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THE EFFECT OF HEAT AND AMMONIA TREATMENT ON COLOUR RESPONSE OF OAK WOOD (*Quercus robur*) AND COMPARISON OF SOME PHYSICAL AND MECHANICAL PROPERTIES

Petr Čermák^{1,*}, Aleš Dejmal¹

ABSTRACT

In this paper the effect of heat and ammonia treatment on the change in colour of oak wood (*Quercus robur*) and comparison of physical and mechanical properties were investigated. Wood specimens were made from heartwood and sapwood in dimensions 30×30×30 mm³. The specimens were subjected to heat treatment at 180°C and 230°C for 2 and 4 hours, others were treated by ammonia for 24 hours. After these processes, CIELAB colour, hardness, EMC, density and MOE of wood were tested in comparison with untreated samples. The results show that the heat treatment contributed to darkening of sapwood and heartwood and the total colour change increased up to 38.47 units (CIELAB) in the radial direction and 37.75 units (CIELAB) in the tangential direction. Previous research into ammonia treatment shows that the most significant changes were noticed after 1 day. The colour changes between sapwood and heartwood were more noticeable in ammonia treatment than in the case of heat treatment. All other observed properties were decreased in the case of heat treatment. Ammonia treatment does not have a significant influence on the other observed properties. The results proved that ammonia treatment is a modification that improves the decorative value but has a minimal effect on technologically relevant properties of solid wood. Nevertheless, the heat treatment can be used as comparable process for colour change of wood.

Keywords: Ammonia treatment, CIELAB, colour change, density, equilibrium moisture content, Janka hardness, heat treatment, modulus of elasticity, *Quercus sp.*

INTRODUCTION

Wood is a complex and natural material that consists of cellulose (35–55%), hemicelluloses (20–35%) and lignin (15–36%) and other inorganic and organic compounds (3–10%). Cellulose represents the crystalline area of the wood, hemicelluloses and lignin make up the amorphous area. These compounds constitute the colour of wood. The colour can be changed by many processes, for example heat and ammonia treatment.

Heat treatment has important effects on the colour and the chemical composition of the wood. Colour is a very important wood property for the final use, and in some cases it is the determining factor for the selection of a specific wood. Most wood colour studies quantify the colour by the CIELAB method with a three axes system (Brischke *et al.* 2007, Baar and Gryc 2012, Bekhta and Niemz 2003). The specimens become darker with an increasing treatment time and temperature as reported by several authors (Mitsui *et al.* 2001, 2003, 2004; Militz 2002, Bekhta and Niemz 2003). Esteves *et al.* (2008) reported that noticeable colour changes could already be obtained for small mass losses of 2–4%, but the effect depended on the extent of treatment and was related to the chemical composition of the heat treated woods. The darker tonality of heat treated wood is often attributed to the formation of coloured degradation products from hemicelluloses (Sehlstedt–Persson 2003, Sundqvist 2004) and to extractives that seem to participate in the colour formation of heat treated wood (McDonald *et al.* 1997, Sundqvist and Morén 2002). The main effect of the heat treatment is the decrease in equilibrium moisture content (EMC). The reduction was already reported in 1920 by Tiemann, who showed that drying at high temperatures decreased the equilibrium moisture of wood and consequently it is swelling and shrinking. According to Jämsä and Viitaniemi (2001), the reason for the decrease in the equilibrium moisture content is that less water is absorbed by the cell walls after the heat treatment

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as a result of the chemical change with a decrease in hydroxyl groups. Boonstra *et al.* (2007) and Korkut *et al.* (2008) found that the Brinell hardness parallel to the grain increased significantly (48%), whereas the hardness perpendicular to the grain increased slightly (5%). One of the main heat treated wood limitations is the decrease in mechanical strength. The first tests made by Stamm *et al.* (1946) showed that MOE increased slightly for wood treated at 180°C and 200°C, decreasing afterwards, reaching a 10% decrease after 20 hours at 180°C and 8 hours at 200°C. With the treatment at 220°C, MOE decreased drastically by about 60% in only 7 hours. Vavrčík *et al.* (2008) reported the average density of oak wood (*Quercus robur*) as 618.2 kg m⁻³. Similar results were obtained by Vavrčík and Gryc (2012), which presented average density 584.3 kg m⁻³. Also was confirmed the influence of stand and position in the trunk. The density of wood treated between 200°C and 260°C decreased from 447 kg m⁻³ to 381 kg m⁻³ and from 623 kg m⁻³ to 617 kg m⁻³ for spruce and beech wood, respectively, corresponding to a decrease of 15% and 1%. Boonstra *et al.* (2007) also reported a 10% and 8.5% decrease in density for heat treated Scots pine and Norway spruce, respectively.

The ammonia treatment as a method to change the colour of wood is well known and has been explored by several authors (Tinkler 1921, Bariska 1969). Weigl *et al.* (2007, 2009a, b) showed the effect of ammoniation on the colour of wood. With proper treatment light-coloured wood is darkened and may imitate exclusive timber (Weigl *et al.* 2009b). Ammonia treated wood is therefore frequently applied in interior design for furniture or flooring. The most often used species for ammonia treatment is oak. Colour changes of many different wood species following ammonia treatment procedure have been studied (Weigl *et al.* 2009c), and values of total colour changes were found to vary between 8 and 42. According to Tinkler (1921), changes in colour are due to the reaction of ammonia with tannin in the wood and atmospheric oxygen. Sapwood of oak contains just a little of tannin, due to which the colour changes is smaller. Significant changes in EMC due to the ammonia treatment process were found by Weigl *et al.* (2012), which was consistent with earlier findings (Weigl *et al.* 2009c). The observed magnitude is not of practical relevance in the case of oak (an average increase of 0.5%), and the same is true for the two softwood (Norway spruce and Scots pine) species showing even lower differences compared to oak. No significant changes in wood density were found using ammonia treatment for any of the investigated species (Weigl *et al.* 2012). That is why EMC and density variations seem to be irrelevant with respect to the possible impact on mechanical properties of ammonia treated wood. Significant changes in MOE were partly observed for oak wood. However, stiffness and strength losses were in the range of 6 to 15%, which is negligible with respect to common solid wood applications.

This study deals with the effect of heat and ammonia treatment on solid wood properties. The main aim of this paper is to compare the influence of these processes on colour response and the extent of the changes of physical and mechanical properties.

MATERIAL AND METHODS

Wood specimens used for this study were obtained from oak wood (*Quercus robur*). Specimens with dimensions 30×30×30 mm³ in tangential, radial and longitudinal directions were used. Half of them were taken from heartwood, the other half from sapwood. Samples were stored at conditions T=20°C; RH=40% until equilibrium moisture content (EMC) was reached – 7.5%. The references values of colour tone and hardness were measured before treatment.

The specimens were divided into sets of 30 samples for each material (sap- and heartwood) and each treatment time and temperature (Table 1). Time of ammonia treatment was chosen based on a previous test. It shows that the most significant colour change occurred during the first day. Heat treatment was performed using a universal high-temperature box SIEMENS HB36D.70. The used procedure was by ThermoWood technology, developed by VTT in Finland. Specimens were exposed to ammonia for 24 h. The ammonia treatment was performed at a temperature of 20°C under atmospheric pressure in a closed fume cupboard. Samples were placed on plastic grids above the open surface of ammonia solution with concentration 25% (0,3 ml of 25% solution per 1 g of wood).

Table 1. Sets of 30 samples for each material and each treatment.

Material	Temperatures (°C)	Treatment	Times (h)
Oak sapwood	180; 230	heat	2; 4
Oak heartwood	180; 230	heat	2; 4
Oak sapwood		ammonia	24
Oak heartwood		ammonia	24
Oak sap/heartwood	reference	untreated	

Colour measurements of all specimens were taken on tangential and radial surfaces of the wood specimens before and after treatments by a spectrophotometer BYK spectro-guide 45/0 in colour system CIELAB. The diameter of sensor head was 11 mm. Measurements were made using a 10-degree standard observer and D 65 illuminant. Colour system CIELAB is defined as follows: L^* is the value of lightness, a^* is the chroma from green to red and b^* is the chroma from blue to yellow. From these values the differences (ΔL^* , Δa^* and Δb^*) can be calculated as well as the total colour difference (ΔE^*) between treated and untreated wood.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

The measurements of hardness and modulus of elasticity in compression were performed on Zwick 050 machine by the Janka method. Janka hardness test measures the resistance of a type of wood to denting and wear. It measures the force required to embed an 11.28 mm steel ball into wood. The values of modulus of elasticity were calculated by software testXpert, hardness was calculated by the following equation.

$$H_j = 4F / 3\pi r^2 \quad (2)$$

Density was measured by common equation (Siau 1984). Equilibrium moisture content was observed on all specimens which were subjected to the same conditions as the untreated ones.

RESULTS AND DISCUSSION

The effect of heat and ammonia treatment on wood colour change

The following graphs show the influence of lightness (L^*), chroma from green to red (a^*) and chroma from blue to yellow (b^*) on the final colour change (ΔE^*). All results are shown for the radial as well as for the tangential surface. In all graphs is also added information about tangential surface in the middle of thickness (testing samples were half-splitted).

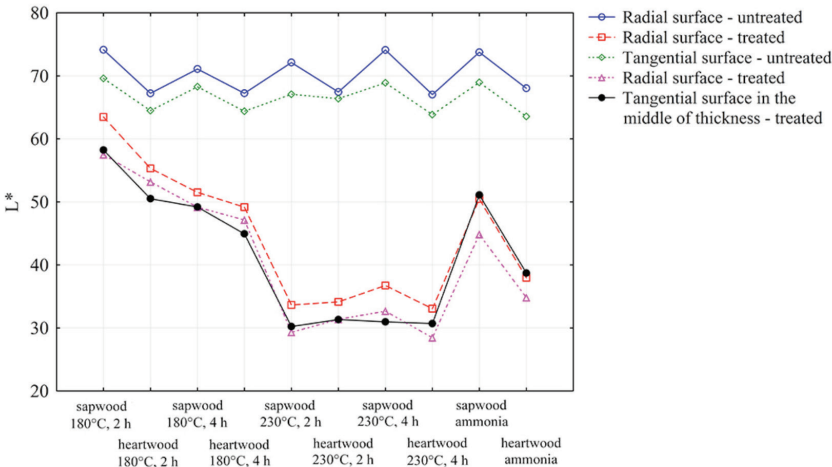


Figure 1. Changes of lightness (L^*) for all treated and untreated specimens.

Figure 1 depicts an influence of treatment, temperature and time on lightness (L^*). This factor most contributed to darkening of specimens. The most significant changes were observed after heat treatment at 230°C on average by 36 units. Bekhta and Niemz (2003) also studied effect of heat treatment on colour response. This work mentioned decrease about 30 units at temperature 200°C for 2 hours respectively 40 units at temperature 200°C for 4 hours. Important changes can be seen for ammonia treatment as well. The differences between sap- and heartwood were more noticeable. Heartwood became by about 6.8 units darker on the radial surface and 4.6 units on the tangential surface more than sapwood. ΔL^* value 25 units due ammonia treatment corresponding to Weigl *et al.* (2012), which mentioned values 17, 22 and 26 for spruce, oak and pine, respectively.

Figure 2 shows an influence of treatment, temperature and time on chroma from red to green (a^*). The changes of this factor are quite small – up to 2 units. A slight increase in this factor can be noticed inside of specimens treated by heat at 230°C or by ammonia. Weigl *et al.* (2012) also observed 2 units difference after ammonia treatment. Also Bekhta and Niemz (2003) show increase about 3-4 units.

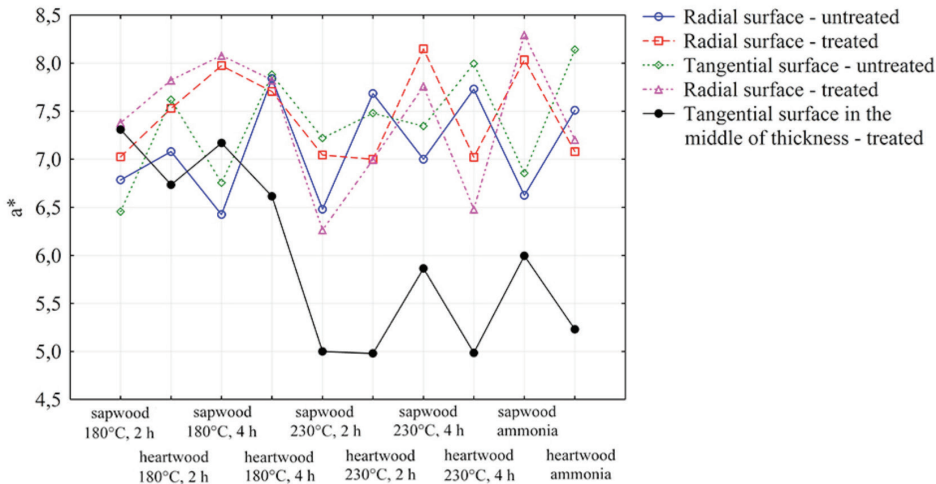


Figure 2. Changes of chroma from green to red (a^*) for all treated and untreated specimens.

Figure 3 depicts an influence of treatment, temperature and time on chroma from blue to yellow (b^*). This factor was more significant than a^* . At temperature 180°C a decrease in yellows tone was noticed on surface by about 3.4 units, while at 230°C by up to 10.4 units. Sapwood treated by ammonia turned to yellows tone by about 0.5 units, while heartwood turned to blue tone by about 6.7 units on the radial and 5.7 units on tangential surface as mentioned by Weigl *et al.* (2012) which presented values 8 for oak wood. Similar values of (b^*) also presented Bekhta and Niemz (2003), increase about 5-10 units.

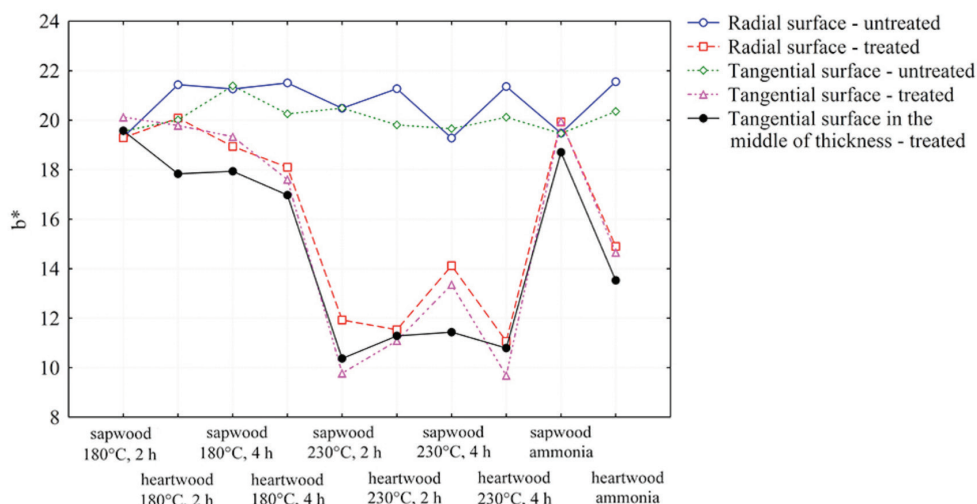


Figure 3. Changes of chroma from blue to yellow (b^*) for all treated and untreated specimens.

Table 2 shows basic statistic values of total colour changes (ΔE^*) for all investigated conditions. The last column of table assess whether data came from a normal distribution or not.

Table 2. Basic statistic values of total colour changes (ΔE^*) for all conditions.

	Surface	No. of values	Average	Median	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation	Normality
Sapwood 180°C 2h	T	30	10,77	10,89	0,49	13,42	5,66	2,38	22,10	NO
	R	30	13,34	12,20	8,23	24,16	12,89	3,59	26,91	NO
Sapwood 180°C 4h	T	30	20,90	18,88	12,13	38,73	47,56	6,90	32,99	NO
	R	30	21,56	21,41	13,30	40,54	36,24	6,02	27,92	NO
Sapwood 230°C 2h	T	30	38,80	36,73	29,61	47,90	26,79	5,18	13,34	NO
	R	30	40,28	40,18	30,86	49,67	23,35	4,83	11,99	YES
Sapwood 230°C 4h	T	30	37,62	37,28	31,53	44,12	10,49	3,24	8,61	YES
	R	30	37,00	36,62	26,33	47,65	14,82	3,85	10,40	YES
Sapwood ammonia	T	30	24,89	23,08	16,13	39,56	39,65	6,30	25,29	NO
	R	30	25,61	24,25	14,46	48,73	61,22	7,82	30,56	NO
Heartwood 180°C 2h	T	30	12,05	11,46	9,13	18,21	5,53	2,35	19,51	NO
	R	30	11,56	11,58	8,20	17,02	6,72	2,59	22,43	NO
Heartwood 180°C 4h	T	30	17,79	17,82	13,70	21,61	4,65	2,16	12,13	YES
	R	30	18,68	18,70	13,55	34,50	15,43	3,93	21,02	NO
Heartwood 230°C 2h	T	30	35,07	34,38	31,59	40,83	4,64	2,15	6,14	NO
	R	30	35,60	35,60	20,43	46,34	24,06	4,91	13,78	YES
Heartwood 230°C 4h	T	30	35,90	35,59	26,89	46,88	12,23	3,50	9,74	NO
	R	30	37,04	36,44	30,59	47,54	16,54	4,07	10,98	NO
Heartwood ammonia	T	30	32,82	31,11	21,97	52,32	53,71	7,33	22,33	NO
	R	30	30,64	29,18	18,66	44,92	42,28	6,50	21,22	YES

Table 3 y 4 depicts the evaluation of total colour changes by Kruskal-Wallis test for the radial and tangential surface. After comparison of the total colour changes between sap and heartwood, treated at the same conditions, no significant statistical differences were observed. It means that the colour unification of sap and heartwood was not noticeable. Result from the radial surface and the tangential surface are almost the same.

Table 3. Evaluation of total colour changes (ΔE^*) by Kruskal-Wallis test – radial surface.

Final evaluation of colour – total colour change (ΔE^*)										
Kruskal-Wallis test					RADIAL SURFACE					
Established difference of data				YES						
Multiple comparisons										
	Sapwood 180°C 2h	Sapwood 180°C 4h	Sapwood 230°C 2h	Sapwood 230°C 4h	Sapwood ammonia	Heartwood 180°C 2h	Heartwood 180°C 4h	Heartwood 230°C 2h	Heartwood 230°C 4h	Sapwood ammonia
Sapwood 180°C 2h		Agr.	Dif.	Dif.	Agr.	Agr.	Agr.	Dif.	Dif.	Dif.
Sapwood 180°C 4h	Agr.		Dif.	Dif.	Agr.	Agr.	Agr.	Dif.	Dif.	Dif.
Sapwood 230°C 2h	Dif.	Dif.		Agr.	Dif.	Dif.	Dif.	Agr.	Agr.	Agr.
Sapwood 230°C 4h	Dif.	Dif.	Agr.		Dif.	Dif.	Dif.	Agr.	Agr.	Agr.
Sapwood ammonia	Agr.	Agr.	Dif.	Dif.		Dif.	Agr.	Dif.	Dif.	Agr.
Heartwood 180°C 2h	Agr.	Agr.	Dif.	Dif.	Dif.		Agr.	Dif.	Dif.	Dif.
Heartwood 180°C 4h	Agr.	Agr.	Dif.	Dif.	Agr.	Agr.		Dif.	Dif.	Dif.
Heartwood 230°C 2h	Dif.	Dif.	Agr.	Agr.	Dif.	Dif.	Dif.		Agr.	Agr.
Heartwood 230°C 4h	Dif.	Dif.	Agr.	Agr.	Dif.	Dif.	Dif.	Agr.		Agr.
Heartwood ammonia	Dif.	Dif.	Agr.	Agr.	Agr.	Dif.	Dif.	Agr.	Agr.	

Agr. - Agreement

Dif. – Difference

Table 4. Evaluation of total colour changes (ΔE^*) by Kruskal-Wallis test – tangential surface.

Final evaluation of colour – total colour change (ΔE^*)										
Kruskal-Wallis test					TANGENTIAL SURFACE					
Established difference of data				YES						
Multiple comparisons										
	Sapwood 180°C 2h	Sapwood 180°C 4h	Sapwood 230°C 2h	Sapwood 230°C 4h	Sapwood ammonia	Heartwood 180°C 2h	Heartwood 180°C 4h	Heartwood 230°C 2h	Heartwood 230°C 4h	Sapwood ammonia
Sapwood 180°C 2h		Agr.	Dif.	Dif.	Agr.	Dif.	Agr.	Dif.	Dif.	Agr.
Sapwood 180°C 4h	Agr.		Dif.	Dif.	Agr.	Dif.	Agr.	Dif.	Dif.	Agr.
Sapwood 230°C 2h	Dif.	Dif.		Agr.	Dif.	Dif.	Dif.	Agr.	Agr.	Agr.
Sapwood 230°C 4h	Dif.	Dif.	Agr.		Dif.	Dif.	Dif.	Agr.	Agr.	Agr.
Sapwood ammonia	Agr.	Agr.	Dif.	Dif.		Dif.	Agr.	Agr.	Dif.	Agr.
Heartwood 180°C 2h	Dif.	Dif.	Dif.	Dif.	Dif.		Agr.	Dif.	Dif.	Dif.
Heartwood 180°C 4h	Agr.	Agr.	Dif.	Dif.	Agr.	Agr.		Dif.	Dif.	Dif.
Heartwood 230°C 2h	Dif.	Dif.	Agr.	Agr.	Agr.	Dif.	Dif.		Agr.	Agr.
Heartwood 230°C 4h	Dif.	Dif.	Agr.	Agr.	Dif.	Dif.	Dif.	Agr.		Agr.
Heartwood ammonia	Agr.	Agr.	Agr.	Agr.	Agr.	Dif.	Dif.	Agr.	Agr.	

Figure 4 shows that when the same treatment was used (treatment temperature and time), the colour of sap- and heartwood was changed almost equally. Due heat treatment the total colour changes 25-40 units are comparable with work from Bekhta and Niemz (2003). Exception was noticed for treatment by ammonia. As can be seen, the total colour change (ΔE^*) of sap- and heartwood was different by more than about 7 units. ΔE^* was due ammonia treatment changed about 17-30 units, similar results were presented by Weigl *et al.* (2009a, 2012), which mentioned values about 24 units for oak wood. The results are comparable with the results presented by Tinkler (1921).

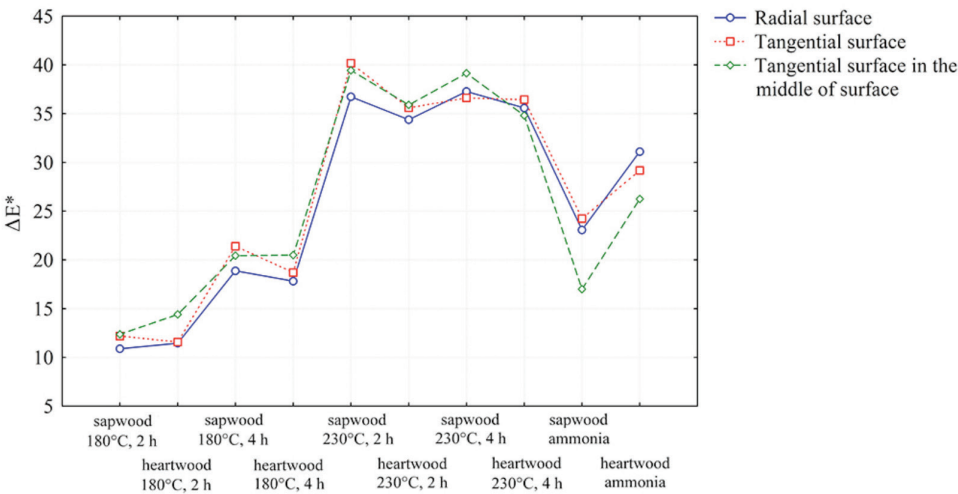


Figure 4. Changes of total colour (ΔE^*) for all specimens.

The effect of heat and ammonia treatment on density (ρ_{12})

Table 5 shows median values of Density before treatment and after treatment for all conditions. Variability of density in all groups can be seen in figure 5.

Table 5. Median values of Density for treated and untreated specimens.

Density (kg m^{-3})		
	Untreated	Treated
Sapwood 180°C 2h	530,49	519,65
Sapwood 180°C 4h	605,92	580,09
Sapwood 230°C 2h	568,39	528,01
Sapwood 230°C 4h	571,46	528,78
Sapwood ammonia	523,73	525,13
Heartwood 180°C 2h	612,48	589
Heartwood 180°C 4h	602,93	583,3
Heartwood 230°C 2h	605,43	562,36
Heartwood 230°C 4h	610,48	558,78
Heartwood ammonia	607,96	603,39

Figure 5 shows the effect of treatment, temperature and time on density of sap- and heartwood. It has been confirmed that density decreased as treatment temperature and duration increased. The most significant changes were observed at heat treatment at 230°C for 4 h. The decrease was by about 42.68 kg m^{-3} for sapwood and about 51.7 kg m^{-3} for heartwood on average. The decrease of density at heat treatment was confirmed by many authors. Boonstra *et al.* (2007) reported a 10% and 8.5% decrease on density for heat-treated Scots pine and Norway spruce, respectively. Similar results were also confirmed by others (Yildiz 2002, Korkut *et al.* 2008). The influence of ammonia treatment on density can be confirmed as insignificant (Weigl *et al.* 2012).

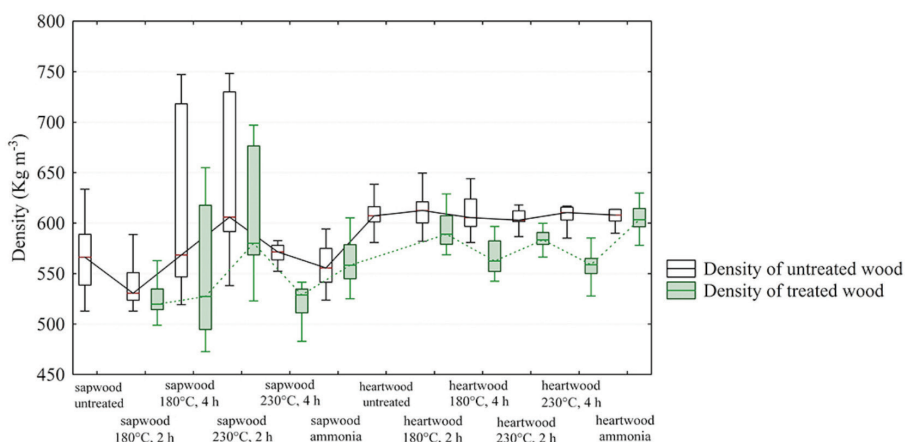


Figure 5. Box plot of density for all treated and untreated specimens.

The effect of heat and ammonia treatment on hardness

Table 6 shows median values of hardness before treatment and after treatment for all conditions in the radial and tangential direction. Results were recalculated for moisture content 12%.

Table 6. Median values of Hardness by Janka method for treated and untreated specimens.

	Radial direction		Tangential direction	
	Untreated	Treated	Untreated	Treated
Sapwood 180°C 2h	31,47	31,31	22,58	23,93
Sapwood 180°C 4h	36,21	36,8	30,22	31,22
Sapwood 230°C 2h	32,97	27,28	26,36	22,13
Sapwood 230°C 4h	32,54	28,33	23,49	19,77
Sapwood ammonia	32,36	31,6	22,98	22,8
Heartwood 180°C 2h	35,85	36,77	26,39	26,15
Heartwood 180°C 4h	33,78	33,11	26,15	26,42
Heartwood 230°C 2h	36,07	28,82	27,05	21,76
Heartwood 230°C 4h	34,95	30,16	27,51	22,18
Heartwood ammonia	34,44	38,32	28,42	29,1

Figure 6 shows the effect of treatment, temperature and time on hardness of sap- and heartwood in the radial and the tangential directions. Minimal changes in the hardness of specimens treated by ammonia and heat at 180°C were noticed. The most significant changes were observed at the highest temperature: decrease of 5.3 MPa in the radial and 7.25 MPa in the tangential direction. Hardness of heartwood treated by ammonia increased by about 3.87 MPa in the radial and 0.68 MPa in the tangential direction. A slight increase can be also seen for sapwood at 180°C for 4 h at 0.6 MPa and for heartwood at 180°C for 2 h at 0.92 MPa.

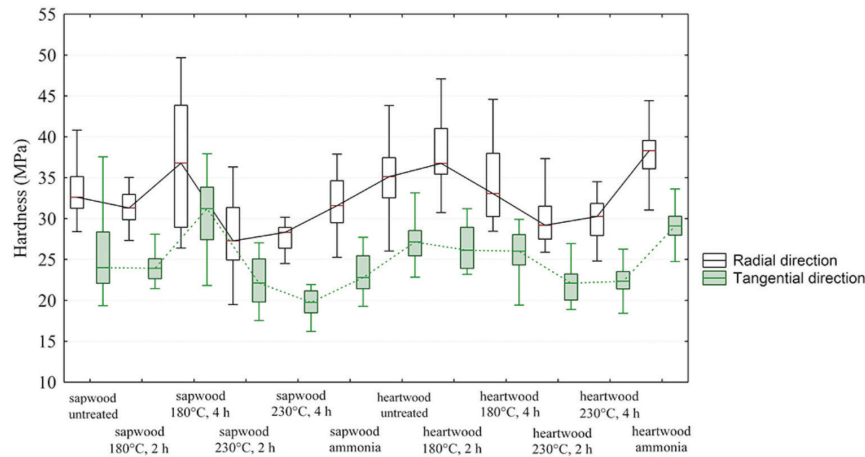


Figure 6. Box plot of hardness in radial and tangential directions for all specimens.

The effect of heat and ammonia treatment on equilibrium moisture content (EMC)

Table 7 shows basic statistic values of equilibrium moisture content for all investigated conditions. The last column of table assess whether data came from a normal distribution or not.

Table 7. Basic statistic values of equilibrium moisture content (%) for treated and untreated specimens.

	No. of values	Average	Median	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation	Normality
Sapwood untreated	30	7,24	7,21	6,9	7,84	0,04	0,2	2,76	YES
Sapwood 180°C 2h	30	3,2	3,16	2,66	3,83	0,07	0,26	7,97	YES
Sapwood 180°C 4h	30	3,21	3,22	2,89	3,5	0,03	0,16	5,06	YES
Sapwood 230°C 2h	30	2,05	2,06	1,46	2,42	0,04	0,19	9,4	YES
Sapwood 230°C 4h	30	2	1,98	1,84	2,22	0,01	0,1	4,93	YES
Sapwood ammonia	30	7,13	7,14	6,76	7,52	0,03	0,18	2,46	YES
Heartwood untreated	30	7,44	7,43	6,96	8,02	0,08	0,28	3,81	YES
Heartwood 180°C 2h	30	3,41	3,4	3,15	4,79	0,09	0,3	8,64	YES
Heartwood 180°C 4h	30	2,89	2,89	2,66	3,21	0,02	0,15	5,32	YES
Heartwood 230°C 2h	30	2,07	2,06	1,87	2,23	0,01	0,08	4,02	YES
Heartwood 230°C 4h	30	1,97	1,96	1,87	2,22	0,01	0,08	3,88	YES
Heartwood ammonia	30	6,5	6,59	3,28	6,98	0,4	0,64	9,79	YES

Figure 7 shows the effect of treatment, temperature and time on EMC of sap- and heartwood. The specimens which were conditioned at a temperature of 20°C and a relative humidity of 40% had moisture content of about 7.5%. The treated specimens were compared with these references values. Results show that EMC decreased as the treatment temperature increased. The influence of time seems to be negligible. EMC of treated specimens was more than 50% lower (1.9–3.2%). Similar results were shown by Bekhta and Niemz (2003), which mentioned improve of EMC about 30-45%. Other authors also reported influence of heat treatment on EMC, Tjeerdsma *et al.* (1998) reported improve about 30-60%. Ammonia treatment seems to have an insignificant effect on EMC.

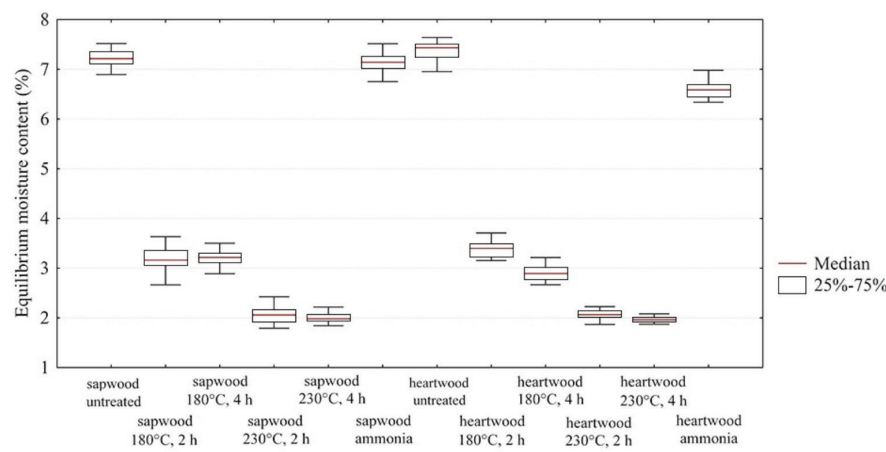


Figure 7. Box plot of equilibrium moisture content (%) for all specimens.

The effect of heat and ammonia treatment on modulus of elasticity (MOE) in compression

Table 8 shows median values of Modulus of elasticity in compression before treatment and after treatment for all conditions in the radial and tangential direction.

Table 8. Median values of Modulus of elasticity in compression for treated and untreated specimens.

Modulus of elasticity in compression (MPa)				
	Radial direction		Tangential direction	
	Untreated	Treated	Untreated	Treated
Sapwood 180°C 2h	977,51	898,14	650,08	705,89
Sapwood 180°C 4h	1155,86	1017,61	921,6	884,17
Sapwood 230°C 2h	1044,92	821,91	783,11	612,32
Sapwood 230°C 4h	1011,88	971,14	670,89	564,1
Sapwood ammonia	930,07	953,75	671,35	683,6
Heartwood 180°C 2h	1075,2	1171,33	757,92	752,65
Heartwood 180°C 4h	1031,53	1131,4	791,82	757,37
Heartwood 230°C 2h	1161,17	983,34	795,99	616,21
Heartwood 230°C 4h	1070,21	895,17	811,79	635,9
Heartwood ammonia	999,42	1203,02	833,08	852,36

Figure 8 shows the effect of treatment, temperature and time on modulus of elasticity in compression of sap- and heartwood in the radial and the tangential directions. No important changes in MOE have been proved. The most significant changes can be seen for sapwood at a temperature of 230°C: a decrease of about 233 MPa in the radial direction and 170.78 MPa in the tangential direction. For heartwood a decrease on average 177 MPa can be noticed. Interesting changes can be noticed concerning the specimens which were treated by ammonia: an increase in MOE for heartwood of about 203.61 MPa in the radial direction and 19.28 MPa in the tangential direction.

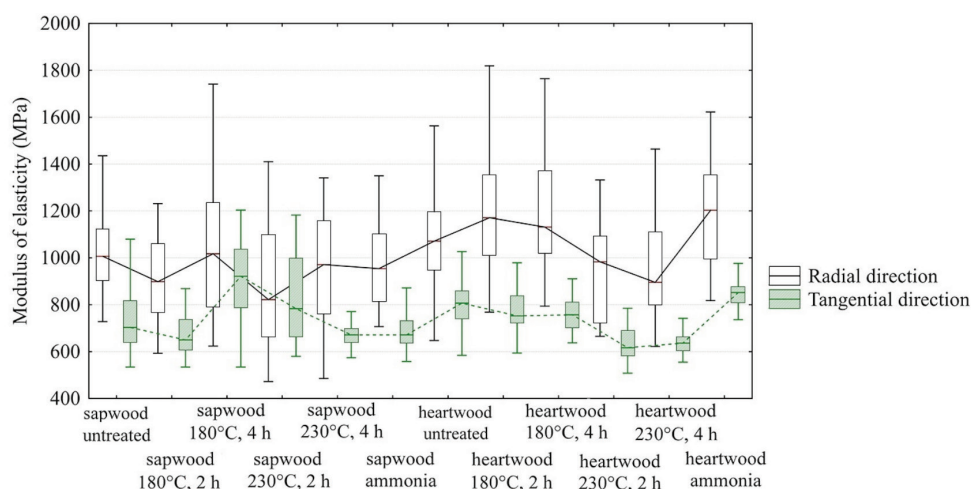


Figure 8. Box plot of modulus of elasticity in radial and tangential directions for all specimens.

Even that used samples were quite small (30x30x30 mm), results or methods can be partially useful for practical application, but another studies of influence of both treatment on demanded properties should be done. Ammonia treatment was in last decades used for plasticizing of wood - Lignamon material (Rosca *et al.* 2002, Bariska 1969), but currently is partly replaced by other modification methods - heat treatment, chemical modification etc. (Hill 2006)

CONCLUSION

The influence of heat and ammonia treatment on colour response of oak wood was studied and physical and mechanical properties were compared. The heat and ammonia treatments have a significant influence on colour change. Differences of total colour changes (ΔE^*) between these processes for sap- and heartwood were observed. The most significant total colour changes between sap- and heartwood were found where comparing specimens treated by ammonia. Ammonia treatment may significantly improve the decorative value of wood. However, the ammonia treatment is a soft modification with respect to physical and mechanical properties. Heat treatment shows the smallest changes in colour at 180°C for 2 h. Then the specimens become darker with increasing treatment time and temperature. However, heat treatment caused a decrease in the values of investigated physical and mechanical properties (EMC, density, MOE and hardness). In this respect, the heat and ammonia treatment are comparable processes for colour change.

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