Desorption strengthening of wood tissue in European larch (*Larix decidua Mill.*) depending on age of trees and social class of tree position in the stand

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Reduction of wood moisture content below saturation point is accompanied by wood strengthening, which may be referred to as "desorption strengthening". According to the desorption strengthening values from wood from the breast height of European larch it was fined irregularity of wood tissue in the ray direction. Core (juvenile) wood of European larch exhibits inferior mechanical properties in comparison to mature wood in each of the examined social classes of tree position in the stand and in each age class.

Juvenile and mature wood, wood quality

Introduction

According to Grzeczyński (1975), assuming basic wood strength to be its strength in green wood, i.e. at moisture content above saturation point (W_n), it may be stated that a reduction of wood moisture content below W_n is accompanied by wood strengthening, which may be referred to as desorption strengthening. In turn, Dudziński (1995) defines desorption strengthening as a change in the numerical value of the examined property as a result of drying from the wet state to adequate final moisture content.

Formation of wood tissue is inseparably connected with stadial tree growth, which is influenced by several external factors. Conditions for tree growth and development have an effect on properties of formed wood tissue, which variation at the stem cross-section may be described using selected mechanical properties of wood.

Methods

The experimental material comprises results of measurements for wood of 12 European larches, growing in fresh forest representing four age classes (II-V) and the dominant stand according to the biological classification according to Kraft. Analyses were conducted on stands growing in the Nowogard Forest Division, where larch was found as an admixture in at least group mixture. Mean sample trees were selected according to the Hartig method from four successive age classes, starting from age class II. Three mean sample trees were selected from each age class.

Samples of specific dimensions were collected from the material harvested at the Nowogard Forest District as blocks of 0.5 m in length collected at 1.10 – 1.60 m distance from the felling cut. Samples were collected from the radius oriented in the northerly direction. The aim of such a selection was to eliminate from analyses wood samples from directions affected by the predominant winds found in Poland, in which reaction wood could have been found and which presence might have had an adverse effect on the recorded results. The first sample due to material losses during cross-cutting and polishing came from the distance of 1 cm from the pith. Samples were numbered in succession starting from the pith towards the circumference (Fig. 1).

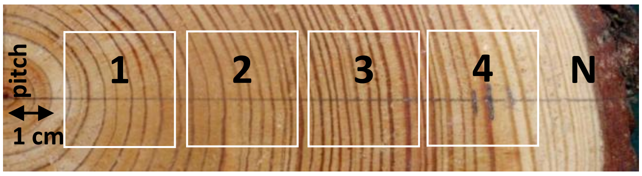


Fig. 1. A scheme for the collection of sample for analyses of selected mechanical properties of larch wood

From methodically collected material samples were prepared for tests of compressive strength along the grain and static bending strength. Strength testing was conducted on absolutely dry wood and at moisture content above fibre saturation point (wet wood). Such a procedure aimed at the determination of desorption strengthening of wood, understood as the difference in wood strength tested at two opposite states of moisture contents in relation to compressive strength along the grain and static bending strength. Moreover, when wood strength is tested at moisture content above fibre saturation point the effect of secondary bonds formed during desorption is eliminated (Grzeczyński 1975).

Compressive strength along the grain was determined using an Instron 33R4204 universal testing machine with load capacity up to 50 kN coupled with a computer equipped with Bluehill 2 software.

Compressive strength along the grain was tested on samples of 20 x 20 x 30 mm, while static bending strength was tested on samples of 20 x 20 x 300 mm. Strength was determined at two moisture content states:

- At wood moisture content of 0% (after 24 h drying at 103°C),
- at moisture content above fibre saturation point (after 5-week soaking in distilled water in a chamber at 20°C).

Compressive strength test was conducted in accordance with the guidelines specified in the standard PN – 79/D – 04102, while bending strength was tested according to the standard PN – 77/D – 04103.

The juvenile wood zone was determined using the algorithm of k-means applying input data in the form of standardised values of annual ring width, percentage share of late wood in the annual ring and length of annul ring radius (Nawrot 2010).

Results

Values of differences between values of strength in the absolutely dry sate and strength above fibre saturation point understood as desorption strengthening are presented in the form of graphs of their ranges.

The previously assumed 1 cm was deducted from the width of the juvenile wood zone obtained using the k-means algorithm and its range on the graphs was hatched in red. The rest of the graph area represented mature wood.

Statistical characteristics of selected physical and mechanical properties of larch wood representing four age classes and the main stand according to Kraft's biological classification are given in Tables 1 - 4.

Except for a predominant tree and a codominant tree of age class II, in the other cases a greater average value of desorption strengthening was recorded in tests of static bending strength (tab. 1 - 4).

Table 1. Statistical characteristics of selected mechanical properties of wood from European larches occupying different social classes of tree position in the stand representing age class II

Kraft class	Statistics	Compressive strength along fibres [MPa]		Bending strength static [MPa]		Desorption strengthening during compression [MPa]	Desorption strengthening during bending [MPa]
		Dry	Wet	Dry	Wet		
1	2	3	4	5	6	7	8
I	Medium value	61,33	18,86	77,94	43,60	42,47	34,35
	Minimum	53,95	14,94	60,40	31,17	39,01	20,18
	Maximum	72,80	23,66	90,73	60,39	49,14	47,93
	Standard deviation	8,08	3,60	12,72	12,23	4,63	11,86
	Coeff. of variation	13,18	19,09	16,32	28,06	10,90	34,54
II	Medium value	59,95	17,07	87,79	38,35	42,88	49,44
	Minimum	44,54	14,57	69,73	32,33	29,97	37,40
	Maximum	81,32	20,51	124,70	47,26	60,81	77,44
	Standard deviation	15,80	2,48	24,95	6,83	13,39	19,05
	Coeff. of variation	26,36	14,56	28,42	17,82	31,23	38,53
III	Medium value	56,95	16,63	64,81	31,18	40,32	33,63
	Minimum	39,89	15,05	50,46	30,17	24,84	18,13
	Maximum	72,44	17,57	81,21	32,33	55,16	50,16
	Standard deviation	16,33	1,38	15,48	1,09	15,17	16,04
	Coeff. of variation	28,68	8,29	23,88	3,48	37,62	47,69

Table 2. Statistical characteristics of selected mechanical properties of wood from European larches occupying different social classes of tree position in the stand representing age class III

1*	2	3	4	5	6	7	8
I	Medium value	56,34	14,09	75,99	30,63	42,20	45,37
	Minimum	34,72	9,39	47,07	20,50	25,33	22,14
	Maximum	80,87	20,59	102,66	50,73	60,28	68,79
	Standard deviation	16,61	3,45	20,47	10,16	13,08	15,55
	Coeff. of variation	29,47	24,48	26,93	33,17	30,98	34,28
II	Medium value	63,14	17,25	90,05	40,14	45,89	49,91
	Minimum	36,59	11,87	14,37	25,46	24,72	11,09
	Maximum	75,53	21,86	115,17	51,58	56,60	71,66
	Standard deviation	14,30	3,93	37,79	11,04	11,09	30,60
	Coeff. of variation	22,65	22,77	41,97	27,49	24,16	61,31
III	Medium value	65,79	24,01	98,62	46,92	41,78	51,70
	Minimum	45,39	15,36	69,64	27,68	28,56	32,28
	Maximum	86,03	33,69	139,00	61,69	55,39	77,31
	Standard deviation	14,47	8,13	26,97	14,97	11,63	18,12
	Coeff. of variation	21,99	33,85	27,34	31,89	27,84	35,05

*) for descriptions see table 2.

Table 3. Statistical characteristics of selected mechanical properties of wood from European larches occupying different social classes of tree position in the stand representing age class IV

1	2	3	4	5	6	7	8
I	Medium value	66,92	19,44	94,87	42,53	47,48	52,35
	Minimum	38,83	10,69	48,94	23,37	28,14	19,63
	Maximum	93,27	26,52	157,99	62,72	67,91	102,69
	Standard deviation	18,90	5,60	41,45	13,80	13,90	30,76
	Coeff. of variation	28,24	28,78	43,69	32,44	29,28	58,76
II	Medium value	84,38	23,45	135,38	54,46	60,93	80,92
	Minimum	41,06	13,27	62,61	27,60	27,79	35,01
	Maximum	110,48	29,57	196,24	72,41	81,88	123,83
	Standard deviation	27,10	6,28	53,44	16,69	21,31	38,63
	Coeff. of variation	32,11	26,78	39,48	30,65	34,97	47,74
III	Medium value	68,10	20,04	106,69	43,80	48,07	62,89
	Minimum	44,40	11,40	43,77	27,04	33,00	16,73
	Maximum	95,28	29,54	151,87	64,52	68,05	94,64
	Standard deviation	19,68	7,38	38,40	14,91	13,01	25,82
	Coeff. of variation	28,89	36,81	35,99	34,03	27,04	41,06

Table 4. Statistical characteristics of selected mechanical properties of wood from European larches occupying different social classes of tree position in the stand representing age class V

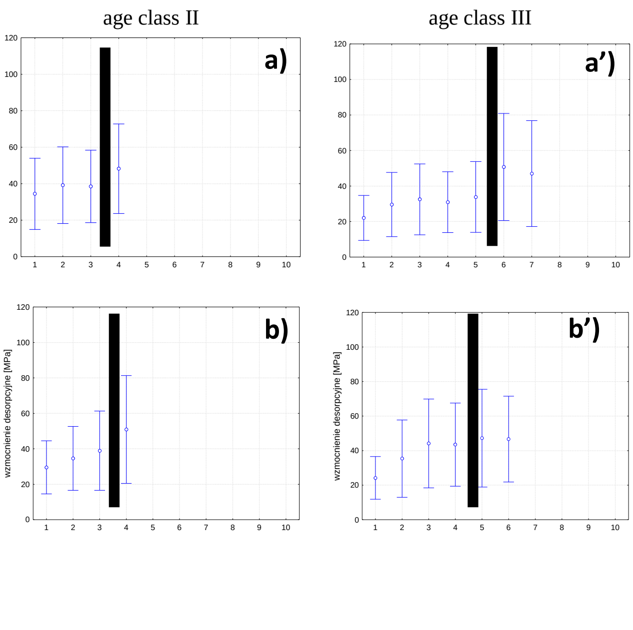
1	2	3	4	5	6	7	8
I	Medium value	78,52	21,79	106,22	48,29	56,39	57,92
	Minimum	53,41	13,81	81,52	30,85	38,73	46,44
	Maximum	102,44	29,80	141,39	66,07	76,12	76,48
	Standard deviation	20,66	6,17	23,25	13,56	15,22	12,16
	Coeff. of variation	26,32	28,30	21,89	28,07	26,99	20,99
II	Medium value	79,27	23,59	128,08	52,17	55,68	75,92
	Minimum	55,49	15,40	56,41	30,96	38,97	25,45
	Maximum	103,39	30,53	179,82	72,35	72,86	120,35
	Standard deviation	19,11	6,53	50,41	15,45	13,07	39,19
	Coeff. of variation	24,11	27,68	39,35	29,61	23,48	51,62
III	Medium value	71,31	20,47	111,02	46,01	50,84	65,01
	Minimum	55,95	13,44	87,23	30,88	42,51	54,51
	Maximum	92,12	27,80	136,12	61,06	64,32	75,06
	Standard deviation	14,15	5,87	17,56	13,78	8,49	9,25
	Coeff. of variation	19,85	28,68	15,82	29,94	16,70	14,23

Desorption strengthening at compression along the grain was presented in the form of graphs of ranges, where the minimum value represents wood strength determined at moisture content above fibre saturation point, while the maximum value is strength of absolutely dry wood.

Differences were found in desorption strengthening of wood depending on the location of samples on the radius of the radial section in individual age classes and social classes of tree position in the stand (Figs. 2, 3).

The highest values of desorption strengthening were found in all trees in the mature wood zone, while they were lowest in the juvenile wood zone. Desorption strengthening increased from the pith to the circumference, to show a decrease in several cases in the last sample located the closest to the stem circumference, in the sapwood zone (Figs. 2, 3).

Among trees of the main stand the highest value of desorption strengthening was found for dominant trees from age classes II and IV, and predominant trees from age classes III and V, while the lowest was recorded for codominant trees from age classes III, IV and V and a predominant tree of age class II (Figs. 2, 3). Desorption strengthening was found to increase with tree age.



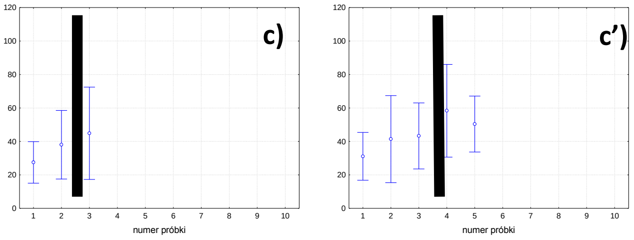


Fig. 2. Desorption strengthening in wood of larches representing age classes II and III depending on the position on the stem radius of: a and a') predominant trees, b and b') dominant trees, and c and c') codominant trees. Primo (') is for III class of age

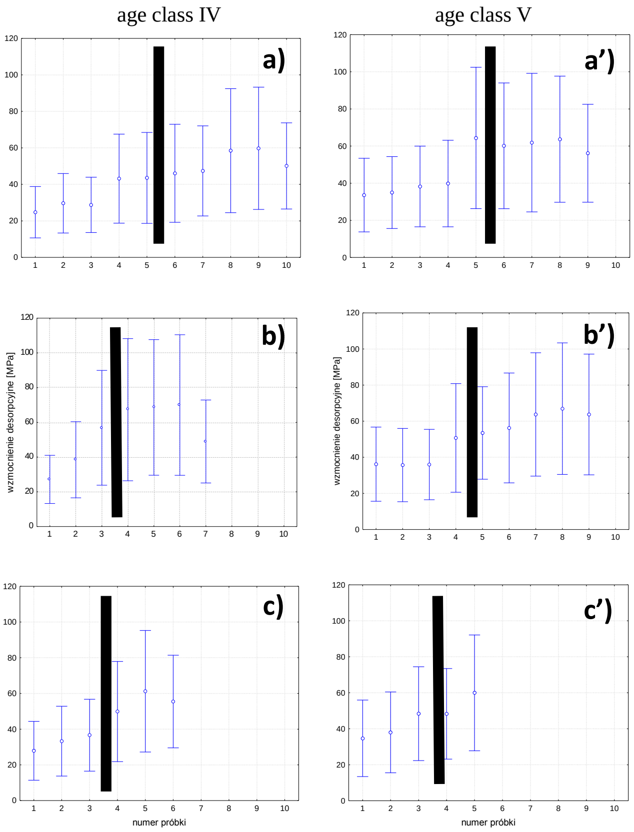


Fig. 3. Desorption strengthening in wood of larches representing age classes IV and V depending on the position on the stem radius of: a and a') predominant trees, b and b') dominant trees, and c and c') codominant trees. Primo (') is for V class of age

Desorption strengthening at static bending is presented in the form of graphs of ranges, where the minimum value represents wood strength at static bending at moisture content above fibre saturation point, while maximum value was strength of absolutely dry wood.

Differences were found in desorption strengthening of wood depending on the location of samples on the radius of the radial cross-section depending on tree age and on the occupied social classes of tree position in the stand (Figs. 4, 5).

Values of desorption strengthening determined at static bending were higher in age classes III, IV and V than those of desorption strengthening at compression along the grain. The trend for desorption strengthening to increase in the direction from the pith towards the circumference was much more marked in the two oldest age classes.

Greater desorption strengthening was observed in the mature wood zone, except for a dominant tree from age class II (Fig. 4 a) and a dominant tree from age class III (4 b'), where the discussed parameter showed higher values in the juvenile wood zone. The highest values of desorption strengthening were found in dominant trees from age classes II, IV and V and in a codominant tree from age class III, while they were lowest in dominant trees from age classes II and III and codominant trees from age classes IV and V (Figs. 4, 5).

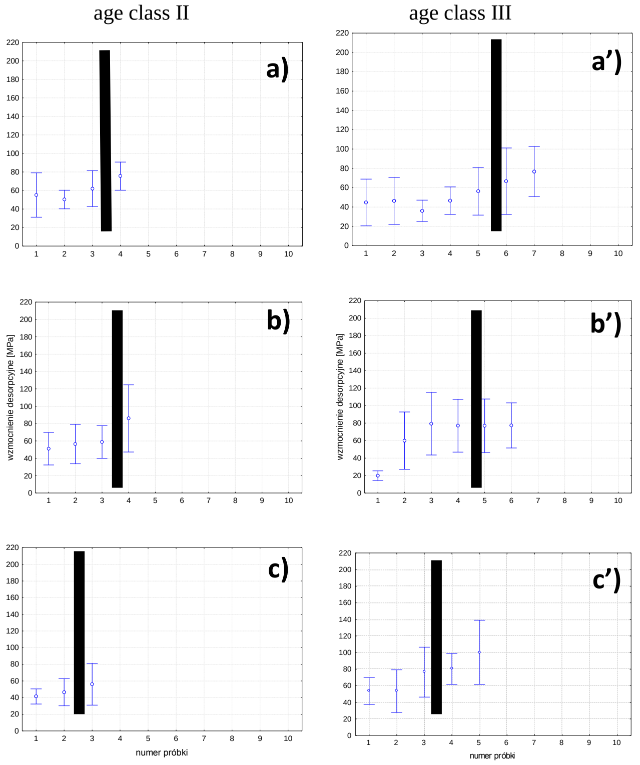
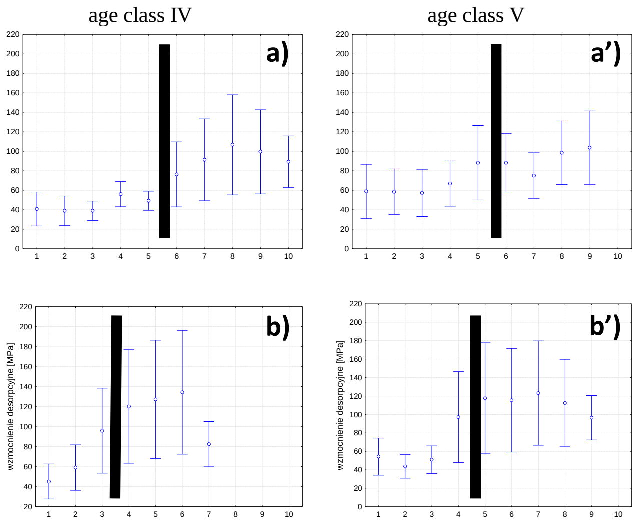


Fig. 4. Desorption strengthening in wood of larches representing age classes II and III depending on the position on the stem radius of: a and a') predominant trees, b and b') dominant trees, and c and c') codominant trees. Primo (') is for III class of age



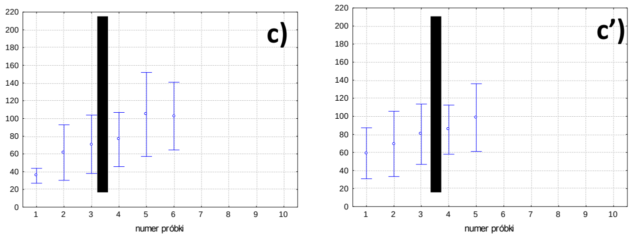


Fig. 5. Desorption strengthening in wood of larches representing age classes IV and V depending on the position on the stem radius of: a and a’) predominant trees, b and b’) dominant trees, and c and c’) codominant trees. Primo (‘) is for V class of age

Discussion

Strength testing was performed at two states of moisture content: absolutely dry and above fibre saturation point (wet wood) in order to calculate desorption strengthening. In the opinion of Krzysik (1978) and Kokociński (2004), an increase in moisture content from the absolutely dry state (0%) to fibre saturation point (~30%) results in a rapid decrease in numerical values of strength, which is confirmed by the conducted tests. These dependencies resulted in desorption strengthening, which as it is reported by Dudziński (1995) refers to a change in the numerical value of the tested property as a result of drying from the wet state to a respective final moisture content. In the opinion of Jelonek et al. (2009), desorption strengthening is a result of micellar structure of cell walls and affinity of cellulose, hemicelluloses and pectin compounds to water. Thus knowing values of desorption strengthening, which maximum values were found in the mature wood zone, preliminary inferences may be drawn on the submicroscopic structure of wood.

As it was reported by Krauss (2010), wood structure may be investigated at the macro-, micro- and submicroscopic levels and properties of wood tissue result from its structure at all its levels. Greater strength of mature wood in comparison to juvenile wood in the opinion of many authors (Kennedy 1995, Sahlberg et al. 1997, Zobel and Sprague 1998, Surmiński 2006, Fabisiak and Moliński 2007, Krauss 2010, Pazdrowski et al. 2010) results from the greater share of late wood in the annual ring, greater length of anatomical elements, while at the submicroscopic level it is connected first of all with a greater content of cellulose, its greater crystallinity and a smaller angle of cellulose fibrils in relation to the longitudinal axis of cells first of all in layer S2 of the secondary cell wall.

In terms of mechanical properties core wood, i.e. juvenile wood, in European larch constitutes an inferior wood material in comparison to mature wood. When analysing testing results of selected mechanical properties of wood they were found to be markedly varied on the radius of the radial cross-section, which is connected with the presence and distribution of juvenile wood and mature wood zones. Irrespective of the age of trees, occupied social class of tree position in the stand and moisture content of tested samples, juvenile wood was characterised by lower values of compressive strength along the grain, static bending strength and desorption strengthening in contrast to mature wood. Results confirm the current knowledge on mechanical properties of juvenile wood in comparison to mature wood. Similar observations concerning disadvantageous strength properties of juvenile wood were made by Dumail and Castera (1997), Dumail et al. (1998), Bao et al. (2001), Larson et al. (2001), MacDonald and Hubert (2002), Pazdrowski and Spława-Neyman (2003), Passialis and Kiriazakos (2004), Pazdrowski (2004), Tomczak (2006), Yeh et al. (2006) and many others.

Conclusions

1. During growth and development of larches in their stems quantitative and qualitative changes occur in the wood tissue, manifested e.g. in changes in mechanical properties of wood connected with the presence of juvenile and mature wood zones.

2. Based on the recorded values of desorption strengthening of wood at breast height heterogeneity was found in wood tissue of European larch in the radial direction.

3. Core (juvenile) wood of European larch exhibits inferior mechanical properties in comparison to mature wood in each of the examined social classes of tree position in the stand and in each age class.

4. Results of selected mechanical properties of wood and desorption strengthening of wood tissue calculated on their basis may be useful in the determination of juvenile and mature wood in trunks and stems of forest trees.

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Увеличение десорбции древесины лиственницы европейской (Larix decidua Mill.) в зависимости от возраста дерева и занимаемой биосоциальной позиции

Изложение

Снижение содержания в древесине влаги ниже предела гигроскопичности волокон сопровождается укреплением древесины, которое можно назвать усилением свойств десорбции.. На основе полученных результатов укрепления древесины отмечена неоднородность ткани европейской лиственницы в радиальном направлении. Древесина прикорневой части молодых экземпляров лиственницы европейской характеризуется более низкими механическими свойствами по сравнению с древесиной зрелых деревьев в каждом из тестовых заданий на лесной делянке, а также в каждой из возрастных групп.

Древесина малолетняя и увиденная, качество древесины

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