0.13
	24	0.25	0.17	0.42	0.09	0.04	0.12
	48	0.24	0.15	0.39	0.08	0.03	0.11
	96	0.21	0.14	0.32	0.07	0.02	0.10
Untreated samples		0.34	0.25	0.58	0.11	0.06	0.16

the increase of dimensional stability. The highest decrease of coefficients was found at temperature of 120 ºC. In this case decrease of shrinkage in tangential direction varied from 26 % to 38 %, in radial direction it was from 24 % to 44 %. The swelling coefficients in tangential direction decreased from 18 % to 36 % and in radial direction most significant stability of dimensions was found, i. e. swelling coefficient decreases from 33 % to 66 %.

According to the obtained results it can be stated that heat treatment at relatively low temperatures (up to 120 ºC) results on the decrease of moisture content of oak wood and its variation limits, but increases dimensional stability. The obtained results also confirm results of other authors [15]. It is believable; that it is due to the fact that highest sorption ability has hemicelluloses (up to 47 % of total moisture), cellulose (up to 37 % of total moisture) and lowest sorption ability has lignin (only 16 %). During the thermal treatment structural changes appear in the both cellulose and hemicelluloses molecules, but the biggest ones is more expressed for hemicelluloses [3, 15]. After thermal treatment content of hemicelluloses decrease and that can be one of main reasons influencing decrease of wood hydroscopicity.

CONCLUSIONS

The moisture content of oak wood and its variations after thermal treatment in relatively low temperatures depends on the both thermal treatment temperature and duration.

The higher temperature and the longer heating duration, the lower wood hygroscopicity can be reached.

The effect of thermal treatment on the moisture content and its variation was observed for wood samples stored indoor and outside. Independently on storing conditions (indoor or outside) moisture content in wood samples after thermal treatment can be lower up to 30 % compare to the untreated ones.

The average changes of moisture content during various seasons after 24 hours of storing indoor decreases down to 60 %, while outside that is only 39 %.

Dimensional stability of wood samples also depends on the both thermal treatment temperature and duration. The higher treatment temperature and the longer duration, the higher dimensional stability can be obtained. The heat treatment of oak wood samples at selected regimes allows to decrease values of shrinkage and swelling coefficients down to 40 %.

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