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THE EFECT OF BIOLOGICAL CLASS AND AGE ON PHYSICAL AND MECHANICAL PROPERTIES OF EUROPEAN LARCH (*LARIX DECIDUA* MILL.) IN POLAND

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ABSTRACT

The study analysed a physical property (specific gravity) and mechanical properties (bending strength and compression parallel to grain) of wood in European larch *(Larix decidua* Mill.*)* coming from production stands in western Poland.

Analyses were performed on wood coming from six larches aged 62 and 82 years, growing under optimal conditions for this species, i.e. fresh mixed broadleaved forest.

Based on tests it was found that age did not have a significant effect on wood properties, i.e. specific gravity density as well as bending strength compression parallel to grain. In turn, the social class of tree position in the community occupied by a given tree in the stand influences wood density, while it does not affect mechanical properties of wood. The highest density was found in trees classified to the dominant group (Kraft's class II), while mechanical properties were similar in all investigated Kraft's classes.

Moreover, a statistically significant dependence was found between wood density and tested strength parameters.

KEY WORDS: european larch, specific gravity, mechanical properties of wood

INTRODUCTION

European larch is a light demanding, pioneer tree species, with a very fast growth rate in the first growing period. In Poland the area of pure larch stands is over 126 thousand ha, which is approx. 1.8% area of the State Forests (Spława-Neyman et al. 1997).

For practice the most important characteristics of wood, determining its applicability, are technical characteristics. The higher wood strength and resistance to all kinds of factors causing timber degradation and depreciation, the higher the value of wood.

The basic and most frequently measured physical properties of wood is density. It is closely correlated to all mechanical properties of wood and to a large extent determines its quality and usability (Krzysik 1978, Haygreen and Bowyer 1996).

Variation in wood density within one specimen and between different trees of a given species was described in many studies, Fabisiak (2005) after Zobel and van Buijtenen (1989), Bala and Seth (1992), Herman et al. (1998). The determination of the effect of a given factor on wood density is difficult to verify, among other things because wood of the same species exhibits different properties depending on growth and development conditions of a given tree and the entire stand (Mc Kimmy 1966).

According to Lars et al. (2005) average wood density of analysed larch is 618 (535-670) [kg/m^3] in Siberian larch and 621 (550-665) kg/m^3 in European larch. In Poland the mean wood density of European larch coming from 21 natural positions was approx. 507 kg/m^3 (Sława-Neyman et al. 1997). Fabisiak (2005) found that specific gravity of European larch does not vary depending on the social class of tree position in canopy in the stand. The highest density was recorded for trees from lower social layers, i.e. intermediate trees; in turn, the lowest density was found in dominant trees (dominant trees 396.7 kg/m^3, medium trees 425.8 kg/m^3, intermediate trees 436.1 kg/m^3) (Wagenfür and Scheiber 1974).

Wood as an anisotropic material exhibits different mechanical properties depending on the investigated anatomical direction (Barnett and Jeronimidis 2003). Variation observed in wood properties within a single stem may be explained, among other things, by the presence of juvenile and mature wood (Brüchert et al. 2000, Saranpää 2003). In comparison to mature wood juvenile wood is characterized by lower density (irrespective of the width of annual rings), on average shorter tracheids, a lower proportion of late wood and a higher proportion of lignin (Zobel and Sprague 1998).

As it was reported by Kokociński (2005), European larch *(Larix decidua* Mill.*)* is characterized by wood with density ranging from 400 to 820 kg/m^3, compression strength parallel to grain of 41-81 MPa and bending strength of 65-132 MPa.

An extensive description of mechanical properties of wood and factors determining them was given in studies by Kollmann and Cote (1968), MacLean (1954), Mallory and Cramer (1987), Green et al. (1999).

The effect of anatomical elements of wood in Siberian larch (*Larix sibirica)* on mechanical properties of its wood was discussed by Koizumi et al. (2003). In terms of physical and mechanical properties Siberian larch was also investigated by Iijima (1983), Gupta et al. (1996) and Gupta and Ethington (1996). The effect of growth ring parameters on properties of Japanese larch *(Larix kaempferi)* was described by Koizumi (2005). In turn, mechanical properties of wood in Dahurian larch (*Larix gmelinii)* were analysed by Gupta et al. (1994, 1996).

In literature on the subject we may relatively frequently find sources describing wood properties of larch; however, there are practically no extensive analyses describing the effect of factors determining growth and development conditions on physical and mechanical properties of wood in this species, especially European larch *(Larix decidua* Mill.*)*

The aim of the study was an attempt at the determination of the effect of social class of tree position in the stand and the phase of stand development (maturing, mature) on selected physical and mechanical properties of European larch *(Larix decidua* Mill.*)* growing in natural positions in western Poland.

MATERIAL AND METHODS

Experiments were conducted in the Babimost Forest District, which constitutes a part of the Regional Directorate of State Forests (RDSF) in Zielona Góra (Fig. 1).

Fig. 1: Babimost Forest District which constitutes part of the Regional Directorate of State Forests (RDSF) in Zielona Góra 52° 09'53.65" N 15° 49'44.70" E

Larch occurred in the analysed stands in the form of group mixture. The trees developed under the conditions of the fresh mixed broad-leaved forest site type and represented the IV (61-80 years) and V (81-100 years) age classes. On all eight experimental sample plots, i.e. two in each of the analysed age classes, breast height diameters of all trees as well as the height of growing trees proportionally to the adopted 2 cm frequencies of thickness degrees were measured. Having obtained the thickness-height characterisation of larch trees in this way, the Urich II (Grochowski 1973) dendrometric method was then applied to determine dimensions of three sample trees representing the main stand, i.e. the three first classes according to Kraft's classification (the pre-dominant, dominant and co-dominant trees) (Kraft 1884). The dimensions of test trees were calculated individually for each of the analysed stands and each age class. The selected test larch trees were characterised by healthy and straight stems and symmetrical, properly developed crowns. A total of 6 test trees was selected (Tab. 1).

Tab. 1: Statistical characterisation of sample trees

Kraft Class	Age [years]	DBH [cm]	Height [m]	Stem volume [m^3]	Crown volume [m^3]
I	62	39.55	25	1.25	177.00
II		31.50	24	0.89	62.26
III		24.93	24	0.60	39.83
I	82	40.30	29	1.72	212.59
II		34.20	28	1.05	48.96
III		26.03	27	0.66	28.43

Before felling of individual model trees, their crowns were projected in order to determine their diameters. The trees were then felled and next their lengths as well as the length of the live crown zones were measured. The measurements were carried out accurate to 1 cm. On the basis of the obtained crown dimensional parameters of the felled trees, areas of the crown projection (using the formula for the area of the circle) and the volume of the crown were calculated. For felled trees material was collected for further analyses of physical and mechanical properties of wood, i.e. specific gravity (q_u), compression strength parallel to grain (Rc) and bending strength (Rg). Material for laboratory testing came from 50cm blocks collected 1.30m – 1.80m from the breast diameter kerf plane. A diagram presenting collected laboratory material is given in Fig. 2.

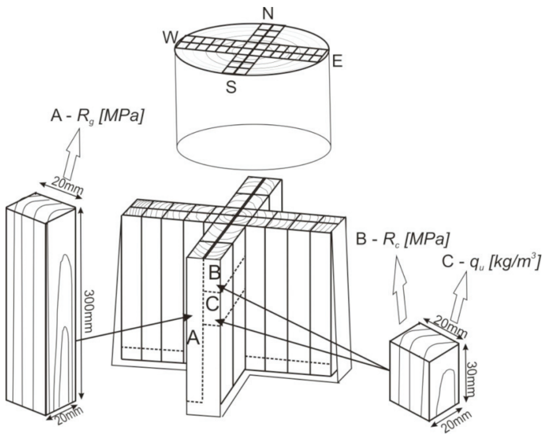


Fig. 2: A diagram of collection of material for tests of physical and mechanical wood properties (T. Jelonek)

A – static bending

B – Compression parallel to grain

C – Specific gravity

Density of wood was determined by stereometry and defined as specific gravity.

Compression strength parallel to grain and bending strength were determined using a Tira Test 2300 testing machine equipped with computer software by Matest Service.

All determinations were performed accurate to 0.01 MPa. Strength parameters of samples were determined at wood moisture content exceeding the fibre saturation point (≤ 30% moisture content).

Wood moisture content was determined using the oven-dry method (PN-77/D-04100).

Testing of wood properties was performed following the respective standards (PN-77/D-04103, PN-77/D-04101, PN-79/D-04102)

Collected empirical material was analysed using methods of mathematical statistics. For this purpose Statistca 8,0 PL software package was applied.

RESULTS

Basic statistical characteristics illustrating analysed properties of wood in European larch *(Larix decidua* Mill.*)* are presented in Tab. 2.

Tab. 2: Statistical characteristics of selected physical and mechanical properties of European larch (Larix decidua Mill.*)*

	N	Mean	Minimum	Maximum	Standard deviation	Coefficient of variation [%]
q [kg/m^3]	132	475.80	315.99	568.68	49.00	10.30
Rg [MPa]	132	57.46	20.39	87.84	13.94	24.25
Rc [MPa]	132	24.75	12.25	34.39	4.71	19.04

Analysed wood exhibited mean density of 475.8 kg/m3, bending strength of 24.8 MPa and compression strength parallel to grain of 57.5 MPa. The biggest variation in analysed characteristics was found for bending strength (24.25%), while the smallest for specific gravity (10.30%).

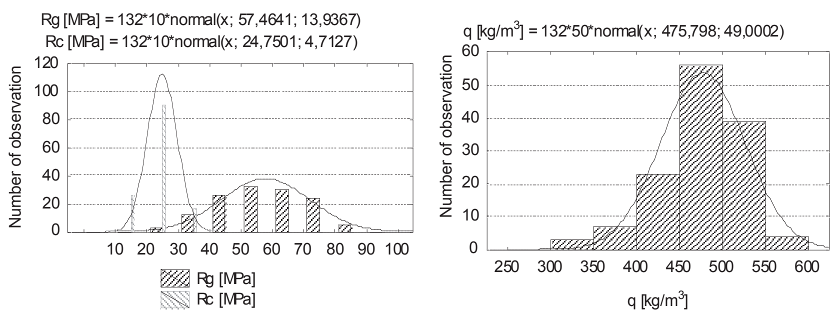


Fig. 3: Histograms of distribution of analysed wood properties

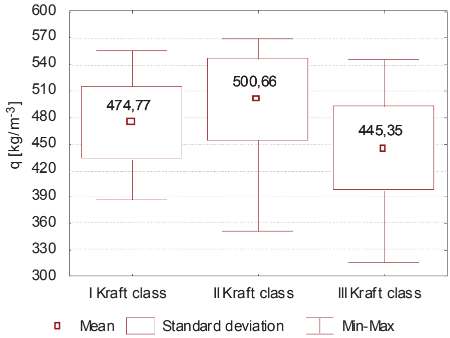
Analysed properties had distributions close to normal distribution (Fig. 3), while conducted analyses of variance showed a lack of statistically significant differences in density and strength parameters (Rg, Rc) between age classes (Tab. 2). However, there were statistically significant differences in density between social classes of tree position in canopy, occupied by trees in the stand (Tab. 3).

Tab. 3: Analysis of variance for analysed variables for age and social class of tree position in the stand

		SS	df	MS	SS	df	MS	F	p
Age	q [kg/m^3]	2.138288	1	2.138288	314531.8	130	2419.475	0.000884	0.976329
	Rg [MPa]	6.338734	1	6.338734	25438.00	130	195.6769	0.032394	0.857446
	Rc [MPa]	10.55419	1	10.55419	2898.860	130	22.29892	0.473305	0.492696
Kraft class	q [kg/m^3]	60319.59	2	30159.80	254214.4	129	1970.654	15.30446	0.000001
	Rg [MPa]	67.04845	2	33.52423	25377.29	129	196.7232	0.170413	0.843506
	Rc [MPa]	63.27604	2	31.63802	2846.138	129	22.06308	1.433980	0.242132

Marked effects are significant at $p < 0.05000$

Since age was not found to have a significant effect on investigated properties, it was not a classifying factor in further analyses. Thus analyses were conducted taking into consideration only the effect of social class of tree position in the main stand on specific gravity, compression strength parallel to grain, bending strength.



	I Kraft class	II Kraft class	III Kraft class
I Kraft class		0.015673	0.015364
II Kraft class	0.015673		0.000022
III Kraft class	0.015364	0.000022	

Fig. 4: Values of wood specific gravity in analysed social classes of tree position

Results are significant at $p \leq 0.05$

Conducted tests showed significant differences in specific gravity of wood between individual Kraft's classes (Fig 5).

Statistically significantly highest density of 501 kg/m^3 was recorded for trees belonging to the dominant layer (Kraft's class II). In turn, the lowest density (445 kg/m^3) was found for trees classified to Kraft's class III, being codominant trees (Fig. 5). No statistically significant differences were recorded in bending strength between social classes of tree position (Kraft's classes) (Fig. 5, Tab. 2).

This strength parameter ranged in value from 57 to 58 MPa and exhibited relatively small variation.

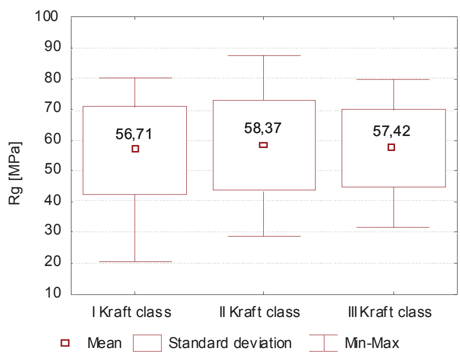


Fig. 5: Values of bending strength in analysed social classes of tree position

Moreover, no significant differences were recorded in compression strength parallel to grain. The biggest strength in this case was found for a tree from the predominant layer (Kraft's class III), amounting to approx. 26 MPa, whereas the lowest was recorded for a tree from the codominant layer (Kraft's class III), which amounted to approx. 24 MPa (Fig. 6).

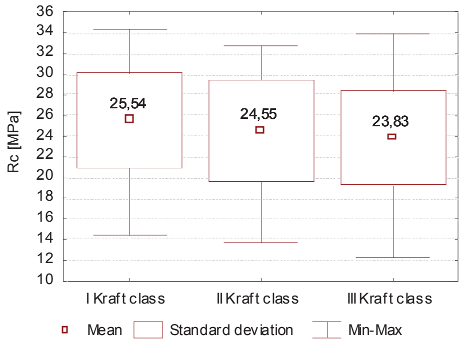


Fig. 6: Values of compression strength in analysed social classes of tree position

Models of mean distributions of density and strength along the north-south radius are presented in Figs. 7, 8 and 9.

At cross-sections analysed properties were observed to fluctuate. This may have been connected with the presence of three types of wood tissue in tree stems. The lowest values of properties were recorded in the pith zone, where juvenile wood is found. Next values of analysed properties increased in the transition wood zone, reaching its maximum in the mature wood zone.

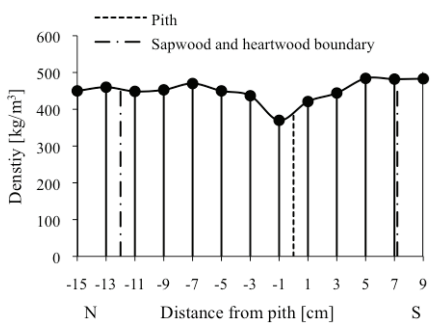


Fig. 7: A model distribution of specific gravity along the N, S radius

It should be stressed that after crossing the boundary between heartwood and sapwood mechanical properties decreased in value, while wood density remained similar to that in mature wood.

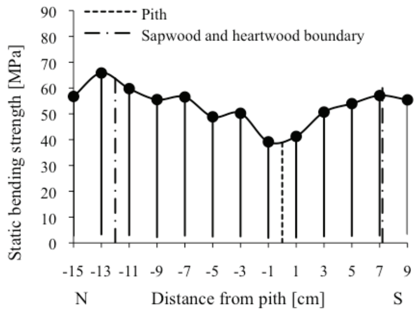


Fig. 8: A model distribution of bending strength along the N, S radius

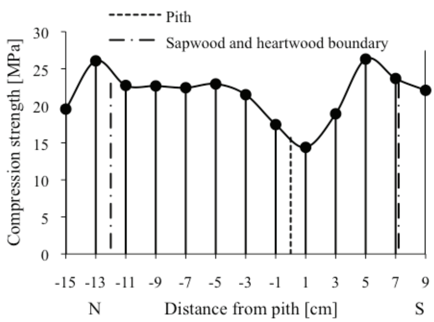


Fig. 9: A model distribution of compression strength along the N, S radius

It was also attempted to determine relationships between investigated mechanical properties and specific gravity of wood (Figs. 10 to 11).

Analysed relationships were statistically significant and positive, and they were described by regression equations and coefficients of determination R^2.

Figures (10 and 11) illustrate trends for investigated dependencies in view of social classes of tree position in the stand. Conducted analyses indicated that Kraft' class, tree position in the community has a significant effect on presented dependencies. Bending strength in case of a predominant tree was dependent on density in 52%, in a dominant tree in 37%, while in a codominant tree in 71%, respectively (Fig. 10).

Moreover, density of wood determines compression strength (Rc) in 75% in case of predominant trees, in 64% in dominant trees and in 61% in codominant trees (Fig. 11).

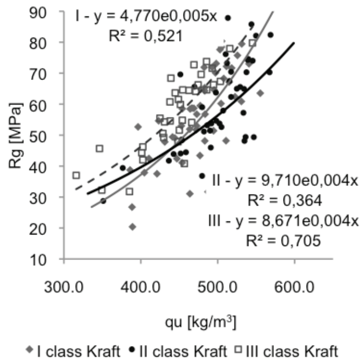


Fig. 10: A dependence of bending strength on specific gravity of wood

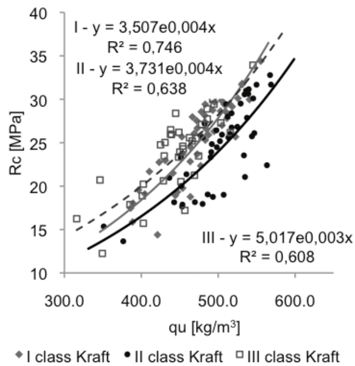


Fig. 11: A dependence of compression strength parallel to grain on specific gravity of wood

DISCUSSION

It was also attempted in this study to analyze specific gravity, compression strength parallel to grain and bending strength in European larch *(Larix decidua* Mill.*)* grown in western Poland under conditions optimal for this species.

At present it is commonly stated in literature sources that in coniferous monocultures the highest density is found in trees from lower social classes of tree position in the stand, i.e. intermediate trees, while it is lowest for trees occupying the best social class of tree position, i.e. predominant and dominant trees (Wanin 1953, Spurr and Hsiung 1954, Kommert 1972, Krzysik 1978, Tsoumis and Panagiotidis 1980, Lindström 1996, Fabisiak 2005). Conducted analyses did not fully confirm the trend presented in literature sources cited above, saying that wood density increases with the transition to lower social classes of tree position. The highest density was recorded in case of dominant trees (Kraft's class II), while the lowest in case of codominant trees (Kraft's class III).

According to Fabisiak (2005) specific gravity of wood in European larch varies depending on social class of tree position in the stand.

Conducted analyses indicate that density determines wood strength, depending on the investigated social class of tree position, in 36% to 75%. Thus it needs to be assumed that other factors, not controlled within this study, affect mechanical properties of wood within the 25% - 64% range.

In the conducted studies differences were found in wood density between social classes of tree position, while no differences were shown in strength, which in each of the analysed classes was similar.

It may have been an analogous situation to that reported in a study by Jelonek et al. (2005), in which the authors explained increased wood strength at unchanged wood density with changes occurring at the cell wall level.

This fact suggests that in wood of larches natural biomodifications of wood tissue may also occur under the influence of auxins, depending on the social class of tree position in the stand. These changes do not have a significant effect on wood density, but they considerably affect its strength. Eventually this mechanism may coordinate the statics of the entire tree, maintaining it at the optimal level for the position occupied by this tree.

Mechanical properties were investigated in wood with moisture content exceeding the fibre saturation point (≥30%), which made it possible to eliminate the role of secondary bonds in wood strength. Thus it may be assumed that in the analysed larch wood quantitative and qualitative changes took place in cell walls, including first of all cellulose polymerization rate and the ratio of crystalline zones in relation to amorphous zones in cellulose.

Moreover, an atypical distribution was also observed for analysed properties in cross-section radii in comparison to those typical of coniferous species. Some literature sources indicate that in coniferous species wood density increases starting from the pith up to the circumference and together with it mechanical properties also increase (Krzysik 1978, Green et al. 1999, Spicer and Gartner 2001, Machado and Cruz 2005).

Thus, when moving from the pith to the stem circumference values of analysed mechanical properties increased until the boundary zone between sapwood and heartwood, after which they slightly decreased (Figs. 9, 10). In turn, the distribution of wood density was slightly different and in the circumferential zone no deterioration of this property was reported. Distribution at the radial section of properties analysed in this study may partly be explained by the specific structure of wood. During the entire ontogenesis in trees under the influence of auxins three types of wood tissue are produced, differing in chemical composition, physical and mechanical properties. In the initial phase, including from several to about a dozen of annual rings, juvenile wood is formed, characterized by e.g. low density. Next transition wood and mature wood with the best mechanical properties are formed (Kretschmann 1998, Zobel and Sprague 1998, Giefing et al. 2008).

Also with age not only quantitative changes take place in wood in terms of basic components of cell walls, including mainly cellulose (Erickson et al. 1974, Berrocal et al. 2004, Toivanen and Alén 2006), but in the circumferential zone as a result of aging processes or other physical, chemical or biological factors processes of cellulose depolymerization (cellulose degradatation) take place, which significantly affects mechanical properties of wood.

No differences were found in this study in the analysed properties of wood between trees aged 62 and 82 years. This may suggest that in European larch already in the maturing stand (approx. 60 years of age) a considerable proportion of wood is found with the character of technically mature tissue, which relatively fast undergoes aging processes and determines deterioration of wood mechanical properties. If the proposed hypothesis is valid, then the introduction of this species to wood production should be investigated for the purpose of wood production in short cycles in plantations of fast-growing trees with extensive applicability.

CONCLUSIONS

Based on the conducted investigations it may be stated that stands in age classes IV (61-80 years) and V (81-100 years) are characterized by wood with similar density, bending strength and compression strength parallel to grain. Specific gravity of wood is significantly affected by the social class of tree position occupied by a given tree in the stand. The highest specific gravity was found for trees classified to the dominant group, while the lowest for trees from the codominant layer. At the same time the social class of tree position in the stand was not found to significantly determine mechanical properties of wood.

The distribution of analysed properties at the radial section is characterized by variation, maintaining an upward trend starting from the pith to the boundary of heartwood and sapwood, with mechanical properties in sapwood zone decreasing up to the cambium zone.

From the point of view of technical wood quality the best parameters were recorded for codominant trees (Kraft's class III), followed by predominant trees (Kraft's class I), where coefficients of strength quality reached the highest values.

It was found that wood strength was significantly determined by specific gravity. Depending on the social class of tree position in the community its effect may range from 36% to75%.

Thus conducted analyses may indicate that in closed production stands, where natural interspecific competition is observed, not only quantitative, but also qualitative biomodification of wood tissue is observed at the cell wall level.

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