Variability in swelling of spruce (*Picea abies* [L.] Karst.) wood with the presence of compression wood

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ABSTRACT: Wood is a hygroscopic material that is affected by shape changes. The aim of this study was to analyse the variability of wood swelling in the individual anatomic directions. Wood swelling was examined on a sample tree containing compression wood. With regard to the presence of compression wood, the sample tree was divided into the following three zones: the compression wood zone (CW), the opposite wood zone (OW), and two side wood zones (SWL and SWR). The results show that the wood containing compression wood swells less at the transverse plane (in the radial and tangential direction). Conversely, the swelling of compression wood in the longitudinal direction is higher. The same proportion was established in the swelling coefficient that grew proportionally to the increasing wood density in all anatomic directions. The proportion of compression wood manifested its effects in different ways. Transversely (in the radial and tangential direction) the swelling coefficient decreased proportionally to the increasing percentage of compression wood, longitudinally, however, the opposite was the case.

Keywords: spruce; swelling; compression wood

Today, wood is a very frequently used material. In comparison with other competitive materials it offers many advantages including the following ones: wood is a renewable resource, given its weight it provides a very high strength and elasticity, it has good thermal insulating properties, it can be easily shaped, it is ecologically recyclable and, last but not least, it has its indisputable aesthetic qualities. But there are also some disadvantages of wood. One of them, hygroscopicity, which induces shape changes, was examined in this study.

If the moisture content changes in terms of bound water, the wood undergoes dimension changes. The changes in moisture content that occur above the hygroscopicity level (i.e. the varying amount of free water) have no significant implications for wood dimensions. The volume shrinkage and swelling (i.e. the removal and the reception of bound water, respectively) are localised in the cell wall where the expansion (the swelling process) or shrinkage of the fibrillar structure (the dry shrinkage process) takes place (Požgaj et al. 1997; Perstorper et al. 2001). The orientation of the fibrils in the S2 layer of the cell wall is a decisive factor for the dry shrinkage and swelling processes. In the S2 layer of normal wood the deflection angle of the fibrils is very small, which explains the low degree of swelling and shrinkage in the longitudinal direction – the water molecules cannot penetrate between the fibrils into the valence chain in the longitudinal direction. The dimension changes take therefore place at the transverse plane (Perstorper et al. 2001).

Both the linear swelling and shrinkage manifest the anisotropic character through different values in the individual directions. The dimension changes are the smallest in the longitudinal direction, amounting to 0.1–0.4%. In the transverse direction the wood swells and shrinks more significantly, in the radial direction by 3–6%, in the tangential direction by 6–12%. The swelling in the individual anatomic directions can be expressed by the following ratio: αt:αr:αl = 20:10:1 (Niemz 1993; Niemz et al. 1993; Požgaj et al. 1997).

In conifers reaction wood is formed in the lower part of bent trees and in the lower part of branches;

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it is referred to as compression wood (Timell 1986). Thanks to its dark colour compression wood is easily recognisable from the surrounding wood. The eccentricity of the pith is another visible macroscopic sign indicating the presence of compression wood, which further leads to the growing width of annual rings in the area of compression wood (Timell 1986; Gryc, Holan 2004). The microscopic features indicating the presence of compression wood are a round profile of tracheids, stronger cell walls, creation of intercellular spaces, and shorter lengths of compression tracheids (Nečesaný 1955, 1956; Casperson 1962; Wagenführ 2000; Gryc, Horáček 2005).

The deflection of fibrils from the longitudinal axis in the middle layer of the secondary cell wall is considerably bigger in compression wood than in normal wood (Nečesaný 1955, 1956; Wardrop, Dadswell 1957; Casperson 1962; Timell 1986; Gindl 2002). The larger microfibrillar angle results in more massive swelling and shrinkage in the longitudinal direction. Moreover, due to the larger microfibrillar angle the difference between swelling (or shrinkage) at the transverse plane and in the longitudinal direction is smaller than in normal wood, where the deflection of fibrils in the middle layer is significantly smaller (Rak 1957; Meylan 1972).

Perstorper et al. (2001) discovered that the longitudinal shrinkage in spruce wood containing compression wood in the annual ring is at least twice as high, whereas the radial and tangential shrinkage falls by 30%. Additionally, they pointed out that the amount of compression wood within the examined volume considerably affects the degree of shrinkage.

The presence of compression wood has negative implications for wood drying. Klaiber and Seeling (2002) found out that in spruce wood there is a relatively strong interdependence between the mean proportion of compression wood and longitudinal diamonding. It was established that the presence of compression wood has a direct connection with the longitudinal twisting of spruce wood (Schulz et al. 1984). The aim of this study is to determine swelling (α – %) and swelling coefficient (K_{α} – %/1%w) in the particular anatomic directions and for the individual stem zones. In addition to that, it will analyse the way the wood density and reaction compression wood influence the swelling coefficient.

MATERIAL AND METHODS

We selected one sample spruce (*Picea abies* [L.] Karst.) tree in which the presence of reaction wood was presumed. The tree was selected in the Training Forest Enterprise Masarykův les at Křtiny – Mendel University of Agriculture and Forestry Brno, Habrůvka training forest district, in the area 164 C 11. The average annual temperature of this site is 7.5°C and the average annual precipitation amounts to 610 mm. The stem axis of the selected tree was deflected from the direction of gravitation. The deflection of the stem axis was observed only at one plane and the deflection angle at the stem base amounted to 21°C. The tree was 110 years old and it total height was 33 m.

The logs (20 cm high) that were taken at the individual heights (6, 8, 10, 12, 15, 18, 20 and 22 m) were marked for the specific measurement directions.

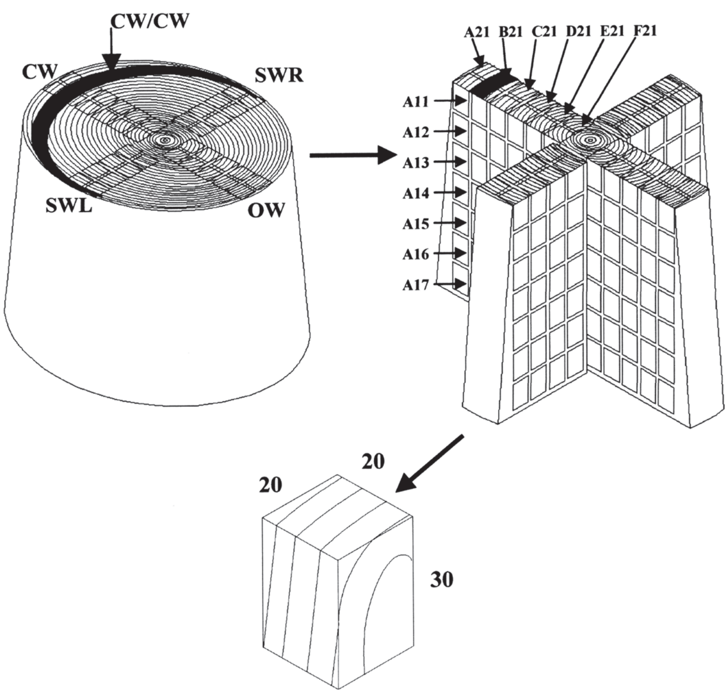

Fig. 1. Scheme describing the production of sample pieces from the log and the sample piece dimensions (CW – compression zone, OW – opposite zone, SWL and SWR – side zones)

The log was subsequently cut with a power saw into blocks according to the individual zones (CW block – the compression wood zone, OW block – the opposite wood zone, and two blocks from the side wood zones, i.e. SWL and SWR). These blocks were dried in a chamber drier to achieve the final moisture content of 8%. After drying the blocks were used to make sample pieces of the following dimensions: length 30 ± 0.5 mm, width 20 ± 0.5 mm and diameter 20 ± 0.5 mm (Fig. 1). The sample pieces had to have a particularly orthotropic shape. The maximum admissible deflection of annual rings as well as the maximum deflection of fibres was set at 5°. Each created sample piece was marked for the later identification of its original position in the stem.

The marked samples were placed into the drier where they were dried at the constant temperature of 103 ± 2°C till their absolute dryness was reached. After that the samples were put into a vessel with distilled water and left there for three weeks. Then the samples were taken out of the vessel and their dimensions were measured again. The established values were used to determine the total linear swelling (%) and the swelling coefficient (%/1%w).

The total linear swelling in the individual anatomic directions was calculated on the basis of the following equation:

$$\alpha_{i\max} = \frac{l_{i\max} - l_{i\min}}{l_{i\min}} \times 100$$

where: $l_{i\max}$ – size of the sample piece (mm) in the particular anatomic direction at the moisture content higher than the hygroscopicity level,
$l_{i\min}$ – size of the sample piece (mm) in the particular anatomic direction at the moisture content 0%.

The volume swelling (%) was determined according to the formula:

$$\alpha_{V\max} = \frac{V_{\max} - V_{\min}}{V_{\min}} \times 100$$

where: $V_{\max}$ – volume of the sample piece at the moisture content higher than the hygroscopicity level (mm^3),
$V_{\min}$ – volume of the sample piece at the moisture content 0% (mm^3).

In the technical practice the swelling coefficient is a useful aid, because it determines the dimension changes the wood undergoes owing to a 1% change in its moisture content. The swelling coefficient (%/1%w) for the individual directions was established according to the formula:

$$K_{\alpha i} = \frac{\alpha_{i\max}}{MH}$$

where: $\alpha_{i\max}$ – the total swelling in the particular anatomic direction (or the volume swelling),
MH – hygroscopicity level.

The frontal surfaces of sample pieces were transformed by an EPSON scanner (Epson Perfection 1660 Photo) into a digital form, which enabled to describe the effect of the proportion of compression wood on wood swelling. The scanning parameters were as follows: colour image with the resolution of 600 dpi. Digital images of the frontal surfaces were transferred into the programme LUCIA. The place with the presence of compression wood was defined in the programme setting. The programme compared the whole surface of the sample piece with the defined compression wood. The ratio of the compression wood pixels to the overall image pinpointed the final proportion of compression wood in the

Table 1. Descriptive statistics of volume swelling (%) and swelling (%) for the individual anatomic directions and zones (statistical values established by all measurements)

Direction	Statistical variable	CW $N = 297$	CW/CW $N = 133$	OW $N = 204$	SWL $N = 202$	SWR $N = 217$
R	Mean (%)	4.89	4.23	5.70	5.59	5.65
	Standard deviation (%)	1.31	1.42	1.09	1.23	1.09
	Coefficient of variation (%)	26.85	33.58	19.12	21.93	19.19
T	Mean (%)	8.86	7.16	10.13	10.07	10.36
	Standard deviation (%)	2.56	1.84	1.68	2.00	1.74
	Coefficient of variation (%)	28.90	25.74	16.55	19.85	16.76
L	Mean (%)	0.79	1.04	0.56	0.61	0.73
	Standard deviation (%)	0.56	0.59	0.44	0.37	0.50
	Coefficient of variation (%)	70.15	56.20	79.64	60.56	68.78
V	Mean (%)	15.23	13.25	17.02	16.89	17.44
	Standard deviation (%)	4.59	5.72	2.32	3.08	2.68
	Coefficient of variation (%)	30.16	43.20	13.63	18.25	15.39

Table 2. Descriptive statistics of the volume swelling coefficient (%/1%w) and swelling coefficient (%/1%w) for the individual anatomic directions and zones (statistical values established by all measurements)

Direction	Statistical variable	CW N = 297	CW/CW N = 133	OW N = 204	SWL N = 202	SWR N = 217
R	Mean (%/1%w)	0.132	0.122	0.153	0.157	0.153
	Standard deviation (%/1%w)	0.033	0.038	0.036	0.038	0.035
	Coefficient of variation (%)	25.238	30.881	23.350	23.873	22.854
T	Mean (%/1%w)	0.237	0.207	0.271	0.275	0.280
	Standard deviation (%/1%w)	0.051	0.047	0.051	0.056	0.055
	Coefficient of variation (%)	21.403	22.442	18.961	20.471	19.813
L	Mean (%/1%w)	0.022	0.031	0.015	0.017	0.020
	Standard deviation (%/1%w)	0.017	0.018	0.012	0.010	0.014
	Coefficient of variation (%)	74.975	57.852	79.539	62.571	69.981
V	Mean (%/1%w)	0.404	0.374	0.457	0.462	0.472
	Standard deviation (%/1%w)	0.072	0.081	0.081	0.092	0.090
	Coefficient of variation (%)	17.849	21.623	17.652	19.850	19.118

sample. In the calculations the samples from the CW zone containing at least 25% of compression wood are referred to as the data file CW/CW.

RESULTS

In view of the anisotropic properties of wood, swelling was analysed in all anatomic directions – radial, tangential and longitudinal ones.

Radial direction

Swelling in the radial direction in the side zones SWL and SWR is about 5.6%. In the opposite zone swelling reaches virtually the same value: 5.7%. In the compression zone (CW) we can observe a reduction in swelling in the radial direction, causing an overall decrease to 4.89% (Fig. 1, Table 1). In relation to the CW zone, swelling in the samples containing compression wood (the CW/CW zone; the amount of compression wood is at least 25%) is one more percent lower. The lowest swelling coefficient in the radial direction (%/1%w) of all measured zones was identified in the CW zone (Table 2).

The statistical survey of the radial swelling coefficient showed a statistically significant difference in the mean values of all zones. Further, it was confirmed that the position of the wood within the stem had an influence on the swelling coefficient in the radial direction. It was found that the effect of the height had only ambiguous manifestations, which means that it is very difficult to identify the heights that would show any statistically significant

Table 3. Resultant functions for the wood swelling coefficient in the particular anatomic directions and in the positions within the stem

Zone	Direction	Function	Coefficient of determination		Coefficients		
			sampling	basis	a	b	c
CW	R	$z = a + bx + cx^2$	0.427	0.416	–0.555	0.0029	–0.000029
	T	$z = a + bx + cx^2$	0.366	0.356	0.061	0.0015	0.000001
	L	$z = a + bx + cx^2$	0.340	0.336	–0.039	0.0001	
OW	R	$z = a + bx$	0.423	0.418	–0.088	0.0005	
	T	$z = a + bx$	0.121	0.114	0.840	0.0004	
	L	$z = a + bx$	0.023	0.021	–0.006	0.0005	
SWL	R	$z = a + bx$	0.310	0.303	–0.055	0.0044	
	T	$z = a + bx$	0.077	0.067	0.117	0.0003	
	l	$z = a + bx$	0.075	0.065	–0.012	0.0001	
SWR	R	$z = a + bx$	0.453	0.447	–0.094	0.0005	
	T	$z = a + bx$	0.350	0.342	–0.062	0.0007	
	l	$z = a + bx$	0.032	0.021	–0.006	0.0001	

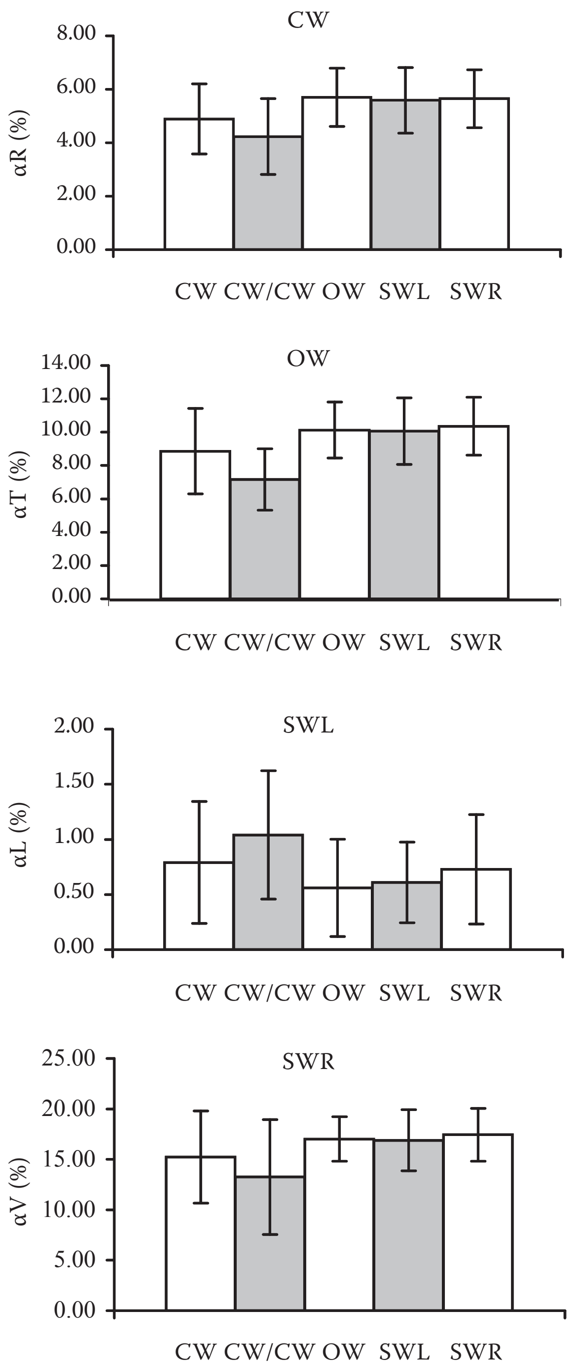

Fig. 2. Bar chart, wood swelling (%) in the individual stem zones (αR – swelling in the radial direction, αT – swelling in the tangential direction, αL – swelling in the longitudinal direction, αV – volume swelling)

effect. Concerning the influence of the radius, the situation seems to be slightly less unclear. In general we can say that in comparison with the annual rings running along the stem circumference, i.e. in the area of mature wood, the annual rings in the central part showed a statistically significant variation in the mean value of the swelling coefficient in the radial direction.

Next, 2D models were created to analyse the influence of wood density on the swelling coefficient in the radial direction (Fig. 3). The coefficient in the zones OW, SWL and SWR has an obvious tendency to increase in relation to increasing wood density. This results from the presence of compression wood in the sample pieces. If the samples with compression wood are filtered off, the radial swelling coefficient increases proportionally to the increasing wood density.

At the density of 500 kg/m^3 the trend is reversed. The increasing density (an indicator of compression wood) goes hand in hand with the decline of the swelling coefficient in the radial direction. The resultant functions describing the relationship between wood density and swelling coefficient in the individual anatomic directions are listed in Table 3.

Tangential direction

Swelling in the tangential direction is represented graphically in Fig. 2. Like in the radial direction we can clearly see a difference between the CW zone containing the CW/CW zone and the other zones. In the opposite and side zones the tangential swelling goes beyond 10%. On the other hand, in the CW zone the swelling decreases below 9%. Filtering off those values from the CW zone that refer to the samples without compression wood, the difference becomes even more apparent. In this case swelling decreases to 7.16% and the difference between compression and opposite wood amounts to 3%. Like in the radial direction, the swelling coefficient in the tangential direction reaches the lowest values in the CW zone, most importantly in the samples containing compression wood (CW/CW – see Table 2).

The statistical survey revealed that compared to the other zones, the CW zone showed a statistically significant difference in the mean value of the swelling coefficient in the tangential direction. There were no other statistically significant differences between the other zones. The influence of the radius and height appears to be statistically significant for the value of the coefficient. Along the stem radius there are clearly visible differences between the peripheral and central parts of the stem. Along the stem height we found some differences between certain heights.

The swelling coefficient in the tangential direction increases in proportion to increasing wood density (Fig. 3). In the OW, SWL and SWR zones there is an obvious trend of the coefficient increasing proportionally to the higher wood density. The trend in the OW and SWL zones is very similar, whereas in the SWR zone the coefficient increases more dramati-

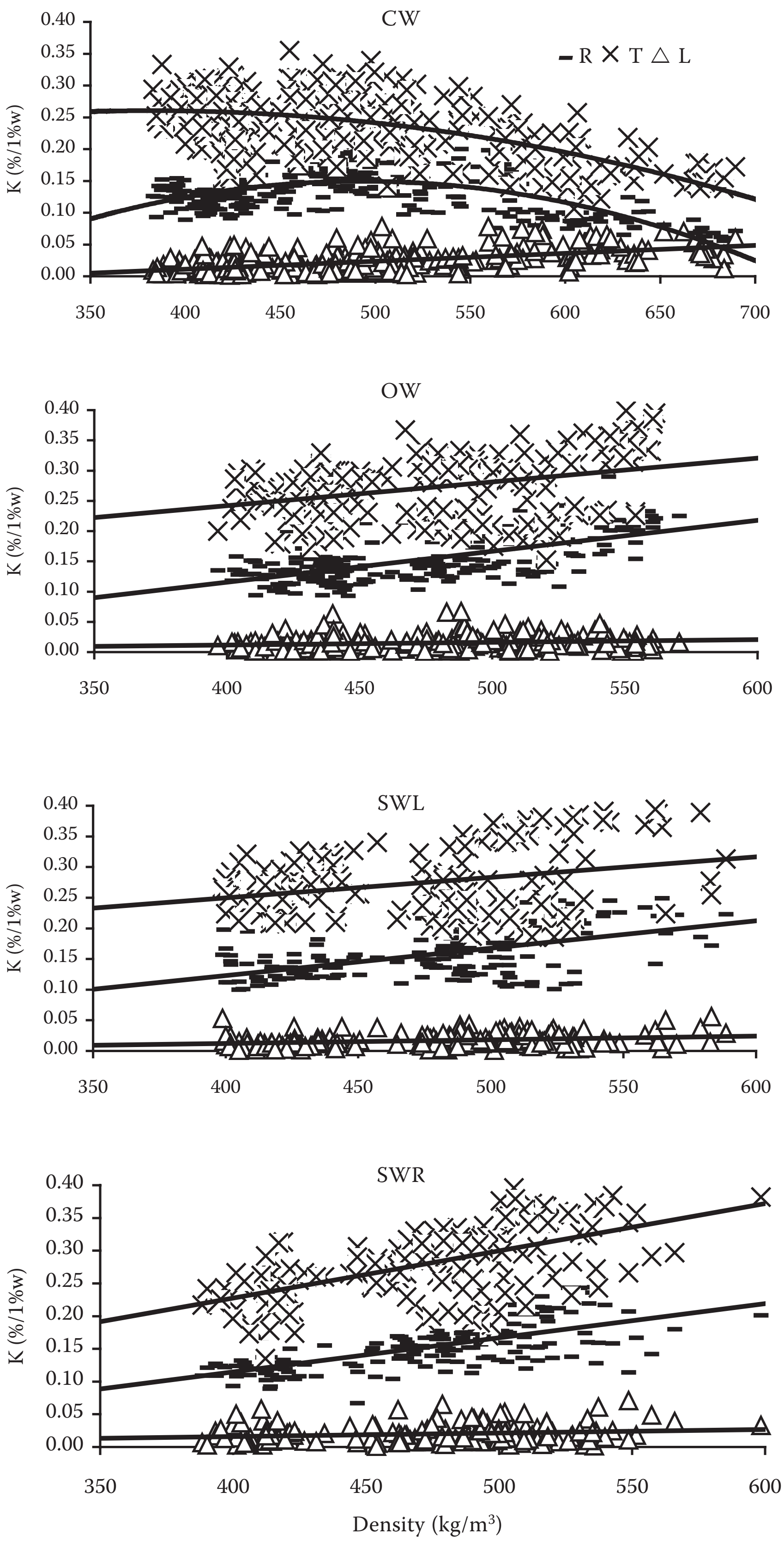

Fig. 3. Influence of wood density on swelling in the particular directions and stem zones; the resultant functions are shown in Table 3

cally. The CW zone with its compression wood is quite specific. Like in the radial, and even in the tangential direction we observed a reverse trend in the compression zone with higher density values (i.e. with the presence of compression wood). The tangential swelling coefficient decreased in proportion to increasing density. In the data file without compression wood there was a positive trend of the

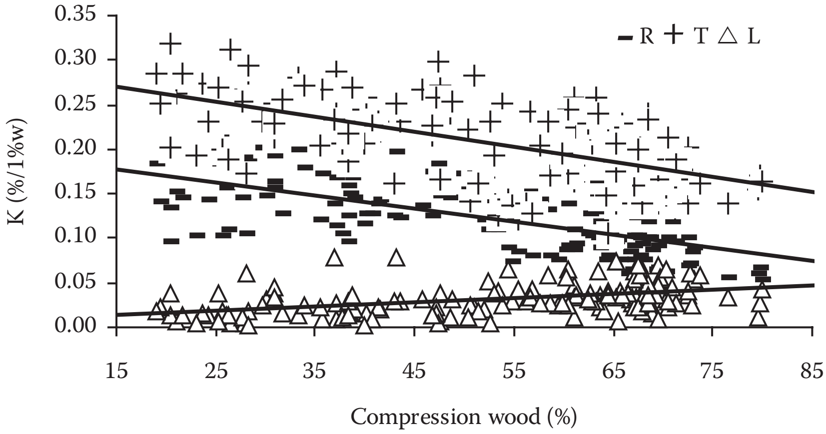

Fig. 4. Influence of the compression wood percentage on the swelling coefficient in the particular anatomic directions

coefficient increasing proportionally to the wood density.

Longitudinal direction

As far as the longitudinal direction is concerned, the wood swells most in the CW zone (Fig. 2).

An even larger degree of swelling – over 1% – is found in the samples containing compression wood. Even in the longitudinal direction, swelling in the OW, SWL and SWR zones is very similar (around 0.6%). The same ratio was identified for the swelling coefficient in the longitudinal direction (Table 2).

The statistical analysis confirmed that in terms of the coefficient mean value for the longitudinal direction, the CW zone shows a statistical difference in relation to the other zones.

The influence of reaction wood on wood swelling

Fig. 4 shows the effect of the varying proportion of compression wood on the individual swelling coefficients. As the percentage of compression wood on the frontal surface of the sample increases, the swelling coefficient in the radial and tangential direction decreases. There is a positive trend in the longitudinal direction, i.e. growing longitudinal swelling in dependence on the increasing percentage of compression wood.

The resultant functions for the swelling coefficient model in the particular anatomic directions, subject to the percentage of compression wood in the sample can be seen in Table 4.

DISCUSSION

Wood is a hygroscopic and porous material and as such, depending on the external conditions, it can either absorb or release water. The absorption and release of moisture on the hygroscopicity level are accompanied in wood by the process of shrinkage and swelling. The anisotropic properties of wood are manifested through different degrees of swelling in the individual anatomic directions. Not much attention is generally paid to the longitudinal change of dimensions. This is caused by the fact that swelling and shrinkage in the longitudinal direction are all but negligible. Nevertheless, the dimension changes that occur at the transverse plane, where swelling and shrinkage are considerably more extensive, can hardly be neglected (Niemz 1993; Požgaj et al. 1997).

The results of swelling and shrinkage in the longitudinal direction in the OW, SWL and SWR zones range around 0.6%, which is very close to the values that are quoted in connection with the swelling and shrinkage processes in spruce wood (Niemz 1993). Having a different structure, compression wood showed an expectedly different degree of swelling. The more massive dimension change in the longi-

Table 4. Resultant functions for the relationship between the swelling coefficient in the particular anatomic directions and the compression wood percentage

Direction	Function	Coefficient of determination		Coefficients	
		sampling	basis	*a*	*b*
R	$z = a + bx$	0.412	0.403	0.198	–0.0014
T	$z = a + bx$	0.360	0.342	0.295	–0.0017
L	$z = a + bx$	0.192	0.181	0.006	0.0005

tudinal direction is caused by the fibrillar angle in the S2 layer of the secondary wall cell. According to the available sources (Timell 1986; Perstorper et al. 2001) the dimension change for the longitudinal direction in compression wood amounts to 1–4%.

The dimension change in the CW zone was larger than in the other zones despite the fact that the analysed file encompassed samples both with and without compression wood. The samples with compression wood had a greater tendency towards swelling in the longitudinal direction (the dimension change exceeding 1%). The result corresponds with the bottom level generally quoted for the longitudinal swelling of compression wood. The lower values that were established in the samples with compression wood resulted probably from the variable percentage of compression wood (20–80%) in the total volume of the sample piece. The swelling in the longitudinal direction analysed in the samples with compression wood (CW/CW) was over 1%. This corresponds with the value for longitudinal swelling established by Schulz et al. (1984) for the samples containing 50% of compression wood.

The values reported by Niemz (1993), Niemz et al. (1993), Požgaj et al. (1997), Reck (2002), and Trendelenburg (1932) in connection with shrinkage and swelling in the radial and tangential direction are 3–6% and 6–12%, respectively. The dimension changes established in the OW, SWL and SWR zones for the radial and tangential direction are 5–6% and 9–10%, respectively. The results lie within the limits given by the literature for the dimension change of normal wood at the transverse plane. The values established in the OW, SWL and SWR zones are very close to the ratio 1:2 quoted by the literature in relation to swelling and shrinkage in the radial and tangential direction.

The larger fibrillar angle in the S2 layer of the secondary cell wall in compression wood contributes to the reduction of swelling at the transverse plane (Timell 1986). Lower values of swelling and shrinkage at the transverse plane were confirmed in the CW zone, or more precisely in the CW/CW zone. The dimension change in the CW/CW data file (i.e. the samples containing compression wood) ranged between 4–7% for the tangential direction (swelling and shrinkage). The degree of swelling measured in the radial and tangential direction is higher than that published in relation to compression wood (Rak 1957; the values established for wood shrinkage – with a bit of simplification the swelling and shrinkage of wood can be regarded as the same processes). The difference can also be put down to different measurement techniques. In this study the values were established by means of standardised formulas, whereas Rak (1957), to name one example, carried out his measurement on the basis of small cubic formulas (a = 8 mm). In this case he measured only compression wood while eliminating the influence of "normal wood" to the largest possible extent. The findings published by Niemz et al. (1993) suggesting that in terms of radial and tangential swelling and shrinkage there are no differences between compression and normal wood, have not been confirmed. In view of this fact, this study underpins the conclusions claiming that at the transverse plane there are smaller differences in compression wood than in normal wood (Rak 1957; Ollinmaa 1959; Timell 1986).

The proportion of swelling in the individual anatomic directions in the opposite zone (OW) is virtually the same as in normal wood. The way the samples containing compression wood (CW/CW) swell in the individual directions is noticeably different from normal wood. The ratio points to more significant swelling in the longitudinal direction, which was probably caused by a higher deflection of fibrils in the secondary cell wall of the compression tracheids.

In practice it is often important to settle the dimension change in materials with the starting moisture content lower than the hygroscopicity level. The swelling and shrinkage coefficients used for this purpose show how much, in terms of percentage, the dimensions will change if the moisture content of wood changes by 1%.

The established swelling coefficients for the individual anatomic directions correspond well with the results published by Perstorper et al. (2001). The authors confirmed that the presence of compression wood considerably affected the shrinkage coefficient. Their study further corroborated the theory that the longitudinal shrinkage coefficient increased in proportion to the increasing percentage of compression wood in the sample, whereas the radial and tangential shrinkage coefficient manifested an opposite trend. Our analysis of the sample tree provided very similar results even in the case of swelling coefficient, irrespective of the fact that this is, admittedly, a reverse process. The differences between the values established for normal wood and for the OW, SWL and SWR zones can be explained by the fact that normal wood cannot be fully compared with the wood taken from a tree containing compression wood. Another reason might be provided by the comparison of the swelling and shrinkage process.

Statistically significant differences in linear swelling and shrinkage between the lower and the upper part of the stem can be substantiated on the basis of different percentages of juvenile wood. Juvenile wood, i.e. the wood in the central part of the stem, has a lower density. In the upper part of the stem there is a higher proportion of juvenile wood and a lower proportion of late wood. This logically leads to less extensive shape changes (Merforth 2000). Reck (2002) found out that swelling and shrinkage in both anatomic directions are lower in the proximity of the pith. He described a connection between the increasingly marked dimension change observed particularly in the radial direction along the stem radius with narrow annual rings and a higher relative proportion of late wood in the peripheral area of the stem. Confining her conclusions to dominant trees only, Seeling (1999) established a slight increase in the radial and tangential shrinkage from the pith to the cambium.

Should swelling and shrinkage in the anatomic directions be dependent on the position in the stem, it is obvious that these changes must be reflected also in the extent of volume changes, in other words, in the value of the volume swelling coefficient. The volume swelling coefficient was analysed by means of a 3D model which described its variability along the stem radius and height.

The higher value of the coefficient along the circumference and in the lower part of the stem in the OW, SWL and SWR zones can be ascribed to a higher wood density in this part of the stem (the wood density is closely linked to the wood structure, i.e. to the annual ring width, late wood proportion, variability of the cell wall thickness). In spite of a higher wood density, this trend could not be manifested in the CW zone because the higher wood density corresponded with the compression wood which has a higher proportion of lignin (Knigge 1958; Timell 1986; Fengel, Wegener 1989). The higher proportion of lignin in the S2 layer of the secondary cell wall (Gindl 2002) accompanied by a lower proportion of cellulose probably caused a decrease in the amount of free OH groups with which the water molecules can combine in the cell wall. The volume swelling of compression wood was therefore lower than the volume swelling of normal wood.

To sum up, shrinkage or swelling which occurs both in normal wood and in compression wood or in the wood containing compression wood in reaction to the changing moisture content does assume the same proportions. Consequently, the specific behaviour of the latter must be duly taken into account when used in the manufacturing processes.

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Variabilita bobtnání dřeva smrku (*Picea abies* [L.] Karst.) s přítomností tlakového dřeva

ABSTRAKT: Dřevo je hygroskopický materiál, který podléhá tvarovým změnám. Byla studována variabilita bobtnání dřeva v příslušných anatomických směrech. Bobtnání dřeva bylo zkoumáno na vzorníkovém stromě s přítomností tlakového dřeva. Vzhledem k přítomnosti tlakového dřeva byl vzorníkový strom rozčleněn do příslušných zón – zóna tlakového dřeva (CW), zóna protilehlá (OW) a dvě zóny postranní (SWL a SWR). Z výsledků vyplývá, že dřevo s přítomností tlakového dřeva bobtná méně v příčné rovině (v radiálním a tangenciálním směru), naproti tomu v podélném směru bylo v případě tlakového dřeva bobtnání vyšší. Stejný poměr byl zjištěn i v případě koeficientu bobtnání. Se zvyšující se hustotou dřeva se koeficient bobtnání ve všech anatomických směrech zvyšoval. Vliv procentuálního zastoupení tlakového dřeva se projevoval rozdílně. V příčné rovině (radiální a tangenciální směr) se s rostoucím procentuálním zastoupením tlakového dřeva koeficient bobtnání snižoval, obrácený trend byl zjištěn v případě podélného směru.

Klíčová slova: smrk; bobtnání; tlakové dřevo

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