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RELATIONSHIP BETWEEN RADIAL AND LONGITUDINAL SWELLING IN DEPENDENCE OF GRAIN ORIENTATION

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ABSTRACT

The aim of this study was to investigate the relationship between the maximum radial and longitudinal swelling of spruce wood. On small samples of varying grain orientation the maximum swelling in radial and longitudinal direction was measured. In dependence of the grain orientation, a decrease of the swelling from maximum radial to maximum longitudinal swelling was observed. A mathematical relationship was established to describe the degree of swelling in dependence of the grain orientation.

KEY WORDS: grain angle, spruce, swelling

INTRODUCTION

Wood as a porous biopolymer with hygroscopic characteristics tends to change its moisture content corresponding to the surrounding atmosphere. The processes of adsorption of moisture in form of water vapour from the air and release of it by desorption from the wood are associated with a change in the dimensions of the wood structure in all anatomical directions due to swelling and shrinking phenomena. While in longitudinal direction swelling and shrinking is marginal, it is in general more pronounced in radial and tangential direction for all wood species (Kollmann 1951, Stamm 1964, Suchsland 2004). Several studies and review articles investigated influential parameters of swelling and shrinking such as wood density, ratio of early- and latewood or rays with regards to the anisotropy of these phenomena in the different anatomical directions (Frey-Wyssling 1943, Keylwerth 1962, Kollmann 1981 and 1982, Skaar 1988). The relation of radial and tangential swelling and shrinking of wood is well described. For instance, Keylwerth described the relationship between radial (β_r) and tangential shrinkage (β_t) as linear shrinkage (β_φ) in dependence on the angle (φ) between tangential and radial direction (equation 1) (Keylwerth 1951):

$$\beta_\varphi = \beta_r \cos^2 \varphi + \beta_t \sin^2 \varphi \tag{1}$$

The aim of the present study was to investigate the effect of varying grain angle of solid spruce wood on swelling. Similar to equation 1, the intention was to describe a relationship between radial and longitudinal swelling.

MATERIAL AND METHODS

Sample preparation

One straight grained flawless Norway spruce wood board (*Picea abies* Karst.) with regular annual rings and a density in the range of 491 ± 35 $kg.m^{-3}$ (at a moisture content (MC) of 9.9 ± 0.3 %) was used to produce the samples for determining the extent of swelling. From the machine-planed board, strips with a thickness of 10 mm were cut. From these strips small samples with the dimension 20 x 20 x 10 mm (tangential x longitudinal x radial) were cut. The grain orientation (φ) of the samples was varied from 0° (longitudinal grain) to 90° (end grain) in incremental steps of 10° (Fig. 1a). In total, 250 samples were produced, i.e. 25 samples of each grain orientation.

The samples were carefully dried in an oven at 40°C to get the dry weight and dry dimension. Afterwards, the samples were stored in a conditioning cabinet at 20 ± 1°C and varying relative humidity (rH), namely of (i) 37.6 ± 2.3 %, (ii) 80.2 ± 1.5 % and (iii) 99.6 ± 0.4 % (saturated atmosphere) each time until the samples reached their respective equilibrium moisture content (EMC). After each step, dimensions and weight of the samples were determined. From the dry and swelled dimensions maximum swelling (α_{max}) was calculated by equation 2a were $l_{0,\varphi}$ is the dry length (mm) and $l_{W,\varphi}$ is the wet length (mm) at saturated atmosphere. Linear swelling (α) was calculated by equation 2b were $l_{0,\varphi}$ is the dry length (mm), $l_{1,\varphi}$ is the length (mm) at EMC (6.3 % ≅ rH 37.6 %) and $l_{2,\varphi}$ is the length (mm) at EMC (15.6 % ≅ rH 80.2 %) according to DIN 52184.

$$\alpha_{\max,\varphi} = \frac{l_{w,\varphi} - l_{0,\varphi}}{l_{0,\varphi}} \cdot 100 \tag{2a}$$

$$\alpha_\varphi = \frac{l_{2,\varphi} - l_{1,\varphi}}{l_{0,\varphi}} \cdot 100 \tag{2b}$$

RESULTS AND DISCUSSION

The equilibrium moisture content (EMC) as well as the fibre saturation point (FSP) of wood and the resulting maximum swelling are influenced by several factors on both, the macroscale, e. g. wood density, as well as on the microscale, e. g. microfibril angle, resulting in the swelling anisotropy. Thus, different values for the EMC at FSP for spruce can be found in literature, i.e. in the range of 30-34 % (Kollmann 1982) or 28-31 % (Popper and Niemz 2009). Popper and

Niemz (2009) calculated a theoretical value of 28.85 % for the FSP of spruce using the Hailwood-Horrobin-Model (HH-Model). In the present study, an EMC of 27.5 ± 0.3 % was observed for the spruce wood samples at saturated atmosphere (rH 99.6 %). Furthermore, an EMC of 6.3 ± 0.4 % was observed at rH 37.6 % as well as of 15.6 ± 0.2 % at rH 80.2 %. These findings agreed well with values described in literature for the EMC of spruce at rH 37 % (7.5 %) and at rH 83 % (16.4 %) (Keylwerth 1969) as well as with the theoretically calculated values from the HH-Model which were 7.95 % (at rH 38 %) and 16.24 % (at rH 80 %), respectively (Popper and Niemz 2009).

Plotting the measured average (n = 25) maximum swelling as well as the linear swelling in longitudinal and radial direction, respectively, against the grain angle, two separate s-shaped curves were obtained. As a result of the variation of the grain orientation, maximum swelling in longitudinal direction for 90° grain orientation (sample dimensions 10 x 20 mm, longitudinal x radial) (Fig. 1a) was the same like maximum swelling in radial direction for 0° grain orientation (sample dimensions 20 x 10 mm, longitudinal x radial). Based on that, the values at 0° and 90°, 10° and 80°, 20° and 70° etc. of the two separated curves described above were summed up leading to the final curve shown in Fig. 1b. In the range of 0° to 30° grain angle, influence of grain orientation on the maximum swelling was not pronounced, while a steady decrease was observed in the range of 40° to 90° grain angle.

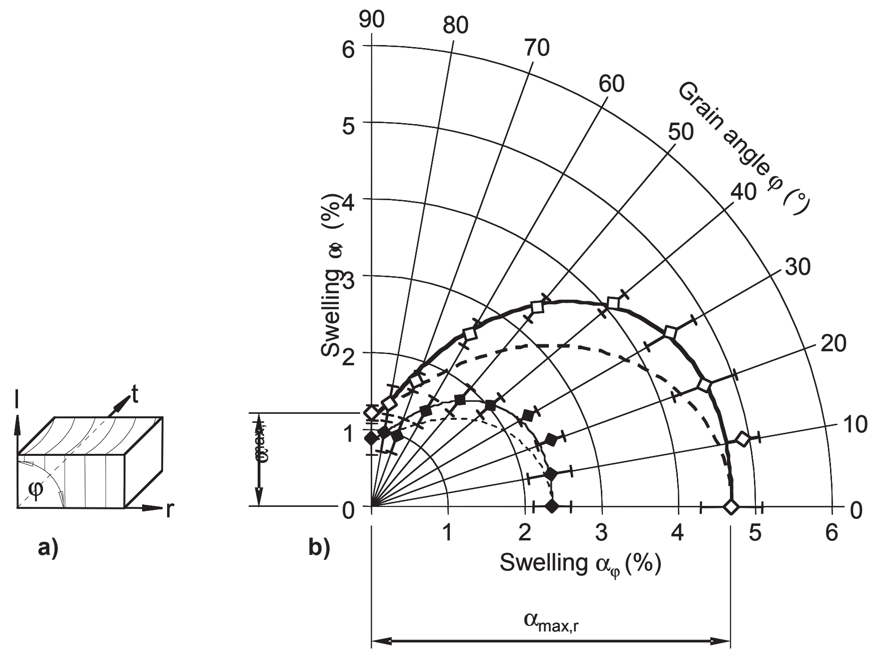

Fig. 1: Sample overview (a) and polar diagram (b) of the average maximum swelling (α_{max}, open symbols) and the linear swelling (α, closed symbols) in dependence on the grain angle (φ). The error bars represent standard deviation (SD). Twenty five samples (n = 25) were measured for each grain angle (longitudinal as well as radial direction) corresponding to 50 data points. The dotted lines represent the theoretic swelling calculated by eq. (3) for the maximum swelling (thick line) and linear swelling (thin line), the solid lines represent the theoretic swelling calculated by eq. (4) for the maximum swelling (thick line) and linear swelling (thin line)

For the mathematical description of the relationship between maximum swelling and grain angle, equation (3) was used in accordance to equation (1) with the starting values $\alpha_{max,r}$ = 4.698, $\alpha_{max,l}$ = 1.211 and the angle (φ radiant):

$$\alpha_{\max,\varphi} = \alpha_{\max,r} \cos^2 \varphi + \alpha_{\max,l} \sin^2 \varphi \tag{3}$$

However, fitting of the data points showed no satisfying correlation (R^2 = 0.89).

Therefore, a new mathematical function, equation (4) was fitted into the data points by using a Levenberg-Marquardt non-linear least square regression.

$$\alpha_{\max,\varphi} = \alpha_{\max,r} - \frac{\sin^n \varphi}{a} \tag{4}$$

With the parameters $\alpha_{max,r}$ = 4.698, n = 3.762, a = 0.285 and φ (radiant) the maximum swelling was calculated showing that equation (4) was much more suitable than equation (3) (R^2 = 0.99). Furthermore, by varying the coefficients to n = 2.0 and a = 0.285 equation (4) corresponds to equation (3). For the two coefficients, ranges between 2 and 4 for n as well as between 0.25 and 0.30 for a are suited. The same procedure was used to calculate the linear swelling by equation (4) with the parameters α = 2.355, n = 3.562, a = 0.680 (R^2 = 0.98).

The presented values for the maximum radial swelling ($\alpha_{max,r}$ = 4.698 %) as well as the maximum longitudinal swelling ($\alpha_{max,l}$ = 1.211 %) of spruce are slightly higher compared to values from literature, e. g. 3.7 % ($\alpha_{max,r}$) and 0.2 to 0.4 % ($\alpha_{max,l}$) (Wagenführ and Scholz 2008), which can be attributed to the geometry of the samples examined in this study. Due to the small size of the samples especially in longitudinal direction, surface roughness negatively influenced measurement accuracy. On the other hand, for $\alpha_{max,r}$, a similar value of 4.58 % was found for spruce wood in an earlier study of our group (Buksnowitz 2006).

CONCLUSION

A decrease of the maximum swelling as well as of the linear swelling was observed in dependence of the grain orientation from maximum radial swelling to maximum longitudinal swelling. In the range of 40° to 90° grain angle, influence of grain orientation on maximum swelling was pronounced. A mathematical relationship between maximum radial swelling and maximum longitudinal swelling was established allowing for the calculation of the degree of swelling by knowledge of the grain orientation.

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REFERENCES

1. Buksnowitz, C., 2006: Resonance wood of *Picea abies*. Doctoral Thesis. BOKU, Vienna, 167 pp.
2. DIN 52184 (1979): Testing of wood; determination of swelling and shrinking
3. Frey-Wyssling, A., 1943: Weitere Untersuchungen über die Schwindungsanisotropie des Holzes. Holz als Roh- und Werkstoff 6(7): 97-198
4. Keylwerth, R., 1951: Untersuchung über freie und behinderte Quellung – Erste Mitteilung: Freie Quellung. Holz als Roh- und Werkstoff 9(7): 253-260
5. Keylwerth, R., 1962: Untersuchung über freie und behinderte Quellung – Erste Mitteilung: Freie Quellung. Holz als Roh- und Werkstoff 20(7): 252-259
6. Keylwerth, R., 1969: Praktische Untersuchungen zum Holzfeuchtigkeits-Gleichgewicht. Holz als Roh- und Werkstoff 27(8): 285-290
7. Kollmann, F., 1951: Technologie des Holzes und der Holzwerkstoffe 2. Auflage Springer Verlag. Berlin, 409 pp.
8. Kollmann, F., 1981: Neues zur Anisotropie der Schwindung und Quellung von Holz. Holz als Roh- und Werkstoff 39(9): 357-360
9. Kollmann, F., 1982: Volumenschwindung von Holz und Rohdichteeinfluß, Ursachen von Ausreißern. Holz als Roh- und Werkstoff 40(11): 429-432
10. Popper, R., Niemz, P., 2009: Wasserdampfsorptionsverhalten ausgewählter heimischer und überseeischer Holzarten. Bauphysik 31(2): 117-121
11. Skaar, C., 1988: Wood-Water Relations. Springer Verlag. Berlin, 122 pp.
12. Suchsland, O., 2004: The swelling and shrinking of wood – A practical technology primer. Forest Products Society. Madison, 15 pp.
13. Stamm, A.J., 1964: Wood and Cellulose Science. The Roland Press Company. New York, 215 pp.
14. Wagenführ, A., Scholz, F., 2008: Taschenbuch der Holztechnik. Fachbuchverlag Leipzig. Carl Hanser Verlag. München, 82 pp.

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