WOOD RESEARCH
64 (5): 2019
789-798

IMPACT OF SILVICULTURAL MEASURES ON THE QUALITY OF SCOTS PINE WOOD PART II. EFFECT OF SITE

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(Received May 2019)

ABSTRACT

This study deals with the variability of wood density, compression strength and the impact bending strength within the trunk of Scots pine (*Pinus sylvestris* L.). The impact of the site on the examined properties was also evaluated. The tree samplers come from four different sites that are representative for Scots pine growth in the Czech Republic. From the samplers the sections representing a basal part of the trunk and a middle part of the tree were cut. The most significant influence of the site was confirmed for wood density; on the other hand, the influence of the site is ambiguous in terms of the examined strength characteristics. A decrease in the wood properties with increasing trunk height was proven for all tested properties. The highest impact of the position was observed for wood density, while the results of vertical variability in mechanical properties are not always significant (compression strength: basal 47.1 MPa and middle 45.8 MPa). A close correlation between mechanical properties and wood density was also proven.

KEYWORDS: Scots pine, wood, mechanical and physical properties, site, vertical variability.

INTRODUCTION

After the spruce, the Scots pine (*Pinus sylvestris* L.) represents our second most important economic coniferous tree species, and its importance will grow with anticipated climate changes (Bílek et al. 2018). The state forest policy is considering the idea of increasing the proportion of Scots pine in forest stands according to Report on the State of Forest and Forestry in the Czech Republic 2016.

However, there are very few studies on the quality of pine wood produced in the Czech Republic. Wood quality is in the focus of both forest managers and the woodworking industry. They must always be understood in the appropriate context, usually in terms of the properties that are important for the final processing and use of wood. Wood density is a physical property that is widely used to evaluate the resulting wood quality (Tsoumis 1991, Požgaj et al. 1997). The reason for using wood density as a quality indicator is that it largely influences other physical, and especially mechanical properties of wood (Kollmann 1951). It is generally supposed that the strength of the wood increases with increasing density (Hautamäki et al. 2014).

When evaluating the variability within a tree, it can be seen that a certain characteristic of wood follows a certain trend. The variability depends on the vertical position inside the trunk and the distance from the center of the trunk (Horáček et al. 2017, Zeidler and Šedivka 2015, Zobel and Van Buitenen, 1989). The vertical variability of wood properties in softwoods has been evaluated by many authors (Požgaj et al. 1997, Muñoz 2008, Repola 2006). Factors that contribute to the vertical variability mainly include the width of the annual rings, the structure of the wood and the different proportion of juvenile wood in the trunk (Zeidler and Šedivka 2015, Zobel and Van Buitenen 1989).

The site is another of the significant factors affecting wood quality. Zobel and van Buijtenen (1989) state that the site is one of the worst determinable factors relating to wood properties, as it is a measure of soil and climate quality, which is collectively referred to as the quality of the site. In some studies, the effect of temperature and wind is referred to as the site indicator (Worrell and Malcolm 1990). The differences in growth rates caused by climate change will lead to differences in wood quality due to the known relationship between growth rate and wood properties. In addition to the direct effects on tree growth, the soil moisture regime is one of the factors of tree stability. These factors interact with each other and have a significant impact on wood quality (Macdonald and Hubert 2002). In general, trees growing in places with high altitude usually produce less dense wood and have shorter tracheids than pine trees growing in low altitude areas. This trend has been confirmed by many studies (Zobel and van Buijtenen 1989, Kollman, 1951, Macdonald and Hubert 2002, Tsoumis 1991). Hautamäki et al. (2014) investigated the impact of a site on Scots pine trees from Finland and Russia, and he found a significant difference between these sites in wood density. The significant impact of site conditions on Scots pine wood density is also confirmed by Jelonek et al. (2005) or Tomczak and Jelonek (2013). Zobel and van Buijtenen (1989) state that the density of coniferous tree species has a growing tendency at poor and less fertile sites.

The aim of this paper is to assess the influence of a site and the effect of vertical position in the trunk on the physical and mechanical properties of Scots pine wood in the Czech Republic. Namely, we tested wood density, impact bending strength and compression strength along fibres. The influence of wood density on the studied strength characteristics was also evaluated. This paper follows the previous study dealing with effect of regeneration methods on wood quality of Scots pine wood.

MATERIAL AND METHODS

Materials

Samplers were collected in four different localities Natural Forest Areas (NFA), which are characteristic for the growth of Scots pine in the Czech Republic, namely NFA 18 - Severočeská pískovcová plošina a Český ráj (North Bohemian Sandstone Plateau and Bohemian Paradise), NFA 6 - Západočeská pahorkatina (West Bohemian Hills), NFA 17 - Polabí and NFA 15b - Jihočeská pánev (South Bohemian Basin), and part of Třeboňská pánev (Třeboň Basin) (Fig. 1). At each locality, two stands were selected that represent a different site (Tab. 1). All of the evaluated pine stands were regenerated using the clear-cutting method.

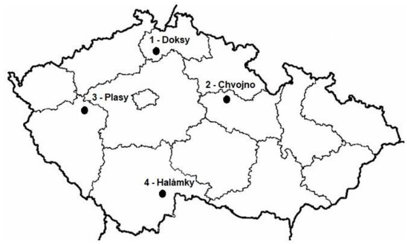


Fig. 1: Location of study areas in the Czech Republic.

Tab. 1: Stand and locality characteristics.

Locality	Stand	Tree height (m)	DBH (mm)	Forest site type*
1	1	18.1	187	*0K*
(Doksy)	2	21.6	204	*2K*
2	1	17.1	180	*4Q*
(Plasy)	2	23.7	238	*2K*
3	1	21.7	224	*2I*
(Chvojno)	2	17.4	213	*2K*
4	1	17.2	180	*0K*
(Halámky)	2	17.3	209	*3K*

DBH – diameter at the breast height

* set of forest types according to the Czech typological system (Viewegh et al. 2003).

A total of 7 samplers were felled at each stand. A total of 56 sample trees were taken for the preparation of test material. An important criterion for the selection of samplers was the representation of characteristic individuals for a given stand and the absence of growth irregularities and defects.

Methods

From each sampler, a 120 cm long section from the trunk base region was taken, followed by a section representing the central trunk section. This operation allowed for the monitoring of the vertical variability of the wood properties. The sections were removed from the forest stands for subsequent cutting on a band saw, and the obtained planks were stored and left to dry naturally until the moisture content drop under 20%. The central plank (Schönfelder et al. 2017) was used for the production of the test specimens. The test material was used for the production of test specimens for physical and mechanical tests. The test specimens for the physical tests were 20 x 20 x 30 mm (radial x tangential x axial). The wood density as a representative of physical properties was tested. Wood compression strength along fibres was determined on identical specimens as regards the wood density, and the impact strength specimens had dimensions of 20 x 20 x 300 mm (radial x tangential x axial). The test specimens were air conditioned to equilibrium moisture content of about 12% in an air conditioning chamber, in conditions with an air temperature of 20°C (± 2°C) and a relative air moisture content of 65% (± 5°C). With their quality, all of the samples met standard ČSN 49 0101 (1980, Wood. General requirements for physical and mechanical testing) and did not have irregularities, growth defects or compression wood.

Standard ČSN 49 0108 (1993, Wood. Determination of the density) was used to evaluate the wood density. We used in total 2435 test samples for the wood density evaluation. The density (ρ) was determined according to the following formula:

$$\rho = \frac{m}{V} \quad (g.cm^{-3}) \tag{1}$$

where: m - the weight of the specimen (g),
V - the volume of the specimen (cm^3).

Compression strength was determined by means of universal testing machine Tira 2850 (Tira GmbH, Schalkau, Germany). Compression strength (σ) was evaluated on 2435 specimens. The test was determined in accordance with standard ČSN 49 0110 (1980, Wood. Compression strength limits parallel to the grain).

$$\sigma = \frac{F}{a \cdot b} \quad (MPa) \tag{2}$$

where: F - the maximum load force (N),
a and b are the cross-sectional dimensions of the specimen (mm).

Another investigated characteristic was impact bending strength. Charpy's hammer (CULS, Prague, Czech Republic) was used for this determination. The hammer impact direction was tangential. The number of test samples used for impact bending strength was 1117. Impact bending strength (A) was determined in accordance with standard ČSN 49 0117 (1980, Wood. Impact strength in flexure).

$$A = \frac{Q}{a \cdot b} \quad (J \cdot cm^{-2}) \tag{3}$$

where: Q - the consumed power to break the specimen (J),
a and b - the cross-sectional dimensions of the specimen (cm).

Multi-factor ANOVA tests (Fisher's F-test) and Duncan's multiple comparison tests were used to evaluate the statistical significance of each factor. The significance level of α = 0.05 was used for all statistical analyses. We used the locality as a factor influencing the physical and mechanical properties. The impact of the vertical position in trunk was also evaluated. A linear regression model was used to assess the effect of density on strength characteristics. Statistical analyses were performed using program STATISTICA 14 (Statsoft Inc., USA).

RESULTS AND DISCUSSION

One of the most important parameters influencing the resulting wood quality is the site (Zobel and van Buijtenen 1989). The impact of the locality was observed in both the basal part of the trunk and at middle of the trunk height (Figs. 2 and 3 and Tabs. 2 and 3). The impact of the stand on the wood density in the basal part of the trunk was significantly reflected at all of the localities ($P < 0.05$). In the central part of the trunk, the impact of the stand was not manifested only at locality 3 ($P > 0.05$). The influence of the stand on the compression strength in the basal part of the trunk was not manifested only at locality 1 ($P > 0.05$). The remaining localities show a statistically significant difference (P <0.05). On the other hand, in terms of impact bending strength, the impact of the stand was confirmed only at locality 4. In the middle part of the trunk, due to the stand, a statistically significant difference was found in compression strength only at locality 3 and for impact bending strength at locality 2 and locality 4 (P <0.05). The other localities do not show statistically significant differences. The results show that impact bending strength is not as influenced by site conditions as compression strength. Different values of pine wood density at different localities were achieved by Jelonek et al. (2005), Hautamäki et al. (2014) and Tomczak and Jelonek (2013). In contrast, Zeidler et al. (2017) found no influence on impact bending strength for the Norway spruce.

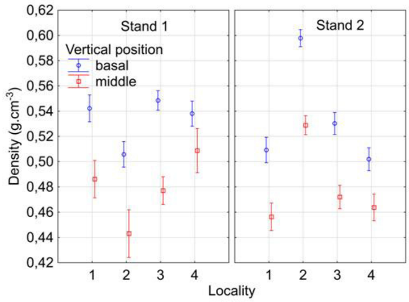


Fig. 2: Impact of locality and vertical position in the trunk on wood density.

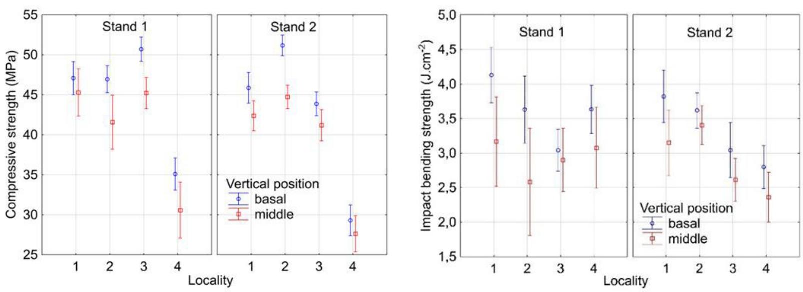
The design of the experiment also enabled comparison of the quality of wood from stands of same set of forest types. This comparison of the quality of wood was monitored always at Stand 2 and yields relatively inconsistent results. Thus, it can be stated that stands growing on the same set of forest types do not produce wood with the same properties. This means that there must be another factor, probably the intensity of silvicultural measures, which can overshadow the effect of the site.

Tab. 2: Descriptive statistics (mean ± standard deviation) – impact of locality and vertical position in the trunk on wood density.

	Basal section		Middle section	
	Density ($g \cdot cm^{-3}$)		Density ($g \cdot cm^{-3}$)	
Locality	Stand 1	Stand 2	Stand 1	Stand 2
1	0.542±0.052	0.509±0.083	0.486±0.044	0.456±0.061
2	0.506±0.067	0.598±0.060	0.443±0.032	0.528±0.043
3	0.548±0.071	0.530±0.073	0.477±0.056	0.472±0.054
4	0.538±0.082	0.501±0.076	0.508±0.041	0.463±0.075

In terms of processing and final use of wood, it is necessary to be aware of the distribution of wood properties in the trunk in the vertical direction, i.e. from the basal part of the trunk to its top. Fig. 2 and 3 and Tab. 2 and 3 show that with increasing trunk height the strength characteristics of the wood decrease. The wood with the highest guality (from a view of the tested properties) is thus found in the basal part of the trunk. Wood density shows a clear trend of decreasing values with increasing trunk height at all sites. Compression strength at stand 1 does not show any significant difference only at locality 1; at stand 2, there was no proven impact of the vertical position on strength at locality 3 and locality 4. Impact bending strength at stand

1 did not demonstrate a difference in strength at locality 3 and locality 4; stand 2 does not show significant impact of trunk position at any of the investigated localities. A decrease in wood quality with increasing trunk height has been observed by many authors (Ivković et al. 2013, Repola 2006). The reduction in wood properties values is associated primarily with the increasing width of annual rings, and the different proportion of juvenile wood in the trunk compared to the basal part of the trunk (Zeidler and Šedivka 2015). Fischer et al. (2016) found out that for the Norway spruce, the wood density increases with trunk height at rich sites, but the effect is the opposite at poor sites. Repola (2006) found a slight decrease in wood density up to half of the trunk, followed by an increase in the upper half.



(a) *(b)*

Fig. 3: Impact of locality and vertical position in the trunk on compression strength (a) and impact bending strength (b).

Tab. 3: Descriptive statistics (mean ± standard deviation) – comparison of the locality on the mechanical properties.

	Basal section				Middle section			
	Compression strength (MPa)		Impact bending strength (J·cm^{-2})		Compression strength (MPa)		Impact bending strength (J·cm^{-2})	
Locality	Stand 1	Stand 2	Stand 1	Stand 2	Stand 1	Stand 2	Stand 1	Stand 2
1	47.1±9.8	45.8±13.0	4.1±1.6	3.8±2.1	45.3±4.7	42.4±8.4	3.2±1.0	3.1±1.3
2	47.0±8.7	51.2±11.4	3.6±1.5	3.6±1.7	41.6±4.1	44.7±7.7	2.6±0.8	3.4±1.1
3	50.7±9.8	43.9±10.9	3.0±1.7	3.0±1.7	45.2±8.3	41.2±7.9	2.9±1.7	2.6±1.9
4	35.1±8.3	29.3±7.3	3.6±1.7	2.8±1.5	30.6±6.4	27.6±5.2	3.1±1.6	2.4±1.1

The correlation between wood density and mechanical properties was confirmed, and it has been confirmed that with increasing wood density, the strength characteristics of wood also increase. In most cases, a higher dependence on wood density was found for compression strength (Tab. 4). Fig. 4 shows the model with the highest achieved correlation coefficient value (R=0.90) between wood density and compression strength. Based on the results achieved, we can say that wood density can be used as an indicator of wood strength characteristics.

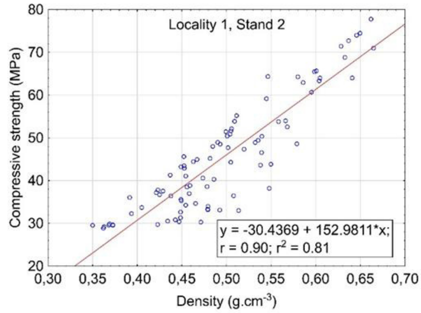


Fig. 4: Dependence of compression strength on density.

Tab. 4: Dependence of strength characteristics on wood density.

Site	Forest stand	Property	Equation	R
Locality 1	Stand 1	Compression strength	y = -8.4779 + 100.8647*x	0.48
		Impact bending strength	y = -10.0338 + 25.0891*x	0.70
	Stand 2	Compression strength	y = -30.4369 + 152.911*x	0.90
		Impact bending strength	y = -6.4456 + 19.6342*x	0.85
Locality 2	Stand 1	Compression strength	y = -10.1386 + 116.6212*x	0.79
		Impact bending strength	y = -3.0463 + 12.3417*x	0.48
	Stand 2	Compression strength	y = -12.5763 + 107.3926*x	0.61
		Impact bending strength	y = -3.8574 + 11.9273*x	0.40
Locality 3	Stand 1	Compression strength	y = -0.505 + 92.8486*x	0.67
		Impact bending strength	y – 3.4923 + 11.855*x	0.53
	Stand 2	Compression strength	y = 0.005 + 82.4892*x	0.58
		Impact bending strength	y = -5.9275 + 16.0231*x	0.61
Locality 4	Stand1	Compression strength	y = 23.9452 + 20.5234*x	0.23
		Impact bending strength	y = -4.4271 + 15.1895*x	0.63
	Stand 2	Compression strength	y = 21.9925 + 12.444*x	0.48
		Impact bending strength	y = -2.4105 + 10.3334*x	0.41

Tab. 5 shows the average values of the properties of each site, regardless of the position in the trunk. The table shows that the ascertained wood density at some of the sites is comparable to literature, while the remaining density values are lower. The strength characteristics are lower than those stated by the authors. The lower values of the ascertained wood properties are due to the low age of the examined trees, which is lower than the felling age of the pine. At a young age, pines have a higher percentage of juvenile wood in the trunk, resulting in lower strength characteristics values (Zobel and van Buitenen 1989). However, it can be assumed that both strength characteristics and wood density will increase with increasing tree age.

Tab. 5: Comparison of Scots pine wood values to literature.

			Density ($g \cdot cm^{-3}$)	Compression strength (MPa)	Impact bending strength ($J \cdot cm^{-2}$)
This study	Locality 1	Stand 1	0.514	46.2	3.7
		Stand 2	0.483	44.1	3.5
	Locality 2	Stand 1	0.475	44.3	3.1
		Stand 2	0.563	48.0	3.5
	Locality 3	Stand 1	0.513	48.0	3.0
		Stand 2	0.501	42.6	2.8
	Locality 4	Stand 1	0.523	32.9	3.4
		Stand 2	0.482	28.5	2.6
Wagenführ (2002)			0.510	55.0	4.0
Novák (1970)			0.540	55.0	4.0
Požgaj et al. (1997)			-	49.9	4.6

CONCLUSIONS

The impact of the vertical position in the trunk, where a decreasing trend with increasing height was showed, was unequivocally confirmed for the wood density. Hence, the highest density wood was found in the basal part of the trunk. The impact of the vertical position of the wood in the trunk on strength characteristics is not as crucial.

The impact of the site conditions was significantly showed for the wood density, while on the other hand, the influence of the site is not that crucial for the investigated strength characteristics. Furthermore, it can be stated that stands growing on the same set of forest types do not produce wood with identical properties.

The linear dependence of strength characteristics on the wood density was proven. In most cases, higher correlation coefficients were found between the wood density and compression strength. Based on the wood density values, wood strength characteristics so can be predicted to great extent.

ACKNOWLEDGEMENT

The research was supported by the Ministry of Agriculture of the Czech Republic [project number QJ1520037 – „Increasing the adaptability of pine (*Pinus sylvestris* L.) silviculture in the conditions of the Czech Republic"] and by Internal Grant Agency of the Faculty of Forestry and Wood Sciences [A19/07].

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