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SELECTED TECHNICAL PARAMETERS OF JUVENILE WOOD IN SCOTS PINE (*PINUS SYLVESTRIS* L.) – VARIATION BETWEEN SOCIAL CLASSES OF TREE POSITION IN THE DOMINANT STAND

Arkadiusz Tomczak
Poznań University of Life Sciences

Abstract. The study compared basic density, compressive strength along the grain, static bending strength and modulus of elasticity of juvenile wood in pines from different Kraft's classes. Analyses were conducted in 8 mature pine monocultures in north-western Poland. In each experimental site a total of 9 trees were selected, thus the analyses were conducted on 72 model trees (with 24 for each social class of tree position in the stand). The highest values of analysed technical parameters were recorded for wood of co-dominant trees, the lowest were found for predominant trees, while intermediate values were recorded for wood of dominant trees. All the reported differences were statistically significant. Similar dependencies were observed when comparing wood from different sections of stems, with the greatest disproportions, frequently statistically significant, found in their lower sections.

Key words: social classes of tree position in the stand, basic density, compressive strength along the grain, static bending strength, modulus of elasticity

INTRODUCTION

Forest is a complex structure, vertically diversified into more or less evident layers, distinguished based on their specific characteristics. Such a biological structure of the forest was described by Paczoski [1928], who referred it to the classification proposed by Kraft [1884], based on the so-called natural or biological classes. Thus trees in the stand may be divided into groups in terms of their position in the canopy. This differentiation in even-aged stands reflects competition and development potential of trees. Borowski [1972] stressed that the social class of tree position in the stand is a more significant factor influencing growth and development of trees that site quality. Borowski [1968] also reported that the share of trees belonging to the first three social classes of tree position in the stand is markedly greater than that of trees forming the second

Corresponding author – Adres do korespondencji: Dr inż. Arkadiusz Tomczak, Department of Forest Utilisation of Poznań University of Life Sciences, Wojska Polskiego 71 A, 60-625 Poznań, Poland, e-mail: arkadiusz.tomczak@up.poznan.pl

storey, with the difference becoming increasingly more pronounced with age. For example, in a 44-year old stand the share of the first three Kraft's classes in the total number of trees is approx. 76.7%, while in an older stand, aged 94 years, this share increased to 90.7%.

Each of the biological classes in the stand may be characterised in terms of the dimensions of the stem and crown. Trees with a better position are typically taller, thicker and with more developed crowns [Kaźmierczak 2009, Turski et al. 2012]. This results from the varied growth dynamics, which significantly affects the structure and properties of wood [Dziewanowski 1965, Jackowski 1972]. Generally wood of thinner and lower trees, which position in the stand is inferior in relation to the neighbouring trees, have wood of better quality [Helińska-Raczkowska et al. 1993, Pazdrowski and Spława-Neyman 1993, 2003, Tomczak and Pazdrowski 2004, Fabisiak 2005, Jakubowski et al. 2005, Jelonek et al. 2006, 2009, Tomczak et al. 2008]. Moreover, the shares of sapwood and heartwood or juvenile and mature wood are connected with the social class of tree position in the stand [Jelonek et al. 2006, 2008, 2010]. Relatively the greatest share of juvenile wood in the stem is found for Kraft's class II, i.e. dominant trees [Tomczak 2006]. Juvenile wood in the case of pine comprises from several to around a dozen annual ring located at the pith [Mutz et al. 2004, Fries and Ericsson 2009]. With progressing cambial age juvenile wood is surrounded by an increasingly wider ring of mature wood. These two types of wood are distinguished based on the structure and properties of wood, which may be observed at the stem cross-section. The basic differences include the share of cellulose and lignin, *MFA*, the length of anatomical elements, the width of annual rings and the share of late wood [Paul 1954, Zobel and Sprague 1998]. For these reasons juvenile and mature wood differ significantly in terms of wood density and strength [Pikk and Kask 2004, Tomczak et al. 2010, Gryc et al. 2011, Tomczak and Jelonek 2012]. As it was stated by Tomczak [2008], juvenile wood differentiates at the stem profile and the changes are similar to the axial variability of wood, being model in character for this species.

According to Szymański [1964], in untended sapling stands the most stabilised part of the stand includes two highest biological classes (I and II). Class III is the most numerous and the most variable, filling the space between trees of the two higher classes. Classes of the secondary stand comprise trees eliminated in natural selection, which life processes gradually cease and from which dead standing wood will develop in the nearest future. The process of natural thinning in pine sapling stands is sinusoid in character, with the greatest intensity in the first period of several years, after closure of sampling stands, when mass die-back is observed for biologically weak trees incapable of living at overcrowding [Szymański 1964]. Assuming that tress with the best positions at a young age survive till maturity with no change in their social class of tree position in the stand, it may be inferred that properties of their juvenile wood will exhibit specific values and that significant differentiation in this respect will be found between Kraft's classes.

METHODS

Analyses were conducted in 8 mature pine monoculture stands in the north-western part of Poland, growing in a mixed fresh coniferous forest site of quality class I, with stand density from 0.7 to 1.1. The age of these stands ranged from 82 to 89 years, the average diameter breast high ranged from 31 to 37 cm, while height ranged from 24 to 27 m, respectively.

In each stand sample plots were established, in which characteristics of all growing trees, i.e. height [m] and diameter breast height, were measured in two opposite directions [cm]. Tree height was measured using a Nikon Forestry hypsometer rounding the results to 0.1 m. Diameter breast high [$d_{1.3}$] was measured twice outside bark with the use of calipers, rounding the results to 0.5 cm, and the result was averaged. Based on these characteristics model trees were identified using the Uricha I dendrometric analyses. For this reason in order to differentiate trees in terms of height, diameter and crown size while selecting model trees, the classification according to Kraft [1884] was applied, considering only the dominant stand. Trees selected for analyses had no evident anomalies in stem shape and had symmetrically developed crowns. A total of 9 trees were selected in each plot, thus analyses were conducted on 72 model trees (with 24 for each social class of tree position in the stand).

After felling stems of model trees were divided into sections. Means for sections were determined at a distance of 1.3 m from stem base and at points corresponding to 20, 40, 60 and 80% stem length. From these points material was collected, from which samples were prepared for analyses of selected wood properties. Samples comprised the section of the stem located between the pith and the circumference on two opposite rays oriented parallel to the eastern and western geographical directions. Further analyses were conducted only on two samples collected the closest to the pith. Such a procedure made it possible to conduct analyses on material coming solely from the juvenile section of the stem cross section.

Four selected wood properties were investigated, i.e. basic density (Q_u), compressive strength along the grain (C_S), static bending strength (B_S) and modulus of elasticity (*MOE*). Basic density [kg/m^3] was determined on samples of 20 × 20 × 30 mm from the ratio of its dry mass to volume at maximum swelling (W > 30%). Boundary moisture content of membranes was obtained by immersion of samples in water until dimensional stability was reached, i.e. until the increment of sample dimensions measured at 72-hour intervals did not exceed 0.2 mm. Sample mass was determined using a laboratory balance with the assumed accuracy of 0.001 g. A slide caliper was used to determine linear dimensions, rounding the results to 0.1 mm. Compressive strength along the grain [MPa] was determined on samples with standardised dimensions of 20 × 20 × 30 mm, while static bending strength [MPa] and modulus of elasticity [MPa] were determined on samples of 20 × 20 × 300 mm following procedures specified in respective standards. Mechanical properties were determined based on strength testing. In order to ensure results comparable to properties of wood found in stems of growing trees, analyses were performed at a moisture content over 30%, i.e. above fibre saturation point [Kokociński 2004].

Each of the wood properties and tree traits was characterised using basic measures of location and scatter. Analyses were conducted on a total of 1320 samples determining Q_u and C_S values, as well as 1278 samples determining B_S and *MOE* values. Each of these sets was divided into three subsets representing individual social classes of tree position in the stand varying in their population size, i.e. Q_uW and C_SW (n = 416), Q_uP and C_SP (n = 443), Q_uG and C_SG (n = 461). For B_S and *MOE* the numbers were as follows: W (n = 395), P (n = 434) and G (n = 448). Within Kraft's classes data were divided into individual stem zones, obtaining sets composed of several dozen data each, which were characterised statistically. Significance of differences was investigated using a non-parametric Mann-Whitney U-test. Calculations were performed using the Statistica statistical software package (Statsoft Inc.).

RESULTS

All analysed technical parameters of juvenile wood differed significantly ($p < 0.01$) between individual Kraft's classes. The greatest basic density (Q_u), compressive strength along the grain (C_S) and static bending strength (B_S) as well as the highest value of modulus of elasticity (*MOE*) were recorded for wood of co-dominant trees (*W*). Intermediate values were found for wood of dominant trees (*P*), while the lowest values were found for wood of predominant trees (*G*). Average Q_uW was thus 432 ±65 kg/m^3, Q_uP was 414 ±62 kg/m^3, while Q_uG was 401 ±62 kg/m^3, respectively. Differences between *W* and *P* and between *P* and *G* were determined to be 18 and 13 kg/m^3, respectively (Fig. 1 a). Mean C_SW was 23.92 ±4.55 MPa, C_SP was 22.30 ±4.41 MPa and C_SG

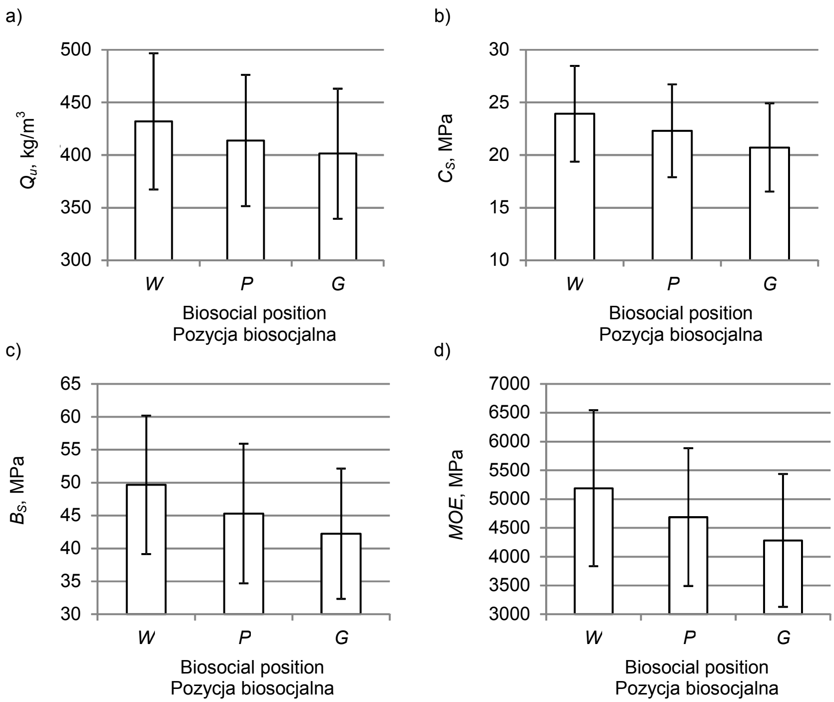

Fig. 1. Variation in properties of juvenile wood in terms of social classes of tree position in the stand: a) basic density, kg/m^3, b) compressive strength along the grain, MPa, c) static bending strength, MPa, d) modulus of elasticity, MPa; *W* – co-dominant trees, *P* – dominant trees, *G* – predominant trees

Rys. 1. Zróżnicowanie właściwości drewna młodocianego w klasach biosocjalnych drzew: a) gęstość umowna, kg/m^3, b) wytrzymałość na ściskanie wzdłuż włókien, MPa, c) wytrzymałość na zginanie statyczne, MPa, d) moduł elastyczności, MPa; *W* – drzewa współpanujące, *P* – drzewa panujące, *G* – drzewa górujące was 20.72 ±4.19 MPa. Between *W* and *P* the difference in wood strength was 1.62 MPa, while between *P* and *G* it was 1.58 MPa (Fig. 1 b). In the case of B_S the values for *W* were 49.66 ±10.54 MPa. In turn, B_SP was 45.30 ±10.61 MPa, while B_SG amounted to 42.25 ±9.90 MPa. With the transition to lower classes B_S decreased successively by 4.36 and 3.05 MPa (Fig. 1 c). Values of *MOE* for *W* trees were determined at 5188 ±1355 MPa. In turn, for dominant trees the value was 4688 ±1196 MPa, i.e. by 500 MPa lower than in *W*. Wood of predominant trees had a modulus of 4281 MPa, i.e. lower than values established for dominant trees by the next 407 MPa (Fig. 1d).

At the stem cross-section values of the analysed technical parameters decreased with an increase in the distance from stem base. Similarly as in the general approach, regardless of the location of the measurement point on the stem, the greatest density, strength and values of modulus of elasticity were recorded for wood of co-dominant trees (*W*). Average values were found in relation to dominant trees (*P*), while they were lowest for predominant trees (*G*). An exception in this respect was observed for the distribution of density in *P* trees. At the point corresponding to 60% height of trees Q_u was lower than values of Q_u recorded for *G* trees and almost identical to Q_uW at the point marking 80% tree height (Fig. 2 a). Exceptionally at the same level the value of B_SP was slightly lower than the value of B_S determined for wood of *G* trees (Fig. 3 a). Compressive strength

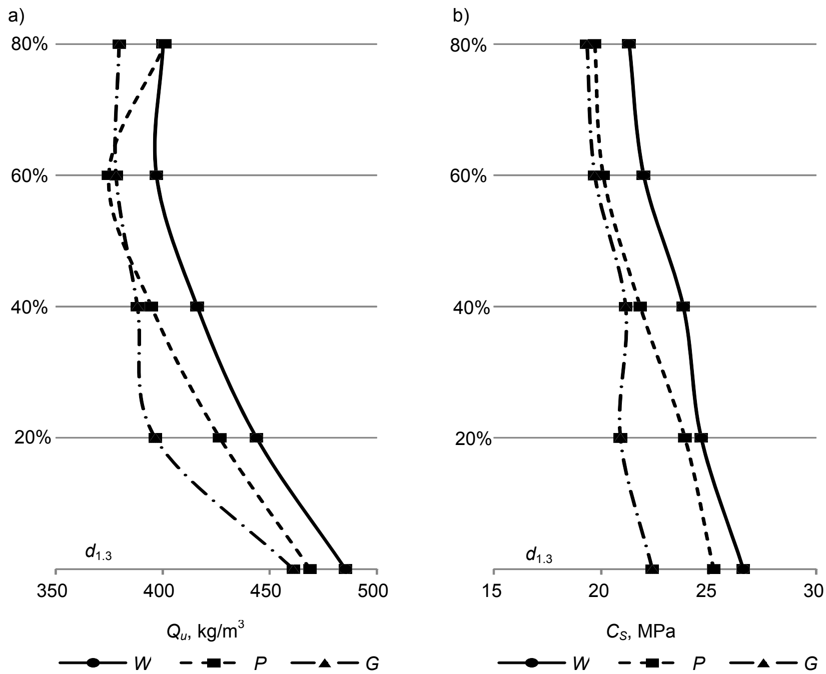

Fig. 2. Axial variation of juvenile wood in social classes of tree position in the stand: a) basic density, kg/m^3, b) compressive strength along the grain, MPa

Rys. 2. Osiowe zróżnicowanie drewna młodocianego w klasach biosocjalnych drzew: a) gęstość umowna, kg/m^3, b) wytrzymałość na ściskanie wzdłuż włókien, MPa

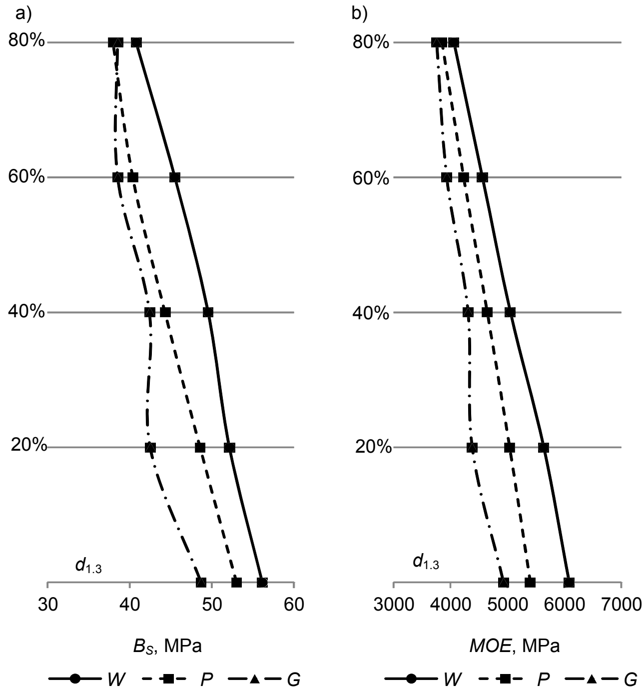

Fig. 3. Axial variation of juvenile wood in social classes of tree position in the stand: a) static bending strength, MPa, b) modulus of elasticity at bending, MPa

Rys. 3. Osiowe zróżnicowanie drewna młodocianego w klasach biosocjalnych drzew: a) wytrzymałość na zginanie statyczne, MPa, b) moduł elastyczności przy zginaniu, MPa

along the grain, static bending strength and the value of modulus of elasticity in co-dominant trees decreased relatively systematically, similarly as it was the case with dominant trees. In turn, in relation to dominant trees it may be observed that values of the above mentioned properties decrease between breast height and the point marking 20% tree height, while at the section (between 20 and 40%) practically no changes are observed. Above the point marking 40% tree height their values again begin to decrease (Figs 2 b, 3 a, b).

Statistically significant differences in basic density of wood were found only at the level of 20% tree height between co-dominant trees (*W*) and predominant trees (*G*) ($p < 0.01$) and dominant trees (*P*) and predominant trees (*G*) ($p < 0.05$). Significant differences in compressive strength along the grain (C_S) were found at breast height and at the point corresponding to 20% tree height. In this case wood of *W* and *G* trees and that of *P* and *G* trees also differed ($p < 0.01$). Static bending strength differed at breast height between *W* and *G* classes ($p < 0.05$), similarly as at the levels of 20% ($p < 0.01$) and 60% tree height ($p < 0.05$). At 20% tree height a significant difference was also found between *P* and *G* trees ($p < 0.01$). In the case of *MOE* at breast height wood of trees from the *W* and *G* classes differed significantly ($p < 0.01$), while it differed higher up, at 20% tree height, between *W* and *G* trees ($p < 0.01$) and between *P* and *G* trees

($p < 0.05$). In upper parts of stems differences in values of analysed properties between social classes of tree position in the stand were not significant statistically.

CONCLUSION

The study compared basic density, compressive strength along the grain, static bending strength and modulus of elasticity in juvenile wood of pines from different Kraft's classes. The highest values of analysed technical parameters were found for wood of co-dominant trees, the lowest values were recorded for wood of predominant trees, while intermediate values were found for wood of dominant trees. All the observed differences were significant statistically. Similar results in relation to density and compressive and bending strength were reported by Pazdrowski [2004] and Tomczak [2006]. Such a distribution of values in terms of individual social classes of tree position in the stand results from the varied dynamics of increment in diameter. Its derivative, i.e. diameter breast high, increases with an improvement of social class of tree position in the stand [Kaźmierczak 2009]. A similar dependence between diameter and social position of a tree may also be observed at other tree heights. In coniferous trees the share of late wood decreases with an increase in width of annual rings, which significantly affects density and strength of wood [Dutilleul et al. 1998]. Several conclusions concerning relationships between properties of early and late wood and social class of tree position in the stand result from studies conducted by Fabisiak [2005]. That author stated, among other things, that at the same share of late wood the worse the growth conditions for a tree, the greater the density of solid wood. This results from the fact that density of late wood in trees occupying inferior positions is greater than that of trees having better growth and development conditions. In this case early wood has no effect, since its density practically does not depend on social position of a tree. Thus density and strength of wood will not be determined solely by the share of late wood. Its structure and properties will also be significant factors.

Differences found between individual social classes of tree position in the stand do not refer only to average values, characterising the whole stem. Similar dependencies were observed when comparing wood from different parts of the stem, while the greatest disproportions, frequently significant statistically, were found in its lower part. Density and strength of wood from the apical part were very similar in all Kraft's classes. Axial variation of juvenile wood is very similar to the model of wood variation described by Repola [2006] and Witkowska and Lachowicz [2013]. Very regular, gradual changes may be observed in co-dominant and dominant trees. In the case of predominant trees density and strength of wood decrease markedly between breast height and the point corresponding to 20% tree height. In the next section (between 20 and 40% height) the differences are slight. Higher up density and strength begin to decrease again. This characteristic heterogeneity of wood is found in the tallest trees, with the greatest diameters and the most developed crowns. According to Zajączkowski [1991], these are the traits significantly correlated with resistance of trees to breakdown. The threat increases with an increase in height, with lesser stem diameter and with a greater crown mass in relation to stem mass. Ochał et al. [2013] nstated that with an improvement of social class of tree position in the stand the share of stem biomass decreases, while the share of branch biomass in the total aboveground biomass of the tree increases. Theoretically the place, in which a stem breaks most frequently, should be the cross-section located at its base. Zajączkowski [1991] reported after Meyer that most often the site of breakdown is located in the section from 0.25 to 0.38 tree height. The low variability of juvenile wood in predominant trees refers to this section and it is highly likely to be related with tree biomechanics. As it was stated by Jakubowski and Pazdrowski [2005], the breakdown point of the stem in pine is most frequently located at the site of dead knots or reaction wood. However, these observations were not confirmed on material coming from mature stands.

There are marked differences between wood properties in trees from different social classes of tree position in the stand. Values of technical parameters increase with the deterioration of tree position in the stand. This principle was confirmed in relation to juvenile wood. However, it needs to be stressed that the greatest variation was observed at breast height level, i.e. in the section in which juvenile wood developed at the very early age of the tree, in the period of highly dynamic changes in stand structure. Studies were conducted in productive stands subjected to systematic tending operations, in order to preempt the natural process of stand thinning and to eliminate specimens with no promising prospects for the future. The greatest chance of survival is thus found for trees with appropriate dimension and quality characteristics, including also a specific structure and properties of wood tissue.

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WYBRANE PARAMETRY TECHNICZNE DREWNA MŁODOCIANEGO SOSNY ZWYCZAJNEJ (*PINUS SYLVESTRIS* L.) – ZRÓŻNICOWANIE POMIĘDZY KLASAMI BIOSOCJALNYMI W DRZEWOSTANIE PANUJĄCYM

Streszczenie. W pracy porównano gęstość umowną, wytrzymałość na ściskanie wzdłuż włókien, wytrzymałość na zginanie statyczne oraz moduł elastyczności drewna młodocianego sosen z różnych klas Krafta. Badania przeprowadzono w ośmiu dojrzałych monokulturach sosnowych, w północno-zachodniej części Polski. Na każdej powierzchni wyselekcjonowano po dziewięć drzew, łącznie badaniem objęto 72 drzewa modelowe (po 24 dla każdej klasy biosocjalnej). Najwyższymi wartościami analizowanych parametrów technicznych charakteryzowało się drewno drzew współpanujących. Najniższymi drewno drzew górujących, dla drewna drzew panujących otrzymano wartości pośrednie. Wszystkie stwierdzone różnice były istotne statystycznie. Podobne zależności zaobserwowano, porównując drewno z różnych części pnia, przy czym największe dysproporcje, często istotne statystycznie, występowały w jego dolnej części.

Słowa kluczowe: struktura biosocjalna, gęstość umowna, wytrzymałość na ściskanie wzdłuż włókien, wytrzymałość na ściskanie statyczne, moduł elastyczności

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