Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 6 (55) No.1 - 2013

EXPERIMENTAL INVESTIGATIONS ON SWELLING PRESSURE OF NATURAL AND HEAT-TREATED ASH WOOD

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Abstract: *The paper presents the results of an experimental research concerning the swelling pressure developed by ash wood (Fraxinus excelsior L.), unmodified, respectively modified by heat-treatment (Thermo wood method), when swelling from oven-dry state until the fibber saturation point was exceeded and maximum swelling was reached. The results show maximum values of the swelling pressure between 3.39 MPa and 4.18 MPa for unmodified wood respectively between 2.95 MPa and 3.35 MPa for modified wood, as well as clear differences between the values of swelling pressures on radial and tangential direction. The results can be useful for various applications related to wood products, especially for the outdoor furniture and the construction fields.*

Key words: *ash wood, heat-treatment, swelling pressure.*

1. Introduction

1.1. Wood swelling pressure

It is known that wood exerts significant pressure onto the obstacles restricting its swelling on moistening. This pressure, referred to as the wood swelling pressure, affects the stress state causing deformation and even damages of wood products.

Performed studies classify the swelling pressure on several types, corresponding to situations met in practice [1]. The normal swelling pressure (Pn) is registered when wood is totally restrained in the direction of measurement and free to swell in the others. Another type is the swelling pressure of incompletely restrained wood (Pi). The effect of restraining the specimen in both transversal (radial and tangential) directions on the swelling pressure (Pc) was tested, because this is common in many practical situations (e.g. to increase the strength in glued joints). Mechanically influenced swelling pressure (Pm) was measured by applying an initial stress. Pre-stressed wood is common where openings caused by shrinkage are unwanted (e.g. in the tread on a wooden bridge).

Swelling pressure of wood has been studied [42], [13], [31], [41], [36], [28], [21], [26], [24] etc. Although the studies carried out so far, in this field, are numerous, they could not cover the whole diversity of wood species, applications and situations met in practice. There are also differences in the researchers ‘opinions referring to the values of swelling pressure, the differences between the values of the swelling pressures on radial and tangential direction, the physical-chemical mechanism of the swelling phenomenon etc. For example, Stamm reported a theoretical

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swelling pressure of 1,630 atmospheres (165.159 MPa) [41], but Tarkow and Turner found an actual swelling pressure of about half that value [42]. Also Rowell shows that by extrapolation of the maximum swelling pressure to the density of the cell wall, a maximum value of swelling pressure of 91MPa it is obtained, while a theoretical value based on an osmotic pressure theory gave a result of 158MPa [34].

From the practical point of view, better understanding of the transverse swelling behaviour, relaxation of stresses and mechano-sorptive creep is needed, in order to avoid cracks and deformations and to increase service life of wood based materials, outdoor furniture, wooden structures and cladding boards and from this point of view the wood swelling pressure is the only experimentally determined index describing the stress in wood on its moistening.

1.2. Heat-treated wood

The modification of wood by the so-called "heat treatment" is not a new issue, related researches having been registered since 1920. Thus, Tiemann (1920) showed that the drying at very high temperatures decreased the equilibrium moisture and the consequent swelling of wood [43]. Kollmann (1936) used high temperatures and densification of wood by hot-press ("Lignostone" process) [18]. Stamm and Hansen (1937) reported that equilibrium moisture, swelling and shrinkage of wood decreased with heating in several gaseous environments [39]. Seborg et al. (1945) created a wood product based on heat-stabilized compressed wood, which they called "Staypack" [37]. Stamm et al. (1946) reported a heat-treatment to improve wood dimensional stability without densification ("Stayb-wood" process) [40]. Other studies were performed later by Seborg et al. (1953) [38], Kollmann and Schneider (1963) [19], Kollmann and Fengel (1965) [20], Fengel (1966) [6], Nikolov and Encev (1967) [30], Burmester (1973) [3], Rusche (1973) [35], Giebeler (1983) [8] and Hillis (1984) [9].

Lately the interest in heat treatment processes has been renewed due to the declining production of durable timber, the increasing demand for sustainable building materials, the deforestation, and the increased introduction of governmental restrictive regulations reducing the use of toxic chemicals [2]. At least eight industrial methods of heat treatment of wood were developed: one in Finland (Thermowood), one in Holland (Plato Wood), one in Germany (OHT- Oil Heat Treatment), two in France (Bois Perdure and Rectification), one in Denmark (WTT), one in Austria (Huber Holz) and one in Switzerland (Balz Holz) [14], [5], [29] and others. Several wood species are used, with different process conditions, depending on species and the final use of the product. All of the processes use sawn wood and treatment temperatures between 160ºC and 260ºC, but they differ in terms of process conditions, such as the presence of a shielding gas, as nitrogen or steam, humid or dry processes, use of oils, etc. [27].

All above-mentioned heat treatment processes lead to important modifications of wood characteristics: chemical composition, mass loss, anatomical structure, equilibrium moisture, swelling and shrinkage/ dimensional stability, durability, mechanical properties, wettability, weathering, finish and gluing properties [43], [39], [38], [19], [20], [6], [8], [9], [45], [16], [25], [14], [32], [44], [23], [5], [4], [17], [29], [33], [7], [15] etc. All involved authors in the field agreed that the heat treatment of wood: modifies the chemical composition of wood by degradation of cell wall compounds and extractives, lead to mass loss, causes development of cracks in the cell walls and in the middle lamella, determines visible changes in the pits, a more open structure of wood and increased size and number of voids in the wood structure. As well, by heat treatment the equilibrium moisture content of wood is reduced, the dimensional stability is improved as well as the durability. The mechanical strengths of heat-treated wood are reduced in comparison with untreated wood, which is one of the main limitations of this treatment method, making this wood unsuitable for most structural applications.

Even if the swelling properties of heat-treated wood were investigated, no references concerning the swelling pressure of this kind of wood was found by the author after a wide bibliographical research.

2. Objective

The objective of the presented work was to determine the level and time evolution of forces developed by some samples of ash wood, in natural state and respectively modified by heat treatment (Thermowood method) when swelling from oven-dry state until the fibre saturation point was exceeded and maximum swelling was reached, in radial and respectively tangential direction.

3. Method and Apparatus

Ash wood (*Fraxinus excelsior* L.) heartwood samples were used in this study. All the samples were obtained from a single plank (edge-sawn timber), with ca. 28mm thickness, 150mm width and 2000mm length. The planck was cut in two pieces with the same dimensions (28mm x 150mm x 1000 mm). Both pieces were oven-dry to a moisture content of 8% and after that one of them was heat-treated by the Thermowood method (18h heating from environmental temperature up to 215°C, actual heat treatment 2h at 215°C, 12 h cooling and stabilizing).

From the two pieces of wood (one only oven-dry and the other also heat-treated), cube block specimens (25 by 25 by 25mm) were cut, oriented so that the faces were strictly transversal, tangential and radial (Figure 1).

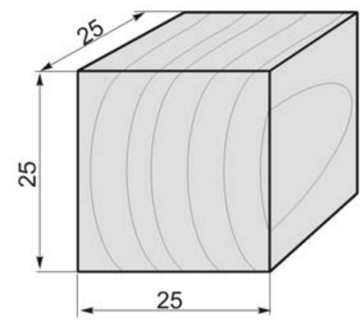


Fig. 1. *Scheme of the wood samples used for the experiments*

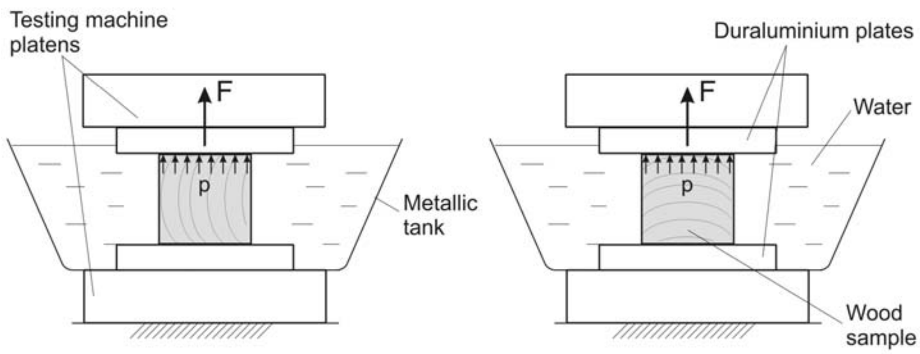
Forty specimens were used within the experiments: 10 specimens x 2 kinds of wood (untreated respectively treated) x 2 directions of measuring the swelling pressure (radial and respectively tangential). The specimens had an average number of annual rings per cm of 5 in the air-dry state.

Afterwards, the samples were dried in an oven at 103±2ºC to the oven-dry state and then cooled in an essiccator to environmental temperature, of 20±2ºC. The average density of untreated wood samples in oven-dry state was 0.78g/cm^3. The same parameter for the heat-treated samples was 0.62g/cm^3.

In order to determine the normal swelling pressure, the specimens were introduced one by one between the platens of the testing machine type ZD 10/90, according to the scheme presented in Figure 2. After applying an initial force of 220N (0.035MPa), in order to ensure zero initial clearance, distilled water was added into the vessel with the wood specimen (see Fig. 2), at room temperature, until the specimen was completely immersed.

The force exerted by the specimen upon the machine platens was read every 3 hours. All specimens were kept in the machine platens for 48 hours. After, 48 hours the average moisture content of untreated specimens was 32.4% (between 30.5% and 33.8%) respectively 25.9% for the heat-treated ones (between 25.2% and 27.1%).

The normal swelling forces F both in radial and tangential direction (see Fig. 2) were measured. After having measured the swelling forces, the swelling pressures were determined.



a. *b.*

Fig. 2. *Scheme of the experimental device for measuring the swelling forces: a. measuring the tangential swelling force; b. measuring the radial swelling force.*

3. Results and Discussion

The obtained results are presented in Tables 1 and 2 and Fig. 3 and 4.

After having analysed the results, the following conclusions could be pointed out:

For the untreated wood:

- in both radial and tangential directions, the maximum swelling pressure was attained after approx. 15 … 18 hours, with an average evolution speed of 0.19Mpa/h for the radial direction and 0.23Mpa/h for the tangential one (for the entire period of the first 18 hours of immersion);
- the average evolution speed of the swelling pressure decreased in time, in radial direction from 0.570Mpa/h in the first 3 hours (first period) to only 0.004Mpa/h in the sixth period (15 to 18h);
- the same phenomenon was recorded for the tangential direction of swelling: the average evolution speed of the swelling pressure decreased in time, from 0.778Mpa/h in the first 3 hours to only 0.001Mpa/h in the sixth period (15 to 18h);
- the maximum average pressure for the radial direction was 3.39Mpa respectively 4.18Mpa for the tangential direction; the maximum average of the swelling pressures was higher in tangential direction that in radial one with 23.3%, in good agreement with the results reported in [22], [1], [11], [12] and in contradiction with [10] who gives the same swelling pressure independent of swelling direction but in restraining conditions of the specimens;
- after the maximum swelling pressure had been attained, a relaxation of swelling stresses was recorded, the swelling pressure decreasing from 3.39Mpa to 2.85Mpa (with 15.9%) on radial direction respectively from 4.18MPa to 3.67Mpa (with 12.2%) on tangential direction, in good agreement with the results reported in [22], [11], [12].

For the heat-treated wood:

- in both radial and tangential directions, the maximum swelling pressure was attained after approx. 12 … 15 hours, with an average evolution speed of 0.19Mpa/h for the radial direction and 0.22Mpa/h for the tangential one (for the entire period of the first 15 hours of immersion);

- the average evolution speed of the swelling pressure decreased in time, in radial direction from 0.541Mpa/h in the first 3 hours to 0.018Mpa/h in the fifth period (12 to 15h);
- the same phenomenon was recorded for the tangential direction of swelling: the average evolution speed of the swelling pressure decreased in time, from 0.650Mpa/h in the first 3 hours to only 0.002Mpa/h in the fifth period (12 to 15h);
- the maximum average pressure for the radial direction was 2.95Mpa respectively 3.35Mpa for the tangential direction; the maximum average of the swelling pressures were higher in tangential direction that in radial one with 13.6%;

Table 1

Swelling pressures p and standard deviations St.dev. in radial direction (Rad) and tangential direction (Tg) at untreated and heat-treated ash wood

Time [h]	Untreated				Heat-treated			
	p [MPa] (averages)		St.dev.		p [MPa] (averages)		St.dev.	
	Rad	Tg	Rad	Tg	Rad	Tg	Rad	Tg
0	0.035	0.035	0	0	0.035	0.035	0	0
3	1.75	2.37	0.22	0.18	1.66	1.99	0.16	0.05
6	2.55	3.32	0.25	0.14	2.37	2.89	0.18	0.07
9	3.04	3.88	0.20	0.14	2.74	3.24	0.20	0.06
12	3.30	4.13	0.19	0.18	2.89	3.34	0.23	0.09
15	3.38	4.17	0.19	0.20	**2.95**	**3.35**	0.24	0.09
18	**3.39**	**4.18**	0.19	0.20	2.95	3.33	0.24	0.09
21	3.38	4.15	0.19	0.21	2.93	3.29	0.24	0.09
24	3.33	4.09	0.18	0.20	2.89	3.24	0.24	0.10
27	3.25	4.01	0.17	0.19	2.86	3.18	0.23	0.11
30	3.16	3.95	0.16	0.17	2.83	3.13	0.23	0.12
33	3.10	3.87	0.14	0.16	2.80	3.08	0.22	0.12
36	3.02	3.81	0.15	0.16	2.77	3.04	0.22	0.12
39	2.97	3.76	0.14	0.16	2.73	3.00	0.22	0.12
42	2.94	3.73	0.15	0.16	2.70	2.98	0.22	0.12
45	2.89	3.70	0.17	0.17	2.68	2.95	0.22	0.13
48	2.85	3.67	0.18	0.17	2.66	2.92	0.22	0.12

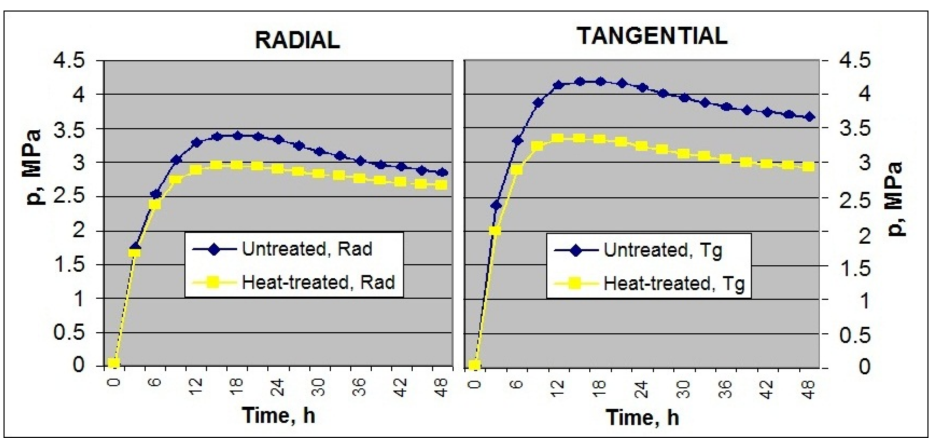


Fig. 3. *Evolution of swelling pressure at untreated and heat-treated ash wood moisturized by water immersion (averages).*

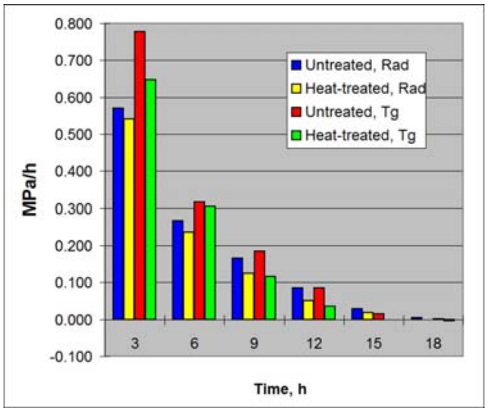


Fig. 4. *Speed evolution of swelling pressure at untreated and heat-treated ash wood moisturized by water immersion (averages calculated on 3h intervals, first 18h).*

–after the maximum swelling pressure had been attained, a relaxation of swelling stresses was recorded, the swelling pressure decreasing from 2.95Mpa to 2.66Mpa (with 9.5%) on radial direction respectively from 3.35Mpa to 2.92Mpa (with 12.3%) on tangential direction.

In order to highlight the differences between untreated and heat-treated wood, a synthesis was made, according to Table 3.

4. Conclusions

The results of the presented investigations on the swelling pressure of ash wood confirm prior researches on the heat-treated wood, even if those were not focused on the swelling pressure. For example, the obtained results confirm that the heat-treated wood is more stable than the untreated one (see the maximum swelling pressure), the heat treatment causes mass loss (see the oven dry density), the wettability of heat-treated wood is smaller than that of untreated wood (see the moisture content after 48h of immersion).

In order to increase the reliability of the results, a much more extended experimental study could be pursued with several wood species.

Table 3

Characteristics	Untreated wood	Heat-treated wood
Oven-dry density [g/cm^3]	0.78	0.62
Average moisture content after 48h of imersion [%]	32.4	25.9
Time to the maximum swelling pressure [h]	15 - 18	12 – 15
Average swelling speed to attain the maximum swelling pressure [MPa/h]	0.19 (Rad) 0.23 (Tg)	0.19 (Rad) 0.22 (Tg)
Maximum swelling pressures [Mpa] (averages)	3.39 (Rad) 4.18 (Tg)	2.95 (Rad) 3.35 (Tg)
Difference between radial and tangential maximum swelling pressure [%]	23.3	13.6
Relaxation of swelling stresses [%]	15.9 (Rad) 12.2 (Tg)	9.5 (Rad) 12.3 (Tg)
Difference between maximum swelling pressure for untreated and heat-treated wood [%]	13.2 (treated less than untreated, Rad) 19.9 (treated less than untreated, Tg)	

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