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LONGITUDINAL DESORPTION SHRINKAGE OF NEEDLES OF SELECTED PINE SPECIES

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Longitudinal desorption shrinkage of needles from 10 pine species was studied. The study indicated considerable differentiation of longitudinal shrinkage of needles from 0.6 to 2.7% while the needles of 5-needle species are characterized by significantly higher shrinkage than the 3- and 2-needle ones. The magnitude of needle shrinkage is comparable to that in juvenile wood and phloem, while it is greater in comparison with normal mature wood.

INTRODUCTION

As results from the survey of literature the data on physical and mechanical properties of nonconventional, in utility sense, tree part as foliage [6, 7, 9] and cones [1, 5] are very scarce. This particulary applies to the case of desorption deformation in needles of coniferous species. In this field — to the author's knowledge — only tentative data on longitudinal desorption shrinkage of needles of four pine species belonging to southern pine group [7] are available. Hence, in order to get more information on this issue, the investigations on longitudinal desorption shrinkage of needles were extended on other pine species.

EXPERIMENTS

The experiments were carried out on two-year old needles of 10 pine species collected in mid December in Dendrological Garden of Poznań Agricultural University from lateral shoots near tops of 15 - 20 years old trees. When collected, the needles were put into polyethylene bags and stored in refrigerator at about 5°C. Table 1 lists the investigated needle species and their basic characteristic. The total needle length in green state was determined on samples of 20 needles. The moisture content of needles in green state, i.e. directly after collecting, was estimated on bundles of 20 needles. The needles were dried to constant mass in an oven heated to $103 \pm 2°C$ for 24 hrs. The water content in the needles was related to their mass in ovendry state. In density measurements the bundles of 20 needles were also used. The density was determined as ba-

Table 1 - Tabela 1

List of investigated pine needle species and their characteristics
Wykaz badanych gatunków igieł sosen i ich charakterystyka

Nedle species Gatunek igieł	Species name symbol Symbol nazwy gatunku	Needles per fascie Liczba igieł na krótkopędzie	Total length Długość całkowita mm	Moisture content in green state Wilgotność w stanie świeżym %	Basic density Gęstość umowna kg/m³
Haploxylon					
P. strobus L.	PST	5	83 (73 - 94)	136 (133 - 140)	240 (230 - 260)
P. griffithi McLell.	PGR	5	84 (74 - 108)	121 (117 - 127)	300 (280 - 330)
P. cembra L.	PCM	5	100 (82 - 105)	118 (115 - 121)	360 (340 - 370)
Diploxylon					
P. rigida Mill.	PRG	3	61 (48 - 72)	120 (118 - 121)	400 (370 - 420)
P. jeffreyi Balf.	PJF	3	166 (157 - 179)	130 (129 - 132)	420 (370 - 470)
P. ponderosa Dougl.	PPD	3	144 (133 - 153)	136 (130 - 140)	400 (380 - 410)
P. banksiaaa Lamb.	PBK	2	30 (27 - 33)	140 (138 - 141)	300 (290 - 320)
P. mugo Turra	PMG	2	49 (43 - 54)	121 (120 - 122)	360 (340 - 370)
P. nigra Aru.	PNG	2	120 (115 - 123)	147 (143 - 149)	370 (340 - 400)
P. silvestris L.	PSL	2	60 (55 - 71)	151 (149 - 153)	380 (360 - 400)

sic density, as a quotient of needles mass in ovendry state and their volume in green state. The volume of needles in green state was determined by a hydrostatic weighting method. Attention was paid to remove air bubbles adjacent to needle surface. By comparing the data in Table 1 with the data on earlier investigated needles of the same species collected from neighbouring and sometimes the same trees [6] we can see some differences, particulary in moisture content and density. In the previous studies, needles were collected in the first half of April, while in this study in the middle of December. This fact explains a higher water content in needles in winter by about 20% of moisture content (from 6% to 32%) as compared with the spring water content in needles. As it is known, tree leaves differ in water content [e.g. 2] depending on the season or even part of the day. The density of the needles is generally slighty lower for the needles collected in December: however for *P. strobus*, the decrease in density amounts up to 50%. To verify these data also in December we studied an additional sample of *P. strobus* needles of moisture content in green state of 150%; and determined their density which on average amounted to 330 kg/m³ (320 ... 340 kg/m³). As follows from the compared data, the density can considerably vary, even for needles originating from the shoots of the same age. However, this problem requires futher studies. In these present investigations on desorption shrinkage, we used the *P. strobus* needles of the density of 240 kg/m³.

The maximum desorption shrinkage of needles along their main axis was determined on 20 mm long samples cut out from the middle part of the needles. The needles were dried out at 103±2°C for 24 hrs. The length of needle samples in green and ovendry states was measured with measuring microscope with the accurancy of 0.01 mm. The maximum longitudinal desorption shrinkage of needles was calculated from the formula

$$\beta_{max} = \frac{\Delta l_{max}}{l} 100\,(\%),$$

where Δl_{max} is the maximum desorption shortening of a sample along the main axis upon drying from the green state to the ovendry state, and l is the initial sample length in the green state.

RESULTS AND DISCUSSION

Table 2 presents measurement results of the maximum shrinkage of needles from various pines. The mean variation coefficient $(V)_{\%}$ for the measurements of shrinkage of needles is 28% (from 8% for *P. strobus* to 48% for *P. nigra*). As can be seen in Table 2, varies the shrinkage of examined needles ranging from 0.6% for *P. nigra* and *P. ponderosa* to 2.7% for *P. cembra*. Needles of 5-needle pines have clearly higher

Table 2 - Tabela 2

Maximum longitudinal shrinkage of needles from selected pine species

Maksymalny stopień podłużnego kurczenia się igieł wybranych gatunków sosen

Needle species Gatunek igieł	Species name symbol Symbol nazwy gatunku	Statistical value Wielkości statystyczne			
		$\bar{x}$	x_{min}	x_{max}	$\pm s$
		%			
P. strobus L.	PST	2.51	2.09	2.89	0.21
P. griffithi McLell.	PGR	2.10	2.02	2.79	0.67
P. cembra L.	PCM	2.66	2.11	3.06	0.28
P. rigida Mill.	PRG	0.86	0.46	1.19	0.26
P. jeffreyi Balf.	PJF	1.14	0.70	1.80	0.33
P. ponderosa Dougl.	PPD	0.60	0.25	1.04	0.23
P. banksiana Lamb.	PBK	0.96	0.48	1.48	0.27
P. mugo Turra	PMG	1.63	1.03	2.18	0.33
P. nigra Aru.	PNG	0.55	0.18	1.12	0.27
P. silvestris L.	PSL	0.93	0.47	1.56	0.28

Mean value from 20 measurements, in case of *P. silvestris* from 40 measurements.

shrinkage (2.1 ... 2.7%) than 3- and 2-needle ones. These data are comparable to the results of the earlier investigations on the maximum shrinkage of needles of four species of southern pine which are given below [7]:

	β_{max} (%)
P. taeda L.	1.58 (1.3 ... 2.3)
P. palustris Mill.	1.65 (1.3 ... 2.1)
P. echinata Mill.	1.85 (1.1 ... 2.8)
P. elliottii Engelm.	2.31 (1.9 ... 2.7)

Needles of the investigated pine species are divided in Table 3 into three classes according to the maximum longitudinal shrinkage; which correspond to low shrinkage (up to 1%), medium shrinkage (from 1 to 2%) and high one (over 2%), respectively.

Table 3 - Tabela 3

Classification of needles from various pine species according to the longitudinal shrinkage
Klasyfikacja igieł różnych gatunków sosen według stopnia podłużnego kurczenia się

Class of desorption shrinkaga Klasa desorpcyjnego kurczenia się	Maximum shrinkage Skurcz maksymalny β_{max} %	Needle species Gatunek igieł
I. Low Skurcz niski	≤1	*P. nigra* *P. ponderosa* *P. rigida* *P. banksiaua* *P. silvestris*
II. Medium Skurcz średni	>1...2	*P. jeffreyi* *P. mugo* *P. taeda**) *P. palustris**) *P. echinata**)
III. High Skurcz wysoki	>2	*P. elliottii**) *P. strobus* *P. griffithi* *P. cembra*

*) According to Howard (1973)

For comparison, Table 4 lists numerical values of the maximum longitudinal shrinkage of various parts of trees of species *Pinus* trees. Due to a lack of sufficient data on logitudinal shrinkage of phloem tentative measurements were carried out for 20-years-old-bark of *P. silvestris*. The bark was collected from the butt part of trees. The outer bark was about 10 mm thick while that of phloem about 1 mm. Green moisture content in the outer bark amounted to 53%, while that of phloem to as much as 250%. Following the drying to ovendry state, the maximum longitudinal shrinkage of phloem was 4.1% (2.6 ... 5.6%) and of outer bark was 2.1% (0.7 ... 3.1%).

Longitudinal shrinkage of pine needle samples is greater than longitudinal shrinkage of normal mature wood. However, it is comparable with longitudinal shrinkage of juvenile wood, phloem and outer bark. The increased longitudinal shrinkage of juvenile wood (core wood) is, as

Table 4 - Tabela 4

Maximum longitudinal desorption shrinkage of various parts of *Pinus trees*

Maksymalny skurcz desorpcyjny różnych części drzew rodzaju *Pinus*

Part of a tree Części drzewa	Maximum longitudinal shrinkage Maksymalny stopień kurczenia się %	According to Według danych
Needles Igły	0.6 ... 2.7 1.6 ... 2.3	author Howard 1973
Wood Drewno		
normal prawidłowe		
mature dojrzałe	0.1 ... 0.3	Kollann, Côté 1958
juvenile młodociane	0.4 ... 2.5	Cockrell 1943, Gaby 1971
compression*) naciskowe	0.8 ... 2.8	Timell 1986
Bark Kora		
inner (phloem) wewnętrzna (łyko)	2.6 ... 5.6	author
outer zewnętrzna	0.7 ... 3.1	author, Raczkowski 1979
Cones Szyszki		
sclerenchymatic fibers włókna sklerenchymatyczne	10 ... 36	Harlow et al. 1964 Allen, Wardrop 1964

*) Extreme values 4.1 ... 8.6% (Włoch 1975, Timell 1986)

it is known, related to the increase in microfibril angle Θ in S_2 layer of secondery cell wall. This angle increases to 45 and more degrees in juvenile and compression wood. Since hygroscopic changes in the size of cell wall occur at right angle to microfibril axis, then a component of shrinkage or swelling along cell axis (along fibers) increases with the increase of

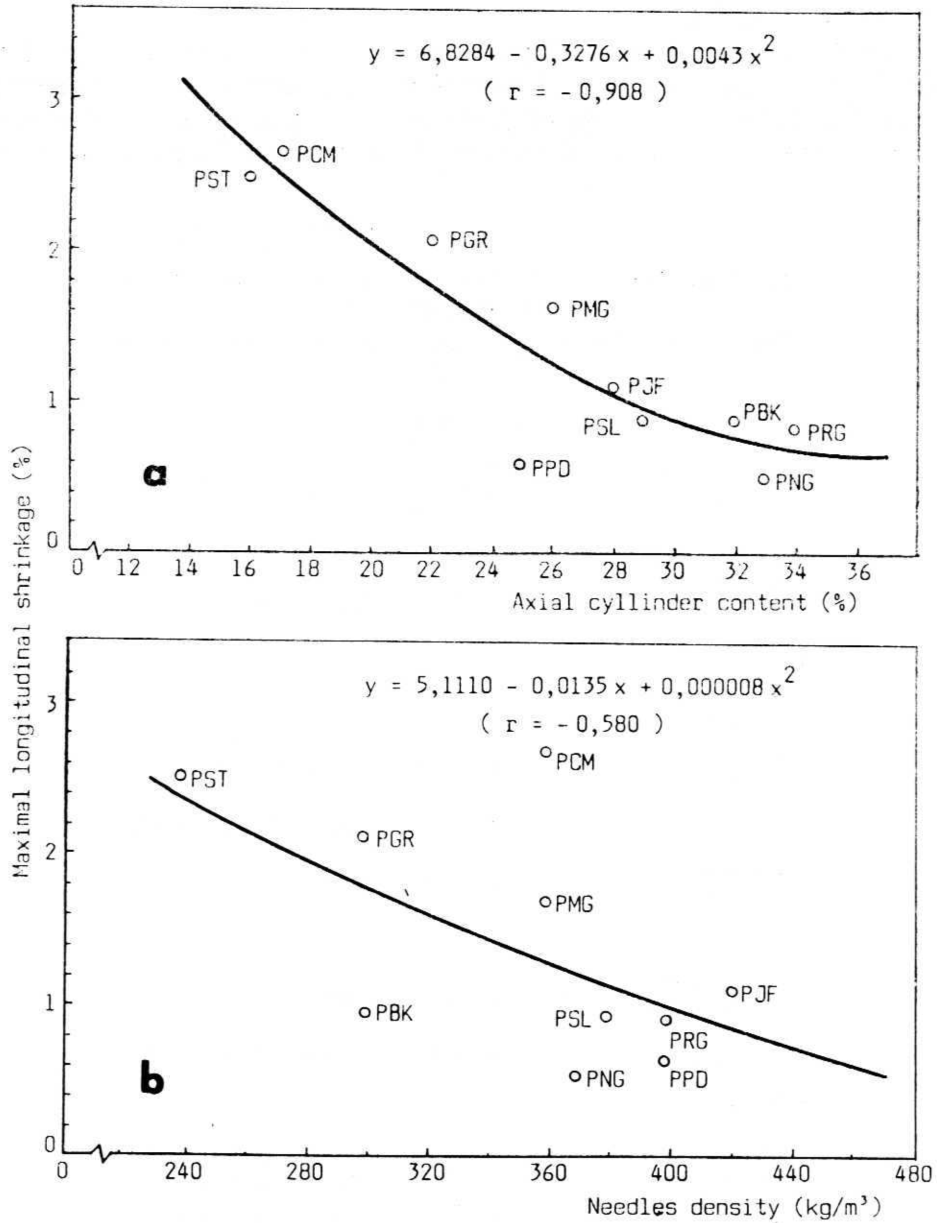

Fig. 1. Relationship between maximum longitudinal shrinkage of various pine needles and percentage of axial cyllinder (a) and needles density (b)

Rys. 1. Zależność maksymalnego stopnia podłużnego kurczenia się igieł różnych sosen od udziału walca osiowego (a) i gęstości igieł (b)

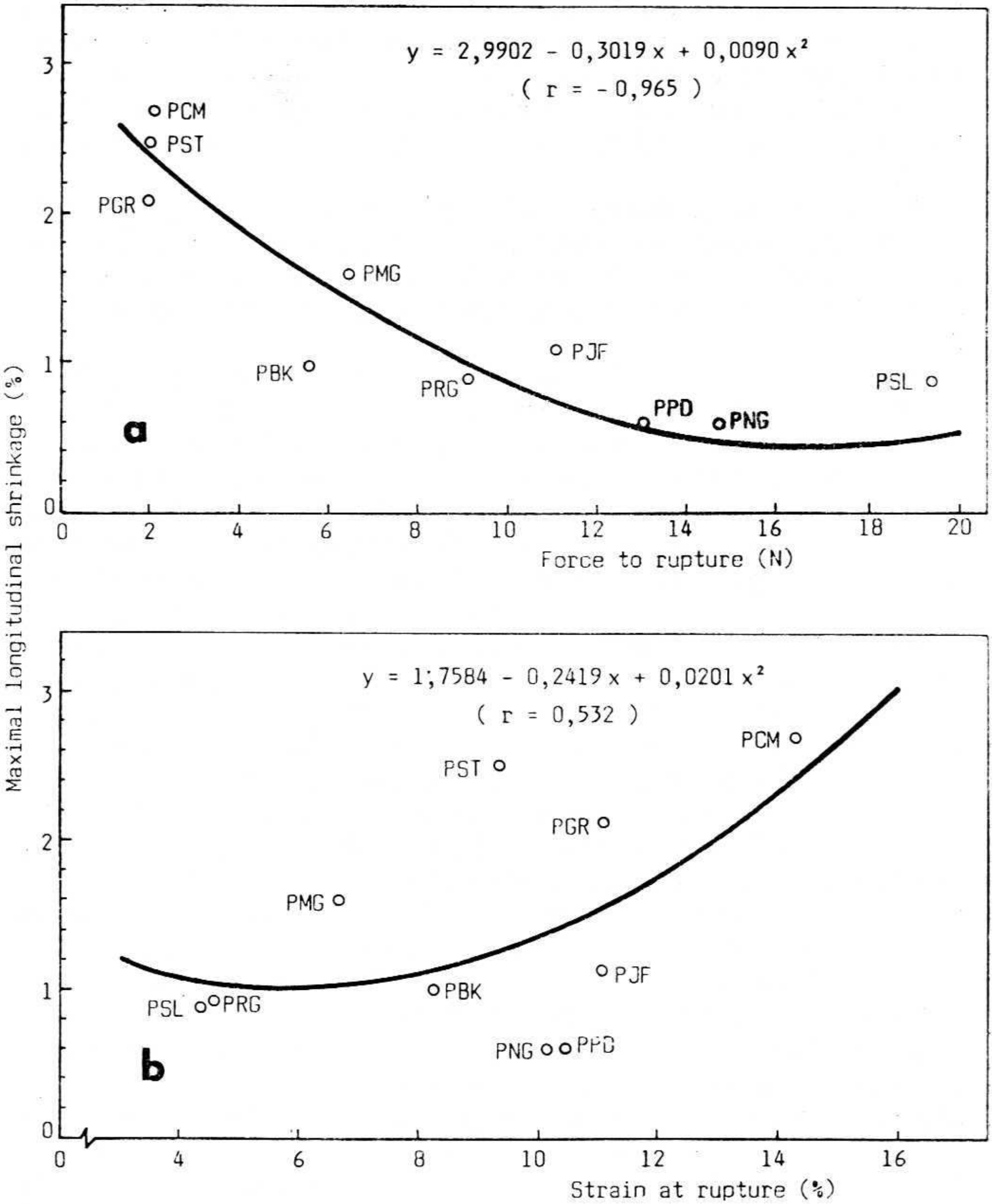

Fig. 2. Relationship between maximum longitudinal shrinkage of various pine needles and force needed to rupture green needles (a) and magnitude of deformation at rupture (b)

Rys. 2. Zależność maksymalnego stopnia podłużnego kurczenia się igieł różnych sosen od wielkości siły potrzebnej do zerwania igieł w stanie świeżym (a) i wielkości odkształcenia w chwili zerwania (b) the microfibril angle Θ [17, 18]. It is worth noticing that from among different elements of pine trees, the greatest longitudinal shrinkage is reported for sclerenchymatic fibers in cones whose degree of shrinkage amounts to 36%(!). This is related to the mechanism of cone opening and almost transversal system of microfibrils in cell wall of sclerenchymatic fibers [1, 5].

In the process of desorptive shrinkage of needles along their main axes fibrous elements play significant role i.e. first of all, phloem-xylem vascular bundles, transfusion tracheids and endodermal cells as well as sclerenchymatic hypodermal cells, fibrous sheat of resin canals and epidermal cells [7, 8].

Earlier studies proved that the participation of axial cyllinder amounts to, depending on pine needle species, from 16 to 34% of the whole cross-section area of a needle [6]. These is a clear negative correlation (Fig. 1a) between the percentage of axial cyllinder and the maximum shrinkage of various pine needle species. As results from the obtained data, the shrinkage of pine needles is about 80% ($R^2=0.80$) determined by the presence of axial cyllinder. Since the area of phloem--xylem bundles is proportional to the whole area of the axial cyllinder, it is possible to suggest that the desorption shrinkage of needles depends mainly on the contribution of phloem-xylem bundles. With the increase in percentage of axial cyllinder from about 16% (*P. strobus* and *P. cembra*) to 34% (*P. silvestris* and *P. nigra*), the maximum shrinkage lowers from about 2.7% to about 0.6%. A negative correlation, though less pronounced, exists also between the shrinkage of needles and their density (Fig. 1b). A positive correlation was found earlier between the percentage of axial cyllinder and tensile strength of needles [6]. Therefore, it is not surprising that with an increase in force required to rupture green needles, their longitudinal desorption shrinkage lowers (Fig. 2a). The correlation between desorptive shrinkage and the force needed to rupture needles is very high since the correlation coefficient is $r=-0.965$.

Longitudinal shrinkage of needles of various pine species is proportional to the magnitude of strain obtained by the needles at the moment of rupture on longitudinal tension in green state (Fig. 2b). In other words, with an increase in needle susceptibility to elongation due to mechanical force, their desorption shrinkage rises. This may be caused by changes in orientation in ultrastructure of cell walls of fibrous elements of phloem--xylem bundles. From studies on desorptive shrinkage of wood along the grain, it is known that with an increase in microfibril angle in the layer S_2 of cell walls, the shrinkage rises and rigidity lowers, i.e. susceptibility to mechanical deformation increases [12, 17]. Within a give wood species with increase of wood density the microfibril angle generally lowers and thus the degree of longitudinal wood shrinkage decreases [18]. However, the finding that the needle shrinkage is inversely proportional to the degree of orientation of ultrastructural elements in cell wall of phloem-xylem bundles, can be only hypothetical in character. To the author's knowledge, there are not enough data about the ultrastructure of xylem and phloem cell walls in the axial cyllinder in needles. The data on orientation of ultrastructure of cell walls of secondary phloem in coniferous and deciduous species [11, 13 - 15] can give some justification of this hypothesis, but they do not confirm it directly since the structure of secondary phloem of stem and phloem in phloem-xylem bundles of needles can significantly differ. Hence, fuller recognition of the causes of the observed relations is not possible without understanding of the ultrastructure of cell walls in fibrous elements of various pine needle species.

CONCLUSIONS

In the study on longitudinal desorption shrinkage of needle samples from 10 various pine species, it was found that the maximum shrinkage is within the interval from 0.6% to 2.7%. The needles of 5-needle pines have significantly greater shrinkage (2.1 ... 2.7%) than the 3- and 2-needle ones (0.6 ... 1.6%). According to the longitudinal shrinkage pine needles can be divided into three classes: I class — with low shrinkage not exceeding 1%, II class — with medium shrinkage from 1 to 2%, and III class — with high shrinkage over 2%. The magnitude of shrinkage of needles is comparable to this for juvenile wood and phloem. There is a clear negative correlation between the percentage of axial cyllinder in needle cross-section and their maximum longitudinal shrinkage. With an increase in axial cyllinder percentage from 16% to 34%, the needle shrinkage decreases from 2.7% to 0.6%. A similar, though less pronounced correlation exists also between the shrinkage of needles and their density. Longitudinal shrinkage of needles decreases with the rise in mechanical force needed to rupture them in green state, and inversely, the shrinkage rises with the increase in mechanical deformation on rupturing. These findings yield a suggestion that the desorption shrinkage of needles is inversely proportional to the degree of orientation of ultrastructural elements of cell walls of phloem-xylem bundles in axial cyllinder of needles.

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DŁUGOŚCIOWE DESORPCYJNE KURCZENIE SIĘ IGIEŁ RÓŻNYCH GATUNKÓW SOSEN

Streszczenie

Badano długościowy skurcz desorpcyjny igieł dziesięciu różnych gatunków sosen. Badania wykazały znaczne zróżnicowanie podłużnego skurczu desorpcyjnego igieł, mieszczącego się w przedziale od 0,6 do 2,7%, przy czym igły sosen 5-igłowych

wykazują wyraźnie większy skurcz desorpcyjny aniżeli igły sosen 3- i 2-igłowych. Wielkość skurczu desorpcyjnego igieł jest porównywalna z wielkością podłużnego skurczu desorpcyjnego drewna młodocianego i łyka, natomiast jest większa w porównaniu z drewnem dojrzałym.

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