

Compression strength parallel to grain of Scots pine (*Pinus sylvestris* L.) wood – relationships between values calculated at different heights of the trunk

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Abstract: *Compression strength parallel to grain in wood of Scots pine (*Pinus sylvestris* L.) – relationships between values calculated at different heights of the trunk.* The aim of the study was to analyse relationships between compression strength parallel to grain determined at different heights of the trunk, particularly between breast height stem cross-section and sections located higher. Analyses were conducted in northern Poland in the Regional Directorate of the State Forests in Szczecinek on material coming from 63 mean sample trees. A total of 315 samples were collected, five from each mean sample tree. Samples were located at different heights, the first at breast height ($d_{1.3}$), followed by 20 (SII), 40 (SIII), 60 (SIII) and 80% (SV) tree height. Each level (section) was represented by two opposite radiuses – eastern and western. Strength testing was performed at a moisture content over 30% (above fibre saturation point). Average compression strength parallel to grain in Scots pine wood was 22,62 MPa. When analysing axial variability the greatest CS value was recorded at breast height [25,77 MPa], while it was lowest in wood coming from the apical section of the trunk [19,82 MPa]. Despite observed differences the relationships between individual parts of the stem were linear in character and they were confirmed by high linear correlation coefficients r . Generally strong relationships, indicated by a high linear correlation coefficient, were found between adjacent measurement levels. It is possible to model compression strength parallel to grain based on values recorded at breast height. In order to obtain a possibly accurate result in the case of sections distant from the model level ($d_{1.3}$) prediction may be based on a potentially numerous set of additional independent variables.

Keywords: heterogeneity of wood, axial variation

INTRODUCTION

Functionality of the wood tissue is based on the assumption of an equilibrium between mechanical and physiological functions [Mencuccini et al. 1997]. In many ways it is an optimal structure and one developed at the lowest possible energy expenditure, obtaining its heterogeneity through histogenesis. Resultant wood properties are thus a consequence of this complicated process. This is because changes in wood structure are accompanied by changes in wood properties. As a result the tree trunk is a highly complex biostructure.

Among other things, early and late wood as well as juvenile and mature wood differ in properties [Moliński, Krauss 2008; Tomczak, Jelonek 2012]. Apart from radial differentiation axial variability is also observed. For example, physical and mechanical properties of juvenile wood in Scots pine are completely different in the butt end and in the apical section of the stem [Tomczak 2008]. For this reason obtaining information on average technical parameters of the wood tissue may require time-consuming analyses. In view of the above, attempts have been made to model one trait on the basis of other, most frequently readily measurable morphological traits of trees. As it was shown by Jelonek [2013], compression strength parallel to grain ($W>30\%$) is correlated with breast height of the tree, slenderness ratio or relative crown length. However, more often morphological traits of trees are also used to determine within the stem the proportions of wood zones with different properties (juvenile and mature wood) or different functions (sapwood and heartwood) [Tomczak et al. 2005; Tomczak et al. 2006; Jelonek et al. 2008a; Jelonek et al. 2008b].

Modeling of wood properties may also be based on other properties or on the same one collected from a location which is representative for the entire trunk [Mazet, Nepvau 199]. Pazdrowski [1992] compared compression strength parallel to grain in Scots pine wood

in 5-meter logs. That author stated that there are strong correlations between individual measurement levels, making it possible to model average strength of the entire log based on local strength – from one location at a section of 3.5 m to 4.5 m, measuring from the log base. However, in practice breast height (130 cm from the stem base) is typically considered to be a representative cross-section. Thus the aim of the study was to investigate relationships between compression strength parallel to grain determined at different stem heights, particularly between breast height section and sections located in other parts of the stem.

MATERIAL AND METHODS

Investigations were conducted in northern Poland, the Regional Directorate of the State Forests in Szczecinek, in the forest districts of Czaplinek, Czarnobór, Łupawa, Miastko (2 experimental sites), Świdwin and Warcino. In stands growing in the fresh mixed coniferous forest site with a broken crown closure and quality class I, aged 82 – 89 years, breast height was 24 – 27 cm and height ranged from 31 to 37 m. Material for tests on compression strength parallel to grain came from 63 sample trees selected on the basis of diameter and height characteristics. A total of 315 samples were collected, five from each sample tree. Samples were located at different heights, the first one at breast height ($d_{1,3}$), followed by 20 (SII), 40 (SIII), 60 (SIII) and 80% (SV) tree height.

At each level (section) analyses were conducted on two opposite radiuses – eastern and western. Samples of a standardized cross-section (20 x 20 mm) were adjacent, parallel to radiuses, with the first one at a distance of at least 1 cm from the pith. Such a procedure eliminated the effect of cambial age on wood properties and thus makes it possible to collect information on the average value for the entire cross stem section. In order to obtain results close to wood properties found in stems of growing trees, analyses were performed at moisture content over 30% (above the fibre saturation point). Boundary membrane moisture content was obtained by immersion of samples in water until dimensional stability has been ensured, i.e. until the time when increments in individual dimensions of the sample measured at a 72-hour interval are max. 0.2 mm (PN/D-04101:1977). Testing of compression strength parallel to grain was performed in accordance with the standard PN/D-04102:1979. Statistical calculations were conducted using the Statistica application. Investigated traits did not have a normal distribution and for this reason nonparametric tests were used in the analyses.

RESULTS

Compression strength parallel to grain decreases with the distance from stem base. Differences between individual sections fall within the range of several MPa and are statistically significant ($p < 0,01$), with the greatest found between sections II and III (2,41 MPa), while the lowest between sections IV and V (0,72 MPa). Median values are very close to arithmetic means. Thus the result was not distorted by the effect of samples with extremely high or low strength. Average compression strength parallel to grain for the whole trunk was 22,62 MPa (tab. 1).

Compression strength of wood parallel to grain from four sections located above breast height showed a correlation with wood strength at the level of $d_{1,3}$. The highest Pearson's linear correlation coefficient characterised the relationship between sections I ($d_{1,3}$) and II. A slightly lower coefficient (within the range of 0,52 – 0,58) was found for the relationships between sections I – III, I – IV and I – V (tab. 2). The highest correlation coefficients were recorded between sections located closest to one another, except for the correlation between sections IV and V.

Tab. 1. Statistical characteristic of compression strength parallel to grain of pine wood in sections

section	average [MPa]	n	standard deviation	min	max	Q25	mediana	Q75
SI (d _{1,3})	25,77	553	4,53	10,28	40,25	23,11	25,53	28,76
SII	24,67	487	4,53	10,96	37,31	21,43	24,65	28,00
SIII	22,27	404	3,86	8,95	36,57	19,67	22,14	24,62
SIV	20,55	316	3,48	13,72	32,37	17,94	20,13	22,56
SV	19,82	179	3,51	13,35	31,91	17,22	19,68	21,75

Tab. 2 Linear correlation coefficients (r) between wood compression strength parallel to grain determined at different stem heights in Scots pine

section	SI	SII	SIII	SIV	SV
SI (d _{1,3})	---				
SII	0,756240	---			
SIII	0,582949	0,624952	---		
SIV	0,526402	0,579205	0,693644	---	
SV	0,552876	0,451014	0,359544	0,407947	---

Marked effects are significant with $p < 0,01$

The coefficient of determination R^2 decreased with an increase in the distance from a section from breast height, successively from 0,543 (d_{1,3} – SII), through 0,333 (d_{1,3} – SIII) and 0,25 (d_{1,3} – SIV) to 0,148 (d_{1,3} – SV). Trend lines being a graphic interpretation of changes in one trait in relation to another and characterising relationships between individual sections are almost parallel. A greater compression strength of wood at breast height will thus mean a greater strength in other parts of the stem (Fig. 1).

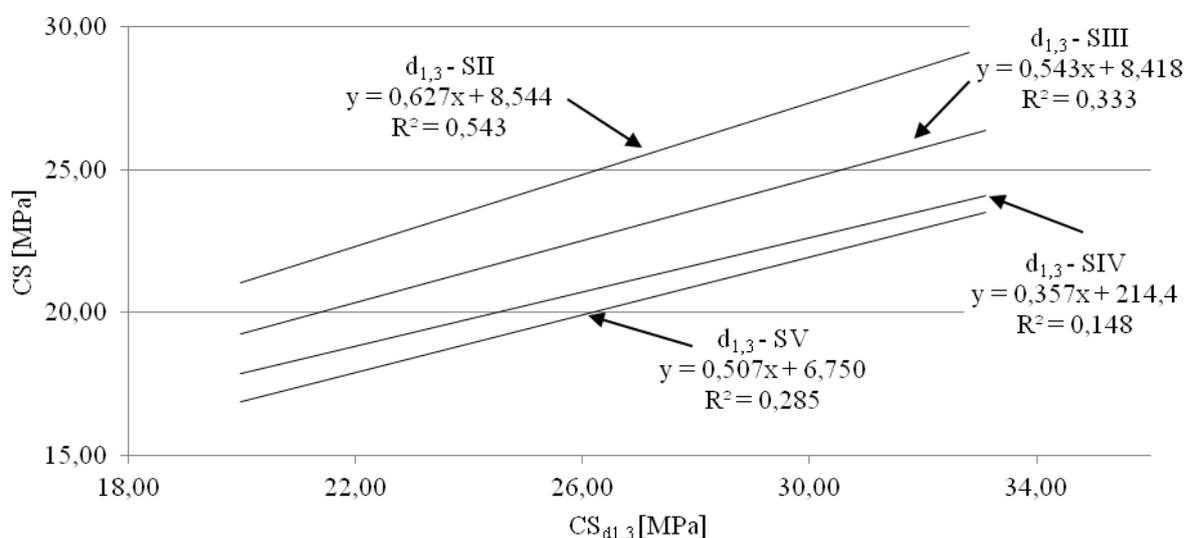


Fig. 1 Relationships between wood strength parallel to grain at breast height and compression strength parallel to grain determined at different stem heights

DISCUSSION

Average strength of Scots pine wood tested parallel to grain was 22,62 MPa. It is a value close to the ones reported e.g. by Raczkowski et al. [1995], Pazdrowski [1992] and Jelonek et al. [2005]. When analysing axial variation the greatest CS value was found at breast height [25,77 MPa], while it was lowest in wood coming from the apical part of the stem [19,82 MPa]. A reduction of strength between individual sections initially was slight (1,09 MPa between sections I and II). More dynamic changes were observed in the central

part of the stem, i.e. 2,41 MPa between sections II and III, and 1,72 MPa between sections III and IV. The described variation reflects, among other things, variation in cambial age and it results from the increasing share of juvenile wood at successive parts of the stem, increasingly more distant from the stem base. The analysed property presents a similar regularity of changes to that for basic density, which may confirm an assumption that these properties are inter-dependent to a certain degree. Wood density also decreases in the direction from the base to the tree top [Tomczak et al. 2013; Witkowska, Lachowicz 2013]. For Scots pine the longitudinal distribution of values for these properties will thus be characteristic.

Despite recorded differences relationships between individual parts of the trunk were linear in character and it was confirmed by high linear correlation coefficients. The strongest relationship was observed between breast height and section II, slightly weaker (0,52 – 0,58) between breast height and sections located higher. Generally strong relationships, characterised by a high linear correlation coefficient, were observed between adjacent measurement levels. An exception in this respect was found for the relationship between sections IV and V. The coefficient of determination was another analysed measure for the goodness of fit for the model. Its value was relatively high at the characteristics of the lower section of the stem and low in relation to the apical part. Thus, compression strength of wood parallel to grain in higher fragments may also be connected with other traits. According to Jelonek [2013], it was with breast height of a tree, slenderness ratio or relative crown length.

Generally it is possible to model compression strength parallel to grain based on values recorded for the breast height level. In order to obtain a possibly accurate result, in the case of sections greatly distant from the model level ($d_{1,3}$) prediction needs to be based on a possibly numerous set of additional independent variables.

CONCLUSIONS

1. Linear dependencies, confirmed by high linear correlation coefficients, were found between wood compression strength parallel to grain at breast height and strength determined at other stem heights.
2. Breast height is a representative cross stem section. Wood compression strength parallel to grain determined at this level may be used to model strength in other parts of the stem.

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Streszczenie: *Wytrzymałość na ściskanie wzdłuż włókien drewna sosny zwyczajnej (Pinus sylvestris L.) – związki pomiędzy wartościami określonymi na różnych wysokościach pnia.* Celem pracy było zbadanie związków jakie występują między wytrzymałością drewna na ściskanie wzdłuż włókien określoną na różnych wysokościach pnia, a w szczególności między przekrojem pierśnicowym a przekrojami położonymi wyżej. Badania przeprowadzono na terenie północnej Polski – RDLP Szczecinek, na materiale pochodzącym z 63 drzew modelowych. Łącznie pobrano 315 prób, po pięć z każdego drzewa modelowego. Próby położone były na różnych wysokościach. Pierwsza na poziomie pierśnicy ($d_{1,3}$), kolejne na 20 (SII), 40 (SIII), 60 (SIII), 80% (SV) wysokości drzewa. Każdy poziom (sekcję) reprezentowały dwa przeciwległe promienie – wschodni i zachodni. Badanie wytrzymałości wykonane zostało przy wilgotności wyższej niż 30% (powyżej punktu nasycenia włókien). Przeciętna wytrzymałość drewna sosny zwyczajnej na ściskanie wzdłuż włókien wynosiła 22,62 MPa. Analizując zmienność osiową stwierdzono, że najwyższą wartością CS charakteryzował się poziom pierśnicy [25,77 MPa], najniższą drewno pochodzące z wierzchołkowej części pnia [19,82 MPa]. Pomimo stwierdzonych różnic związki pomiędzy poszczególnymi częściami pnia miały charakter prostoliniowy i potwierdzony wysokimi współczynnikami korelacji liniowej r . Generalnie silne związki, charakteryzowane wysokim współczynnikiem korelacji liniowej, występowały między sąsiednimi poziomami pomiarowymi. Modelowanie wytrzymałości na ściskanie wzdłuż włókien na podstawie wartości uzyskanych na poziomie pierśnicy jest możliwe. Aby uzyskać wynik możliwie dokładny, to w przypadku części bardzo oddalonych od poziomu modelowego ($d_{1,3}$) predykcję należy oprzeć na możliwie licznych zbiorze dodatkowych zmiennych niezależnych.

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