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DENSITY AND MECHANICAL PROPERTIES OF SCOTS PINE (*PINUS SYLVESTRIS* L.) WOOD FROM A SEEDLING SEED ORCHARD

*Seedling seed orchard (SSO) growing conditions are different to those in the forest. Trees grow in wide spacing with more access to sunlight and competition between trees is less intense causing larger annual rings and limited height growth. The objective of this research was to: 1) determine the density and mechanical properties of Scots pine (*Pinus sylvestris* L.) wood grown in an SSO and 2) suggest the most suitable use of this wood. Five trees (25-year-old) were selected using the Urich II method. Final samples (from the height of dbh) were cut from pith to bark, in the four cardinal directions. From all five trees, 159 samples were used to determine: 1) the wood density, 2) the compressive strength parallel to the grain, 3) the modulus of rupture, and 4) the strength quality coefficient. For each property the following mean values were obtained: 327 kg m⁻³, 32 MPa, 59 MPa and 0.10, respectively. The density did not depend on the dbh or mean width of annual ring. At the same time, the mechanical properties depended strongly on the wood density. In all cases, the wood property values of the Scots pine from the SSO were lower in comparison with those published for Scots pine grown in regular stand conditions. Therefore, pine wood from SSOs should be used in the paper industry.*

Keywords: compressive strength, modulus of rupture, strength quality coefficient

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Introduction

Scots pine is a basic species in Polish forests, comprising 61.3% of the area and 63.9% of the volume in the State Forests [Biuro 2013]. Pine is widely used in the Polish wood sector and industry demand for this timber is very high. Therefore, pine wood from seedling seed orchards (SSOs) can be an alternative to wood from regular stands. In the forest, pine grows in relatively narrow spacing, which impacts on the dynamic height growth and natural tree pruning. In SSOs, spacing is very wide and at the early stage of growth, trees attain intensive trunk increment with slow height growth and limited pruning. These characteristics have been observed in regular stands where very intensive thinning resulted in a greater share of trees with large increments and low quality [Dziewanowski 1965, Jackowski 1972, Pazdrowski 1988]. However, it was also found that in a beech stand, a weak correlation (though significant) was observed between stand density and ring width [Bouriaud et al. 2004].

It is therefore recommended that a balance is kept between the individual growth of one tree and valuable wood properties [Cameron 2002]. Trees grown in wide spacing have a larger share of early wood and properties of lower values [Krzysik 1978]. A large share of early wood is typical for juvenile wood, which has different properties to mature wood [Pazdrowski et al. 1995, Person et al. 1995, Wróblewska and Splawa-Neyman 1995, Pazdrowski et al. 1997, Pazdrowski and Splawa-Neyman 1999].

In relation to the above-mentioned findings, it was hypothesised that pine wood from an SSO would be characterised by lower density and lower mechanical property values in comparison with the same features of pines from regular stands. Therefore, the objective of the research was to determine: 1) the wood density, 2) the compressive strength parallel to the grain, 3) the modulus of rupture, and 4) the strength quality coefficient of Scots pine wood from the SSO. In addition, the research aimed to make suggestions as to the most suitable use of this wood.

Materials and methods

The research material was collected from Scots pine trees grown in an SSO established in 1983 in the Forest of District Zdrojowa Góra (Regional Directorate of the State Forests in Piła). In compartment 95a, all the dbhs and heights were measured. Furthermore, 5 trees were selected using the Ulrich II method (dbh/tree number): 19/247, 21/246, 24/256, 26/251 and 28/244. North and West were marked on selected trees.

The wood density and mechanical properties were measured on specimens selected from tree trunk sections around the dbh area, free from any defects and

knots. Samples were cut from pith to bark. In the four cardinal directions, two lines of specimens were prepared, but the same number of samples were not obtained in every line, due to trunk eccentricity. Between 26 and 39 samples were prepared, for the thinnest and the thickest tree, respectively. Eventually, 159 samples were used to measure each property:

- 1) basic density ρ ($\text{kg}\cdot\text{m}^{-3}$);
- 2) compressive strength parallel to the grain R_c (MPa);
- 3) modulus of rupture R_g (MPa);
- 4) strength quality coefficient J .

Samples of $20 \times 20 \times 30$ mm were used to calculate the wood density. The measurement process was carried out according to standard UNI ISO 3131.

In addition, samples of $20 \times 20 \times 30$ mm were used to measure the compressive strength parallel to the grain according to UNI ISO 3787. Samples of $20 \times 20 \times 30$ mm were also used to measure the modulus of rupture in accordance with standard UNI ISO 3133. In both cases, air-dry wood specimens were used. All the strength properties were measured on a TIRA TEST 2300 machine with MATEST software.

The data was collected for each tree and descriptive statistics were calculated for further comparisons: the arithmetic mean, the minimal and maximal values, the coefficient of variation and the number of samples. The coefficient of determination (R^2) was also calculated to find out how well the values of the mechanical properties were determined by density; the respective linear trend lines were also created.

Results and discussion

The analysed wood from the pine trees taken from the seedling seed orchard was characterised by low density, amounting to a mean value of $327 \text{ kg}\cdot\text{m}^{-3}$ (table 1). Additionally, all the analysed mechanical properties consisted of low values.

Selected trees were of large annual rings with a mean value equal to 5.83 mm, as presented by Mederski et al. [2013] in an earlier publication (results based on the same wood material). These big increments were the consequence of the habitat of each tree being too large, as they were planted with a spacing of 4×4 m. This was much larger than the spacing of pine trees planted on forest land (artificial stand regeneration with a spacing of $1.5 \text{ m} \times 0.5\text{--}0.8$ m). Additionally, trees in the SSO were selected and removed as a result of other treatments, which made the spacing even wider [Mederski et al. 2013].

Table 1. Values of analysed wood properties with descriptive statistics

dbh/tree no	19/247	21/246	24/256	26/251	28/244	mean
	basic density (kg·m ⁻³)					
mean	330	318	347	304	338	327
minimum	268	256	276	252	268	264
maximum	410	415	665	400	464	471
coefficient of variation (%)	12	12	20	11	12	13
	compressive strength parallel to grain (MPa)					
mean	31.21	28.50	39.26	26.55	35.56	32.22
minimum	14.36	16.86	27.07	16.36	19.63	18.86
maximum	48.99	43.82	53.00	38.09	60.74	48.93
coefficient of variation (%)	29	25	17	22	24	23
	modulus of rupture (MPa)					
mean	59.22	54.70	64.33	50.21	64.61	58.61
minimum	39.30	41.57	42.91	36.23	40.77	40.16
maximum	102.60	79.59	109.83	74.36	95.17	92.31
coefficient of variation (%)	27	15	27	19	23	22
	strength quality coefficient					
mean	0.09	0.09	0.11	0.09	0.11	0.10
minimum	0.05	0.05	0.05	0.05	0.06	0.05
maximum	0.14	0.13	0.14	0.13	0.16	0.14
coefficient of variation (%)	26	24	16	21	19	21
n for analysed properties	26	26	30	38	39	32

The wood of Scots pine grown in stand conditions usually shows the following regularity: the bigger the annual ring, the lower the wood density and the lower the mechanical property values [Krzysik 1978]. In the analysed case, the biggest values were observed for trees with dbh 19, 24 and 28 cm, while the lowest values were for trees with dbh of 21 and 26 cm (table 1). The results obtained, where wood density did not lower when the annual rings grew bigger, are unusual and should be treated with caution. One possible explanation for such an unusual trend could be that the trees had unlimited access to sunlight. If this was the case, each tree was able to produce annual rings of the same optimal quality, irrespective of the width of the increments. Different widths of annual rings could depend on particular site (microsite) conditions and the genetic properties of individual trees. However, it was also found that various provenances of spruce growing on the same site conditions can be characterised by different basic wood density [Szaban et al. 2014].

Growth conditions and site factors are also recognised by other researchers as influencing variations in wood properties [Lo Monaco et al. 2015].

However, when the trees were juxtaposed with respect to the growing values of wood density – from the lowest to the highest – all the properties followed this trend: the higher the wood density, the bigger the value of the mechanical properties (fig. 1).

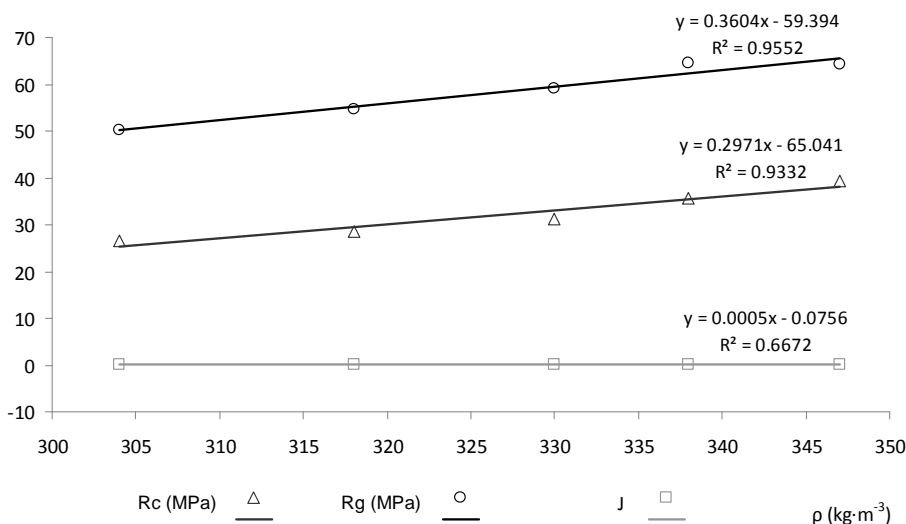


Fig. 1. Growing wood density followed by growing mechanical wood properties.

It was also found in beech wood that density was a main factor influencing other wood parameters [Lo Monaco et al. 2015]. This follows the principle that mechanical properties mainly depend on wood density [Krzysik 1978].

The values obtained for the wood density and mechanical properties of pine wood from the SSO were significantly lower in comparison with those for pine from a regular stand (table 2). The equivalent values of Scots pine wood properties (table 2) were taken from earlier publications by Krzysik [1978], Kubiak and Laurow [1994], Mederski et al. [2013] and Tomczak [2013].

The different properties of the pine wood from the SSO make it suitable for particular applications. It is recommended that it should be used in the paper industry, where high values of mechanical properties are not necessary for the final product. 25-year-old pine trees from the SSO had features of juvenile wood [Mederski et al. 2013]. Juvenile wood with short fibres and thin cell walls is more flexible and suitable for fine paper surfaces [Zobel, Sprague 1998]. For the full range of wood properties of pine from an SSO, it would be necessary to continue research on its chemical properties. Currently, when pine wood from an SSO is sold on the market, the customer should be informed about its origin.

Table 2. Wood properties comparison of Scots pine (*Pinus sylvestris* L.) from SSO and regular stands

Properties	Scots pine from:	
	SSO ¹	regular stand
mean width of annual ring (mm)	4.6 ÷ 7.1	0.5 ÷ 2.0
share of late wood (%)	28 ÷ 45	5 ÷ 35
basic density of juvenile wood (kg·m ⁻³)	304 ÷ 347	401 ÷ 432
compressive strength parallel to grain (MPa)	25.3 ÷ 37.3	41.3 ÷ 46.1
modulus of rupture (MPa)	48.2 ÷ 62.0	85.2 ÷ 87.0
strength quality coefficient	0.09 ÷ 0.11	0.17 ÷ 0.21 ²

¹ Values were calculated for MC 15% using the Bauschinger formula: $R_{15} = R_{MC}(1 + \alpha(MC - 15))$, where: R_{MC} – specimen strength at MC, in %; α – coefficient of wood strength change due to wood MC change by 1% (for compressive strength parallel to grain $\alpha = 0.05$, for modulus of rupture $\alpha = 0.04$); MC – moisture content, in % [Krzysik 1978].

² Values calculated from data presented in this table.

Conclusions

The mean value of the wood density of the pine wood from the SSO amounted to 327 kg·m⁻³ and was lower by ca. 28% in comparison with the mean density of pine from a regular stand (considered density: 455 kg·m⁻³). Additionally, the density of the pine wood from the SSO was also ca. 21% lower in comparison with the mean density of juvenile wood from pine grown in a regular stand (considered density: 416 kg·m⁻³).

The mean value of the compressive strength parallel to the grain amounted to 32.22 MPa, which was lower by ca. 26% in comparison with the respective mean value for wood from a regular stand (43.7 MPa).

The modulus of rupture mean value amounted to 58.61 MPa, which was lower by ca. 32% in comparison with the respective mean value for wood from a regular stand (86.10 MPa).

The mean value of the strength quality coefficient amounted to 0.10, lower by ca. 47% in comparison with the respective mean value for wood from a regular stand (0.19).

The values of the density and mechanical properties of Scots pine wood from the SSO were significantly lower in comparison with respective values for pine wood from regular stands. Therefore, the customer should be informed about the origin of this wood to make appropriate use of it. Preferably, pine wood from SSOs should be used in the paper industry.

All the analysed properties did not depend on the dbh or width of the annual rings. However, the mechanical properties greatly depended on the wood

density: the bigger the value of the basic density, the bigger the value of the mechanical properties.

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List of standards

- UNI-ISO-3131** Wood. Determination of density for physical and mechanical tests
- UNI-ISO-3133** Wood. Determination of ultimate strength in static bending
- UNI-ISO-3787** Wood. Determination of ultimate stress in compression parallel to grain