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LIQUID WATER UPTAKE FROM TEMPORARY FROZEN BEECH AND SPRUCE WOOD*

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Abstract:
*In addition to sorption processes within the hygroscopic range, water absorption at direct water contact plays another important role in the field of building physics. Therefore, the water absorption coefficient was measured for Norway spruce (Picea abies [L.] Karst.) and European beech (Fagus sylvatica L.) in the principal anatomical directions. Thereby, the influence of sapwood and heartwood and of antecedent freezing at -40°C was investigated (48h, 77h and 120h freezing after climatization at 20°C/65% RH and under green conditions).The values were widely spread in all directions and were clearly higher for beech than for spruce. A significant influence of the prefreezing was only shown for green prefrozen beech in the tangential and longitudinal directions. For further investigations, a higher number of specimens with similar density distributions per type are necessary for a more accurate quantification of the influences of density and prefreezing. (*The paper is an extract from chapter 4.2 of the dissertation of Sonderegger (2011) at ETH Zurich).*

Key words: *beech; spruce; liquid water uptake; frozen wood.*

INTRODUCTION

In addition to sorption processes within the hygroscopic range, water absorption at direct water contact plays another important role in the field of building physics. Therefore, the water absorption coefficient was measured for Norway spruce (*Picea abies* [L.] Karst.) and European beech (*Fagus sylvatica* L.) in the principal anatomical directions. Thereby, the influence of sapwood and heartwood and of antecedent freezing was investigated.

Temporary freezing of wood was already applied at various occasions to upgrade the wood properties (Ilic 1995). Thereby, the assumption is given, that prefrozen wood increases the water path through a higher permeability and therefore decreases the drying time. At most, however, it was used to reduce swelling and thereof generated failures during drying. Investigations into this technique were primarily located in the United States and Australia. An overview of these investigations is shown by Ilic (1995). According to him, the effect of prefreezing is very different and strongly depends on the wood species. Whereas several wood species were not influenced by prefreezing, for others, a shrinkage reduction of more than 20% could be found. For Toon (*Toona ciliata* M. Roemer) even a tangential shrinkage reduction of 53% to 57% was measured by Sharma et al. (1987), which however included a significant component of cell collapse. This influence is also shown by Ilic (1999) who determined a collapse reduction of 36% within prefrozen boards of mountain ash (*Eucalyptus regnans* F. Muell.).

MATERIAL AND METHOD

The material originated from the lower four meters of a spruce and a beech tree grown in the Federal Institute of Technology's research forest in Zurich. Boards with dimensions 65cm (length) x 10cm (thickness) were cut from logs. Thereafter, three-quarter of the green boards were frozen for 48, 77 or 120 hours at -40°C and then all boards were air-conditioned at normal climate of 20°C and 65% RH and cubes sized 5cm and oriented in the principal anatomical directions were cut from them.

In addition, from similar cubes of spruce and beech wood from the region of Zurich that were previously air-conditioned at normal climate, also three-quarter were frozen for 48, 77 or 120 hours at -40°C and then again air-conditioned at normal climate.

After reaching equilibrium MC, the water absorption was determined on the cubes in the tangential, radial and longitudinal directions according to ISO 15148 (2002). Table 1 shows the test conditions and specimens number per type.

Table 1

Test conditions with freezing time at -40°C and specimen number per type. R = radial, T = tangential, L = longitudinal

Condition before freezing	Freezing time [h]	Spruce			Beech		
		T	R	L	T	R	L
Mixed (normal climate)	0	6		1	6		5
	48	6		2	6		3
	77	6		4	6		3
	120	6		1	6		2
Sapwood (green)	0	6	6	6	6	5	6
	48	6	4	4	6	6	6
	77	6	5	5	6	5	5
	120	6	6	6	6	6	6
Heartwood (green)	0	6		4	6		1
	48	6		1	6		
	77	6			6		
	120	6	3	4	5		

The mean equilibrium MC before the tests for the green prefrozen specimens was 14.1% and for the at normal climate prefrozen specimens was 12.6%. The water absorption was measured after 5 and 20 minutes and 1, 2, 4, 8, 12 and 24 hours. Thereof, the water absorption coefficient was calculated as follows:

$$A_w = \frac{\Delta m'_{tf} - \Delta m'_0}{\sqrt{t_f}} \text{ [kg/(m}^2\text{s}^{0.5})] \quad (1)$$

A_w – water absorption coefficient [kg/(m^{2}s$^{0.5}$)]
t_f – duration of the test [s]
Δm – mass gain per face area [kg/m^2]
$\Delta m'_{tf}$ and $\Delta m'_0$ – values of Δm on the straight line in Figure 1 at time t_f and time 0 [kg/m^2]

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Fig. 1 shows that a straight line through the values of Δm against the root of time can be drawn after a short initial period of stabilisation. $\Delta m'_{tf}$ and $\Delta m'_0$ are thereby the values of Δm on the straight line at time t_f and time 0, respectively. Thus it appears that the slope of the straight line corresponds to A_w.

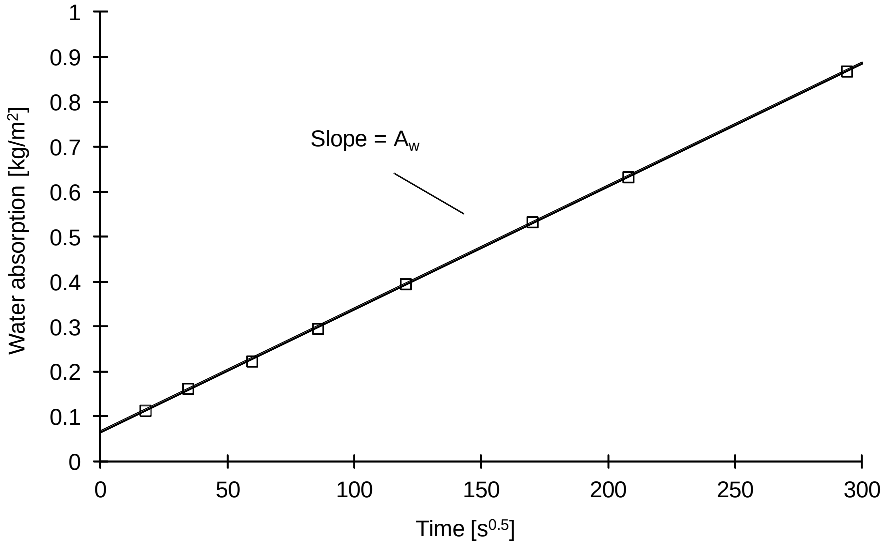

Fig. 1

Determination of the water absorption coefficient:

Water absorption in tangential direction of spruce sapwood at –40°C prefrozen at green conditions over a period of 77 hours. Mean values of six specimens.

RESULTS AND DISCUSSION

The water absorption coefficients within all directions show a wide spread for both investigated species (Table 2). Thereby, the mean values of beech were clearly higher than for spruce within all three directions. This tendency is also shown by Wang and Niemz (2002) who, however, measured generally higher values. Although Kiessl and Möller (1989) show similar, or slightly lower, values for beech than for spruce.

The specified values of the water absorption coefficients for spruce are shown in Table 3. Clearly the lowest values were measured on the specimens conditioned at normal climate before freezing. Besides a possibly different influence of prefreezing, this observation may be due to the different wood structure. Whereas the specimens that were first conditioned at normal climate had small year rings of about 2mm and therefore high density, the green prefrozen specimens had wide year rings and low density. Due to the clearly higher early wood portion of the latter, which is responsible for the water conduction, a higher water absorption coefficient was expected.

At the green prefrozen specimens, sapwood shows higher values than heartwood. This is due to the fact that heartwood possesses a higher portion of extractives and the water conduction within the tracheids is interrupted (cf. Bosshard 1984).

The influence of prefreezing is low but higher for the green prefrozen specimens than for the specimens that were first conditioned at normal climate, and additionally the influence of density is superimposed. Therefore, investigations with a higher number of specimens are necessary to verify the influence of prefreezing.

Table 2

Water absorption coefficients A_w of spruce and beech in the tangential (T), radial (R) and longitudinal (L) directions independent of the prefreezing (minimum, mean and maximum values); n = number of specimens

Direction	Spruce		Beech	
	n	A_w [kg/(m^{2}s$^{0.5}$)]	n	A_w [kg/(m^{2}s$^{0.5}$)]
T	72	0.0011…0.0020…0.0029	71	0.0022…0.0037…0.0064
R	24	0.0018…0.0030…0.0041	22	0.0026…0.0042…0.0059
L	38	0.0097…0.0167…0.0232	37	0.0126…0.0421…0.0765

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Table 3

Mean values of the water absorption coefficient A_w [kg/($m^2s^{0.5}$)] of prefreezing spruce wood; ρ = density [kg/m^3] at normal climate (20°C/65% RH).

Condition before freezing	Freezing time [h]	Tangential		Radial		Longitudinal	
		ρ	A_w	ρ	A_w	ρ	A_w
Mixed (normal climate)	0	464	0.0014	-	-	414	0.0111
	48	465	0.0014	-	-	472	0.0119
	77	438	0.0016	-	-	441	0.0130
	120	477	0.0016	-	-	427	0.0101
Sapwood (green)	0	347	0.0022	349	0.0024	347	0.0159
	48	370	0.0025	370	0.0034	386	0.0225
	77	377	0.0027	369	0.0038	367	0.0219
	120	400	0.0022	403	0.0034	416	0.0177
Heartwood (green)	0	325	0.0018	-	-	323	0.0139
	48	348	0.0020	-	-	358	0.0152
	77	329	0.0021	-	-	-	-
	120	326	0.0021	326	0.0018	332	0.0152

Table 4 shows the specified values of the water absorption coefficients for beech. As for spruce, high differences were measured between specimens that were first conditioned at normal climate and the green prefrozen specimens. This is mainly due to density differences. The at normal climate prefrozen specimens – possessing a very low density – showed clearly larger pores visible to the naked eyes than the green prefrozen specimens that also had up to four times higher water absorption coefficients in the longitudinal direction. Thereby, the greatest differences were measured on the unfrozen reference specimens.

Table 4

Mean values of the water absorption coefficient A_w [kg/($m^2s^{0.5}$)] of prefreezing beech wood; ρ = density [kg/m^3] at normal climate (20°C/65% RH)

Condition before freezing	Freezing time [h]	Tangential		Radial		Longitudinal	
		ρ	A_w	ρ	A_w	ρ	A_w
Mixed (normal climate)	0	631	0.0046	-	-	613	0.061
	48	617	0.0045	-	-	626	0.069
	77	621	0.0047	-	-	620	0.062
	120	642	0.0042	-	-	639	0.068
Sapwood (green)	0	792	0.0027	818	0.0041	807	0.014
	48	720	0.0037	720	0.0043	722	0.034
	77	750	0.0038	722	0.0049	753	0.025
	120	705	0.0040	709	0.0035	700	0.049
Heartwood (green)	0	739	0.0028	-	-	744	0.017
	48	714	0.0031	-	-	-	-
	77	720	0.0032	-	-	-	-
	120	702	0.0037	-	-	-	-

No, or only little, influence by prefreezing is shown for the specimens that were conditioned at normal climate before freezing. In contrast, the green prefrozen specimens show significant higher water absorption coefficients than the unfrozen reference specimens in the tangential and longitudinal directions. Thereby – as was shown for spruce – the influence of density was superimposed. Fig. 2 exemplifies this influence for the sapwood specimens in the longitudinal direction.

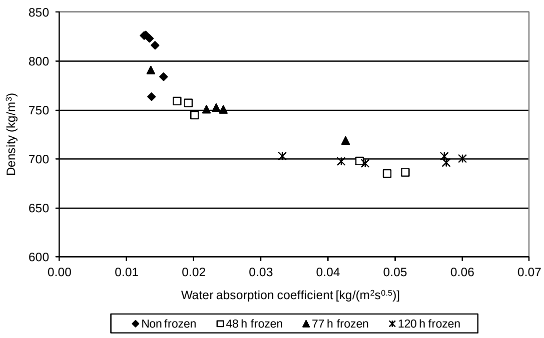

Fig. 2

Water absorption coefficients of green prefrozen beech sapwood in the longitudinal direction depending on density.

CONCLUSION

The water absorption coefficient was measured for spruce and beech in the principal anatomical directions. The values were widely spread in all directions and were clearly higher for beech than for spruce. A significant influence of the prefreezing was only shown for green prefrozen beech in the tangential and longitudinal directions. For further investigations, a higher number of specimens with similar density distributions per type are necessary for a more accurate quantification of the influences of density and prefreezing.

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