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Relationship between the anatomical structure elements and physical properties in the trunk transverse and longitudinal direction for wood of Norway spruce (*Picea abies* (L.) Karst.) growing in Latvia

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Abstract. The aim of the present work was to characterise the relationship between the main anatomical structure parameters and physical properties of spruce wood. The main anatomical structure parameters under study were: annual ring width (G_{pl}), share of late wood in the annual ring ($G_{vk\%}$), tracheid length (T_L), double wall thickness and cross-section in radial direction in early wood ($T_{2w\ ak}$, $T_{R\ ak}$) and late wood ($T_{2W\ vk}$, $T_{R\ vk}$). The main characteristics of the physical properties were as follows: wood density (ρ_o), volume swelling (α_v) and shrinkage (β_v), linear swelling in radial (α_{rad}) and tangential (α_{tg}) directions, linear shrinkage in radial (β_{rad}) and tangential ($ß_{tg}$) directions, water ($W_{ū}$) and moisture absorption (W_m) values. These physical characteristics, as well as the anatomical structure elements, were determined at four trunk heights (at the butt-end – R, ¼, ½ and ¾ parts of the trunk height, which corresponds to the trunk's relative lengths 0, 25, 50 and 75%, respectively), and in the radial direction from heart pith to sapwood. The tracheid length decreases in the direction from the trunk's butt-end to the top in longitudinal and radial direction from sapwood to heart pith. Thus, for example, the tracheid length ratio in the direction from sapwood to heart pith is 1.31, ¼ – 1.27, ½ – 1.23 and ¾ – 1.18. In comparison with pine wood, the average tracheid length throughout the trunk' length for spruce wood is higher by 25% and is equal to 4.0 mm. The ratio of the early wood tracheid double wall thickness in the direction from sapwood to heart pith in the trunk's longitudinal direction and at the butt-end is 1.25, ¼ – 1.12, ½ – 1.13 and ¾ – 1.05. Hence, the location of the sample in the tree trunk is very important, because it influences the anatomical parameters and physical properties of wood. For the first time, a comprehensive study on the distribution of the anatomical elements and physical properties of wood in the trunk's longitudinal and transverse direction, as well as their correlation, was carried out. The distribution of spruce wood density in both sapwood and core in the direction from the butt-end to the top decreases, which coincides with the higher content of late wood in the annual ring and tracheid lengths in these trunk's parts. The exception is ¾ from the trunk's length, where the density increases in both the core part and sapwood, because juvenile wood prevails at such a trunk's height.

Keywords: Norway spruce, anatomical structure, physical properties

INTRODUCTION

Although Norway spruce (*Picea abies* (L.) Karst.) is the third dominant tree species in Latvia, there is no exhaustive information about the relationship between its structure and physico-mechanical properties, and anatomical structure elements. Up to now, a whole range of studies on the anatomical structure and physical properties of spruce wood have been carried out (BALODE et al. 1999, 2002, 2004; HROLS et al. 2005; PRIEDKALNS et al. 2002; POLUBOJARINOV 1976). However, their changes throughout the height and radius of the trunk have not been determined.

The present work is the first comprehensive study on the relationship between the anatomical elements of spruce wood grown in Latvia and its mechanical properties, both throughout the length of the trunk and in the transverse direction, as well as their correlative interrelationships.

MATERIAL AND METHODS

For mutual comparison of the obtained data, determination of the anatomical parameters and physical properties of wood in the same trunk's site was proposed as the task of the study. In practice, it is difficult to obtain sample trees of identical dimensions for mutual data comparison. Therefore, in the present work, the sample tree trunk was divided at proportional heights (butt-end – R, ¼, ½ and ¾ from the trunk height).

The trunk's cross-section is schematically represented in Fig. 1. To determine the physical properties, the samples were chosen in the transverse direction (samples' transverse sizes 20 × 20 mm, length – 10 mm) from the heart pith to sapwood (Fig. 2).

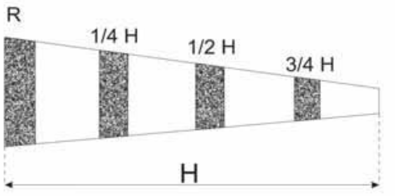

Figure 1. Schematic representation of trunk sampling.

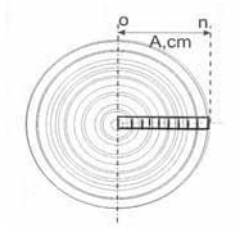

Figure 2. Determination of the physical properties numeration in the trunk sample's cross-section.

The original direction of the samples' numeration was accepted from heart pith to sapwood (0 or 1 in the centre and further, depending on the sample's diameter 2, 3, 4.... n).

To avoid the variation in the properties of natural wood among different trees, one pine tree was used in our experiment. Probably, this limits the number of experimental data, and definite conclusions on the relationships between the anatomical structure elements and physical properties cannot be made based on one tree's data. In the present study, the first attempt was made to show at least tendencies in looking for such relationships.

To investigate the anatomical parameters of wood, a special optical microscope MTKΦ-1 with a video camera TK-C721EG (JVC Color) was used, employing the software *IMAGE-PRO EXPRESS* for picture analysis in reflected light. The physical characteristics of wood were determined in accordance with the following standards (DIN 52 182, DIN 52 184, GOST 16 483.18 – 72). The tracheid length distribution throughout the trunk's height and in the transverse direction determines many physical characteristics of spruce wood.

RESULTS AND DISCUSSION

The values of the anatomical parameters of spruce wood are shown in Table 1.

Table 1. Values of spruce wood anatomical parameters

Part of trunk, H	A, cm	$T_{R\ vk}$, mkm	$T_{R\ ak}$, mkm	$T_{2w\ vk}$, mkm	$T_{2w\ ak}$, mkm	T_L, mm	G_{vk}, %	G_{pl}, mm
butt-end, R	16	23.0	40.8	13.3	5.9	4.6	28.0	1.51
	10	22.9	39.9	12.4	5.1	3.8	24.6	1.58
	6	23.3	38.7	11.1	4.7	3.5	23.6	2.27
1/4	10	21.3	40.3	11.6	4.6	4.7	20.3	1.03
	7	21.4	39.0	11.8	4.6	4.4	20.8	1.11
	4	20.8	36.9	10.1	4.1	3.7	12.8	1.87
1/2	8	19.8	38.9	10.9	4.4	4.2	14.0	1.04
	6	19.7	37.1	10.6	4.2	4.1	14.6	1.17
	4	19.4	36.4	10.2	3.9	3.4	12.2	1.48
3/4	5	19.5	36.5	9.9	4.1	4.0	13.7	1.25
	3	18.6	35.1	9.5	3.9	3.4	9.3	2.10

Legends: H – relative height of the trunk; A – distance from the pith; $T_{R\ vk}$ – diameter of late wood tracheids; $T_{R\ ak}$ – diameter of early wood tracheids; $T_{2w\ vk}$ – double cell wall width of late wood tracheids; $T_{2w\ ak}$ – double cell wall width of early wood tracheids; T_L – tracheids length; G_{vk} – late wood percentage in the annual ring; G_{pl} – width of annual rings, mm.

Values of the spruce wood density and physical properties are shown in Table 2.

Table 2. Values of spruce wood density and physical properties

H, %	ρ_o, g/cm^3		$W_{\bar{u}}$, %		$K\alpha$, % / %						W_m, %	
					Ra		Tg		V			
	S	H	S	H	S	H	S	H	S	H	S	H
R	0.496	0.484	168	172	0.13	0.13	0.38	0.34	0.53	0.48	16.8	16.9
1/4	0.479	0.458	180	191	0.17	0.17	0.41	0.39	0.60	0.58	16.8	16.7
1/2	0.443	0.440	198	197	0.16	0.15	0.38	0.38	0.56	0.55	16.8	16.8
3/4	0.517	0.448	159	177	0.17	0.09	0.37	0.22	0.57	0.32	17.0	17.1

Legends: H – height of the trunk; ρ_o – density of oven dry wood; $W_{\bar{u}}$ – water absorption; $K\alpha$ (Ra, Tg, V) – coefficient of swelling (radial, tangential, volumetric); W_m – moisture absorption; S – sapwood; H – heartwood

The spruce wood density (ρ_o) distribution at the butt-end and ¼ from the trunk's height throughout the trunk's radius (A) is shown in Fig. 3. It can be seen that the density at the top's end in the direction to sapwood grows more dramatically than in the trunk's central part. The spruce wood density (ρ_o) distribution at ½ and ¾ from the trunk's length throughout the trunk's radius (A) is shown in Fig. 4.

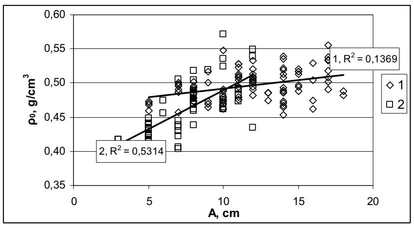

Figure 3. Distribution of density (ρ_o) on the spruce trunk radius: 1 – R, 2 – ¼.

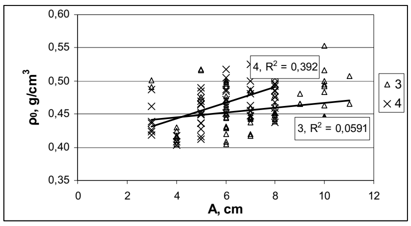

Figure 4. Distribution of density (ρ_o) on the spruce trunk radius: 3 – ½ un ¾.

The tracheid length and the distribution of the late wood content throughout the trunk height and the transverse direction determine many physico-mechanical characteristics of spruce wood. The longer the tracheids and the greater the content of late wood in the annual ring, the higher is the density and the greater is the swelling coefficient.

CONCLUSIONS

1. The tracheid length in the direction from the trunk's butt-end to the top in the transverse and radial direction from sapwood to heart pith decreases. Thus, for example, the tracheid length ratio in the direction from sapwood to heart pith is 1.31, ¼ – 1.27, ½ – 1.23 and ¾ – 1.18.
2. The ratio of the early wood tracheid double wall thickness from sapwood to heart pith in the longitudinal direction decreases and is equal to 1.25, ¼ – 1.12, ½ – 1.13 and ¾ – 1.05 at the butt-end. However, the ratio of the late wood tracheid double wall thickness in the direction from sapwood to heart pith in the trunk's longitudinal direction decreases not so dramatically as in early wood, and is equal to 1.20, ¼ – 1.15, ½ – 1.07 and ¾ – 1.04 at the butt-end. The ratio of the share of late wood in the direction from sapwood to heart pith varies according to another regularity, reaching the maximum ratio ¼ from the trunk's height (1.19, ¼ – 1.59, ½ – 1.15 and ¾ – 1.47 at the butt-end).
3. The distribution of spruce wood density, both in sapwood and heart pith, decreases in the direction from the butt-end to the top, which agrees with the greater lengths of the late wood content in the annual ring and the tracheid lengths in these parts of the trunk. The exception is ¾ from the trunk length, where density grows, both in the heartwood part and sapwood, because juvenile wood prevails at this height of the trunk.
4. The distribution of spruce wood density in the oven dry state in the trunk's transverse direction from heart pith to sapwood is positive. At the butt-end and at ½ from the trunk's length, it is insignificant (r = 0.37 and 0.24, respectively). However, it is essential at ¼ and ¾ from the trunk's length (r = 0.73 and 0.63, respectively).

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Streszczenie. Zależność pomiędzy strukturą anatomiczą i własnościami fizycznymi a położeniem w osi i na średnicy pnia świerka (Picea abies (L.) Karst.) rosnącego na Łotwie. Celem niniejszej pracy jest wykazanie zależności pomiędzy strukturą anatomiczną i własnościami fizycznymi drewna świerka. Rozpatrywano: szaeokość słoja rocznego (Gpļ), zawartość drewna późniego w słoju (Gvk%), długość cewek (TL), grubość ściany oraz przekroju w kierunku promieniowym drewna wczesnego (T 2w ak, TR ak) and late wood (T2W vk, TR vk). głównymi wskaźnikami własności fizycznych były: gęstość drewna (ρo), spęcznienie objętościowe (αv) skurcz objętościowy (βv), spęcznienie w kierunku promieniowym (αrad) spęcznienie w kierunku stycznym (αtg) , skurcz w kierunku promieniowym (βrad) skurcz w kierunku stycznym (ßtg), absorbcja wody (Wū) i absorpcja wilgotności (Wm). Własności fizyczne oraz anatomiczne były mierzone w 0, 25, 50 i 75%,wysokości pnia oraz promieniowo od rdzenia do bielu. Długość cewek zmniejsza się w kierunkach od pnia w górę strzały oraz od rdzenia do bielu. Podobnie gęstość drewna maleje wraz z położeniem w kłodzie od pnia w górę strzały, wraz z mniejszą zawartością drewna późnego.

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