Drewno 2016, Vol. 59, No. 196.
DOI: 10.12841/wood.1644-3985.132.11

RESEARCH REPORTS

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VARIABILITY IN STATIC BENDING STRENGTH OF THE "TABÓRZ" SCOTS PINE WOOD (*PINUS SYLVESTRIS* L.)

The paper presents the results of research on variability in the static bending strength of the "Tabórz" Scots pine wood (Pinus sylvestris L.). The wood samples for examination were obtained from the trunks of 260-year-old Scots pines felled in the "Sosny Taborskie" Nature Reserve. The mean value for all the tested wood samples amounted to 77.3 MPa, whereas for the individual trunks it reached 105.3 MPa, 66.4 MPa and 60.1 MPa, respectively. It is believed that the research results presented here are the first empirical data published concerning the mechanical properties of the wood of the "Tabórz" Scots pine, the trunks of which, due to their high quality, are considered in Europe to be extremely valuable timber.

Keywords: "Tabórz" Scots pine, static bending strength, wood

Introduction

Scots pine (*Pinus sylvestris* L.) is the predominant tree species in Polish forests, while its trunks are the most common raw material used by the wood-based industry. Regarding all of the species of trees growing in forests in Poland, the properties of pine wood are the most investigated [Paschalis 1980; Buchholz 1984; Paschalis and Staniszewski 1994; Tomczak et al. 2009, 2010; Jelonek et al. 2010, 2012; Tomczak and Jelonek 2012]. Particularly valuable specimens of Scots pine grow in Puszcza Taborska (Taborska Forest), within the Forest District of Miłomłyn, known as "Tabórz" Scots pine. The quality of this timber has been recognised in Europe since the 16^{th} century, when it was mentioned for the first time in historical records. Despite the fact that the timber in question is

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well known and highly regarded all over the world, it is believed that no empirical data have yet been published describing its properties . This paper aimed to fill this gap, partially at least, and presents the results of studies on variability in the static bending strength of the "Tabórz" Scots pine wood.

Materials and methods

The research material was obtained from compartment 94a of the Forest Subdistrict of Tabórz, situated on the edge of the "Sosny Taborskie" Nature Reserve, in the Forest District of Miłomłyn. According to the stand description, the pine trees in question are 260 years old [Forest Management Plan... 2014]. They grow in a fresh mixed deciduous forest, on rusty podzolic soil, mixed with beech (of 80, 120 and 200 years old) and oak trees (of 120 years old). Closure of the stand was determined as moderate, while the site index class for the pine was assessed as I. In the course of the sanitation cutting performed in this stand, three pine trees were felled. From each of them, a block with a length of 0.5 m was cut. Before cutting down the trees, their diameters at breast height were measured and the north direction was marked on their trunks, while after felling, the lengths of their stems were also measured. Due to the high monetary value of the butt-end parts of the felled trees, permission was only given for samples to be taken from the higher parts of the trunks. Therefore, the blocks were sampled from the stems at their half-length. A radial board enclosing the pith was cut out from every block in the N-S direction marked on the trunk, and then, two radial boards were taken out in the E-W direction. These boards were cut lengthwise into wood samples, the cross-sections of which had dimensions of 20 × 20 mm, according to the scheme presented in figure 1. The wood samples were then trimmed so their lengths were equal to 300 mm, and their longitudinal sections were smoothened. Within each of the geographically oriented segments (N, S, E and W), the wood samples were given respective numbers corresponding with a certain section of the trunk radius, according to the scheme in figure 1. Tests for static bending strength were performed on the

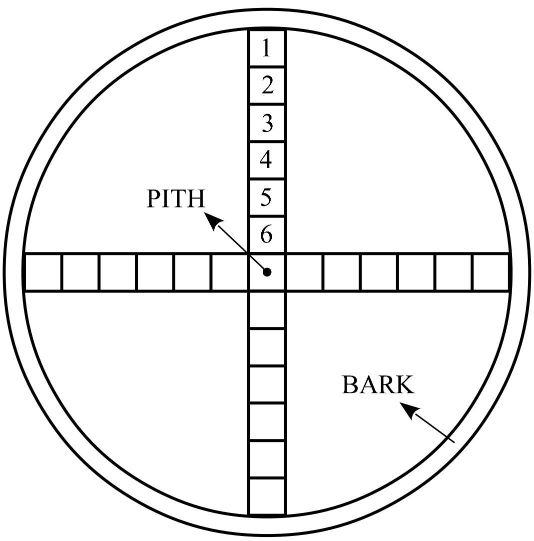

Fig. 1. Scheme presenting the wood sample collection method

EDZ-20 universal testing machine with a measuring range of 0- -200 kN. The samples were placed on the supporting elements of the machine and tests for static bending strength were performed on a three-point bending system, i.e. one pressing and two support-ing elements, according to the procedure as referred to in the PN-77/D-04103:1978 standard. Following this, the moisture content of the wood was deter-mined [PN-77/D-04100: 1978]. The value of the static bending strength of the wood obtained at a moisture content of W%, measured at the moment of the test performance, was recalculated and converted into the bending strength at a moisture content of 12%, according to the PN-77/D-04103:1978 standard. The computed values of the static bending strength at a moisture content of 12% were compared within the individual trees and the entire research material, and based on this, mean values and coefficients of variation were calculated.

Results and discussion

As mentioned above, the research material was obtained from the middle parts of the trunks of three felled pine trees. The diameters at breast height and lengths of their stems amounted to: 50 cm and 28 m for tree no. 1, 51 cm and 30 m for tree no. 2, 53 cm and 30 m for tree no. 3, respectively. The diameters of the 0.5-metre blocks, cut out from the trunks and measured with the bark, were as follows: tree no. 1: 37 cm, trees nos. 2 and 3: 38 cm each. The three aforementioned blocks were cut into 52 boards, which served to test the static bending strength of the wood. Tree no. 1 provided 21 boards (tab. 1): five boards from each of the northern (N), southern (S) and eastern (E) sections, and six boards from the western (W) one. From tree no. 2, a total number of 15 boards were obtained: five from the N section, four from the S one and six from the W section. Due to the fact that there was a knot in the eastern section of the block, obtaining boards from this part of the trunk proved to be impossible. The block cut out from tree no. 3 provided 17 boards: three boards from each of the N and S sections, six from the W one and five from the E section.

As shown in table 1, the mean value of the static bending strength for the entire research material amounted to 77.3 MPa. The mean values for the three examined trees were as follows: tree no. 1: 105.3 MPa, tree no. 2: 66.4 MPa and tree no. 3: 60.1 MPa. With regard to this parameter, the variability between the analysed trees amounted to 31.7%. A lower level of variability was observed for the trees that displayed similar values of the coefficient of variation: 16.1% for tree no. 1 and 19.5% for tree no. 3. The lowest static bending strength, amounting to 37.2 MPa, was recorded for a wood sample obtained from section 6, on the western side of tree no. 2, whereas the highest, 133.7 MPa, was for a sample from section 3, on the western side of tree no. 1.

Tab. 1. Presentation of the results of measurements concerning the static bending strength of the "Tabórz" pine wood

Tree number	Geographical orientation	Section number	σ_{12} [MPa]	Tree number	Geographical orientation	Section number	σ_{12} [MPa]	Tree number	Geographical orientation	Section number	σ_{12} [MPa]
1	N	1	104.5	2	N	1	65.9	3	N	1	46.5
		2	116.6			2	66.0			2	64.8
		3	109.4			3	77.4			3	76.6
		4	109.3			4	86.9				
		5	82.8			5	55.6				
		mean	104.5			mean	70.4			mean	62.7
		V [%]	12.4			V [%]	17.1			V [%]	24.2
	S	1	106.1		S	1	69.7		S	1	59.1
		2	98.6			2	65.5			2	72.4
		3	102.7			3	77.8			3	59.6
		4	90.2			4	68.7				
		5	111.9								
		mean	101.9			mean	70.4			mean	63.7
		V [%]	8.0			V [%]	7.4			V [%]	11.8
	W	1	108.9		W	1	63.6		W	1	40.2
		2	130.6			2	60.6			2	49.2
		3	133.7			3	75.5			3	54.1
		4	123.7			4	65.8			4	44.6
		5	83.2			5	60.1			5	53.0
		6	116.7			6	37.2			6	72.6
		mean	116.0			mean	60.5			mean	52.3
		V [%]	17.8			V [%]	21.0			V [%]	21.5
	E	1	115.7		E	–	–		E	1	53.6
		2	123.2							2	57.2
		3	71.6							3	68.5
		4	91.6							4	73.1
		5	80.8							5	77.2
		mean	99.9							mean	65.9
		V [%]	21.5							V [%]	15.4
mean			105.3	mean			66.4	mean			60.1
V [%]			16.1	V [%]			17.2	V [%]			19.5
In total		mean	77.3								
		V [%]	31.7								

σ_{12} – static bending strength of wood at a moisture content of 12%, V – coefficient of variation

The variance analysis revealed that there were statistically significant differences in the static bending strength between the investigated trees, while

Scheffe's test proved that this value for the wood of tree no. 1 was significantly higher when compared with the other two specimens, between which no statistically significant differences were detected (fig. 2).

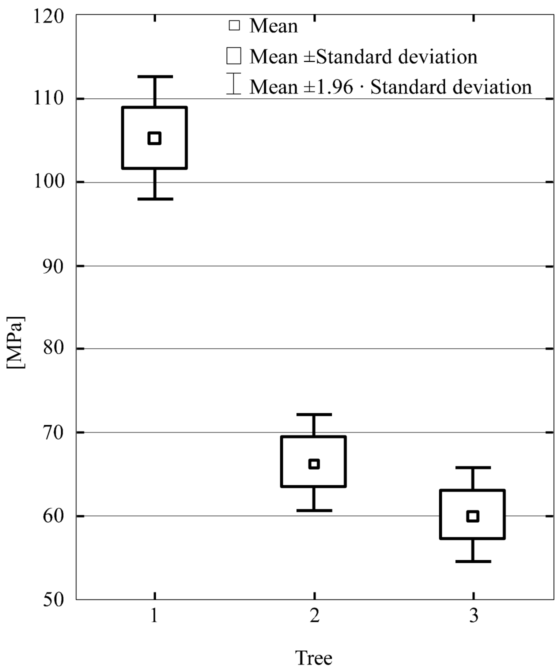

Fig. 2. Static bending strength of the wood from the three investigated trees

Due to the detection of clearly visible resinosis in 14 wood samples obtained from tree no. 1, the results of the tests performed for this specimen were subjected to the T-test, aimed at verifying whether the differences between the samples taken from the wood with and without resinosis were significant. However, it was not possible from this test to reject the hypothesis that there were no statistically significant differences ($p = 0.61276$). The mean values obtained for both of the examined groups amounted to 107.0 MPa for the wood with resinosis and 102.1 MPa for the wood without resinosis.

With regards to the geographically oriented segments, from which the wood samples were taken, no significant differences in the investigated parameter were established (Kruskal-Wallis test: $p = 0.4277$). The particular sections of the trunk radius did not differ in this respect either (variance analysis: $p = 0.7664$). Nevertheless, as presented in figure 3, an alignment of mean values for particular sections of the trunk radius took the characteristic shape of a curve, similar to a reversed parabola. The lowest mean value, 63.5 MPa, was recorded for samples from section 6, taken from the central part of the trunk, while the highest, 87.2 MPa, was observed for section 3.

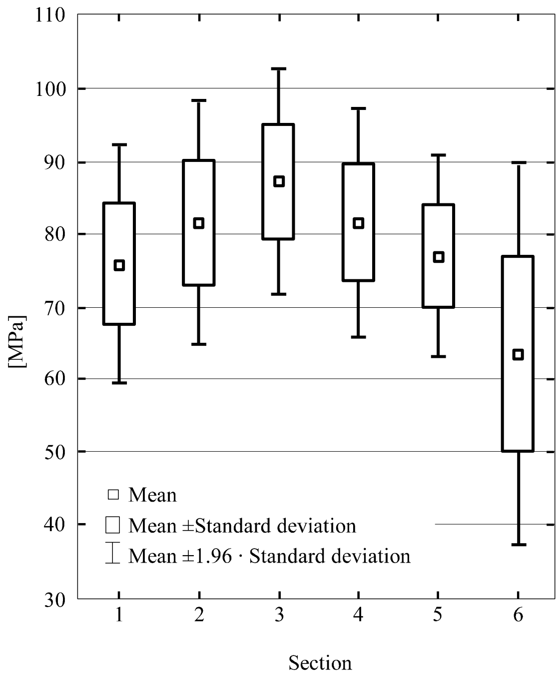

Fig. 3. Static bending strength in particular sections along the radius of the trunk cross-section

The mean value of the static bending strength of the "Tabórz" pine wood, obtained in the course of this study and amounting to 77.3 MPa, falls within the very wide range given in the existing literature, comprising values between 34 and 205 MPa [Galewski and Korzeniowski 1958; Krzysik 1974, SpławaNeyman and Owczarzak 2006]. Such a wide range is most likely due to the fact that the studies were conducted on highly diversified material, taken from trees of varying ages, growing in varied habitats and under different climatic conditions. For instance, considerably lower values of static bending strength, compared with those presented here, were given by Vestøl and Høibø [2010] for pine trees from Norway and Great Britain, where they amounted to 50.3 MPa and 53.8 MPa, respectively. Considering that in the above-mentioned research the wood from the butt-end parts of the trunks (near the nominal diameter for round wood) was examined, while the research material for this study was taken from the stems at their half-length, it can be assumed that comparing the values of the static bending strength of the butt-end parts of the trees in question would reveal even greater differences. This hypothesis is based on the results of the investigations carried out by Jelonek et al. [2011], according to which the static bending strength of wood sampled from a pine tree at its half-length is significantly lower than that of a sample taken at breast height. Such assumptions are also supported, though indirectly, by studies conducted by

Repola [2006], as well as Witkowska and Lachowicz [2012, 2013], which indicated that the density of pine wood decreases from its tip towards the trunk base, and this is the physical property that correlates with the mechanical properties of wood, the static bending and compression strength in particular [Krzysik 1974; Jelonek et al. 2005].

If it is assumed, based on the results of the investigations conducted by Jelonek et al. [2011], that the static bending strength of pine wood at a moisture content ranging between 30% (fibre saturation point) and 0% (absolutely dry wood) increases by ca. 1.5 MPa when the moisture content drops by 1%, the mean value obtained in this study is slightly lower (by ca. 3 MPa) than the one given in the above-mentioned research for a wood sample taken from the trunks of pine trees coming from the Forest District of Olesno (southern Poland), at their half-length.

The mean value of the static bending strength for tree no. 1, amounting to 105.3 MPa, was significantly higher when compared with the other two specimens. The value of the static bending strength of the wood sampled from tree no. 2 was lower by 37%, while for tree no. 3 it was lower by 43%. It is believed that such differences could primarily have been due to the resinosis recorded in 14 wood samples taken from tree no. 1. However, the statistical analyses did not confirm this assumption since the differences in the static bending strength between the samples with and without resinosis proved to be insignificant. Thus, it is possible that the significantly higher static bending strength of the wood samples from tree no. 1 was due to higher density of its wood, which may also be associated with its varied macrostructure. Indeed it was proved that the wood density of conifers is correlated with certain properties of their macrostructure, such as annual ring width and share of late wood [Wąsik 2007].

An analysis concerning the variability in the static bending strength of the "Tabórz" pine wood depending on the distance of the wood sample from the trunk pith indicated that its highest values were recorded more or less at the half-length of the radius of the trunk cross-section (section 3), whilst the lowest values were encountered in the centre, near the pith, comprising so-called juvenile wood. Similar results were obtained by Aleinikovas and Grigaliūnas [2006] for pine trees from Lithuania, as well as Tomczak and Jelonek [2013] for pine trees from western Poland. Moreover, the latter authors reported similar distributions of wood density along the trunk radius. This confirms the relationship between the mechanical properties of pine wood and its density, as mentioned above. Therefore, one might expect the wood density of the investigated "Tabórz" Scots pine to be highest at the half-length of the radius of the trunk cross-section, although this is just an assumption and should be verified at a further stage of the research.

The "Sosny Taborskie Nature Reserve", where this research was carried out, is passively protected [Dziekoński 2004]. A discontinuation of silvicultural treatments, supporting the main objective of establishing the nature reserve for this particular Scots pine, may result in a decrease in the highly regarded quality of its wood in the future. This concern is based on the results of comparative studies relating to the technical quality of the wood of spruce trees growing in commercial stands and nature reserves [Michalec et al. 2013]. Furthermore, Dziekoński [2004] indicated in recent years a marked decrease in the share of pine in the "Sosny Taborskie" Nature Reserve, with the pine being displaced by broadleaved species, mostly oak and beech. The above-mentioned author anticipates that maintaining the current form of protection may result in an absolute elimination of pine species from the reserve. In this context, the results of the examination of the "Tabórz" Scots pine in terms of the static bending strength of its wood, presented in this paper, may become a valuable historical record in the future. For the very same reasons, the scope of investigations into this particular pine wood should be extended to include other mechanical and physical properties, as well as its macrostructure and anatomy.

Conclusions

Based on the results obtained from studies on the variability in the static bending strength of the "Tabórz" Scots pine wood, the following statements and conclusions may be drawn:

- The mean value of the static bending strength of the wood for the entire research material amounted to 77.3 MPa, while the mean values for particular trees were as follows: 105.3 MPa, 66.4 MPa and 60.1 MPa, respectively.
- The wood from tree no. 1 was characterised by a significantly higher static bending strength, when compared with the other two specimens, which might have been due to its different macrostructure and density.
- The mean value of the static bending strength of the "Tabórz" pine wood obtained in this study was higher than those reported for pine trees from Finland and Great Britain, whereas it was similar to that of pine trees from southern Poland.
- The lowest value of the static bending strength was recorded for the wood from the central part of the trunk, located near the pith, while the highest was observed at the half-length of the radius of the trunk cross-section.
- Regarding the fact that there are no published empirical data describing the properties of the "Tabórz" pine wood, it is recommended that the scope of research is extended to include other mechanical and physical properties of this pine wood, including the variability in its macrostructure and anatomy.

References

Aleinikovas M., Grigaliūnas J. [2006]: Differences of Pine (*Pinus sylvestris* L.) Wood Physical and Mechanical Properties from Different Forest Site Types in Lithuania. Baltic Forestry, 12 [1]: 9-13

Buchholz J. [1984]: Wpływ wieku na jakość techniczną drewna sosnowego (Effect of age on the technical quality of pine wood). Folia Forestalia Polonica. Ser.B 15: 17-31

Dziekoński H. [2004]: Próba oceny zasadności stosowania ochrony biernej w rezerwatach utworzonych z drzewostanów zagospodarowanych na przykładzie rezerwatu „Sosny Taborskie" (An attempt to assess the usefulness of passive protection in reserves established in managed stands on the example of the "Sosna Taborska" Reserve). Sylwan 148 [5]: 60-68

Forest Management Plan for the Forest District in Miłomłyn in 2014-2023 [2014]: Biuro Urządzania Lasu i Geodezji Leśnej, Oddział w Olsztynie (Bureau of Forest Management and Geodesy, Olsztyn Division)

Galewski W., Korzeniowski A. [1958]: Atlas najważniejszych gatunków drewna (Atlas of the most important wood species). PWRiL, Warszawa

Jelonek T., Pazdrowski W., Arasimowicz-Jelonek, Tomczak A. [2010]: Właściwości drewna sosny zwyczajnej (*Pinus sylvestris* L.) pochodzącej z gruntów porolnych (Properties of wood of Scots pine (*Pinus sylvestris* L.) growing on former farmlands). Sylwan 154 [5]: 299-311

Jelonek T., Pazdrowski W., Tomczak A., Grzywiński W. [2012]: Biomechanical stability of pines growing on former farmland in northern Poland. Wood Research 57 [1]: 31-44

Jelonek T., Tomczak A., Jakubowski M., Pazdrowski W. [2005]: Properties of Scots pine (*Pinus sylvestris* L.) timber growing on former arable and forest land. Acta Scietiarum Polonorum. Silvarum Colendarum Ratio et Industria Lignaria 4 [2]: 35-47

Jelonek T., Tomczak A., Jakubowski M., Remlein A. [2011]: The estimation of biomechanical stability parameters of trees growing under former farmland conditions. Annals of Warsaw University of Life Sciences – SGGW, Forestry and Wood Technology 74: 150-155

Krzysik F. [1974]: Nauka o drewnie (Wood science). PWN, Warszawa

Michalec K., Barszcz A., Wąsik R. [2013]: Jakość surowca świerkowego pochodzącego z drzewostanów naturalnych (rezerwatowych) i drzewostanów gospodarczych (The quality of spruce timber from natural stands (forest reserves) and managed stands). Drewno – Wood. Prace Naukowe, Doniesienia, Komunikaty 189 [55]: 25-37

Paschalis P. [1980]: Zmienność jakości technicznej drewna sosny pospolitej we wschodniej części Polski (Variation in technical quality of Scots pine wood in the eastern part of Poland). Sylwan 124 [1]: 29-44

Paschalis P., Staniszewski P. [1994]: Zmiany niektórych wskaźników własności drewna sosny z terenów zanieczyszczonych przemysłowo (Variability in certain indices of properties of pine wood from the areas affected by industrial pollution) Sylwan 138 [8]: 35-41

Repola J. [2006]: Models for vertical wood density of Scots pine, Norway spruce and birch stems, and their application to determine average wood density. Silva Fennica 40 (4): 673-685

Spława-Neyman S., Owczarzak Z. [2006]: Użytkowe gatunki drewna **(**Usable timber species). Instytut Technologii Drewna. Poznań. www.itd.poznan.pl

Tomczak A., Jelonek T. [2012]:Parametry techniczne młodocianego i dojrzałego drewna sosny zwyczajnej (*Pinus sylvestris* L.) (Technical parameters of juvenile and mature wood in Scots pine (*Pinus sylvestris* L.)). Sylwan 156 [9]: 695-702

Tomczak A., Jelonek T. [2013]: Promieniowa zmienność właściwości drewna sosny zwyczajnej (*Pinus sylvestris* L.) wyrosłej na gruntach porolnych (Radial variation in the wood properties of Scots pine (*Pinus sylvestris* L.) grown on former agricultural soil). Leśne Prace Badawcze 74 [2]: 171-177

Tomczak A., Jelonek T., Zoń L. [2010]: Porównanie wybranych właściwości fizycznych drewna młodocianego i dojrzałego sosny zwyczajnej (*Pinus sylvestris* L.) z drzewostanów rębnych (Comparison of selected physical properties of the juvenile and mature wood of Scots pine (*Pinus sylvestris* L.) from mature stands). Sylwan 154 [12]: 809-817

Tomczak A., Pazdrowski W., Jelonek T., Grzywiński W. [2009]: Jakość drewna sosny zwyczajnej (*Pinus sylvestris* L.) Część I. Charakterystyka wybranych cech i właściwości drewna wpływających na jego jakość (Quality of Scots pine (*Pinus sylvestris* L.) wood Part I. Characteristics of selected wood traits and properties affecting its quality). Sylwan 153 [6]: 363-372

Vestøl G. I. Høibø O. [2010]: Bending strength and modulus of elasticity of *Pinus sylvestris* round timber from southern Norway. Scandinavian Journal of Forest Research, 25: 185-195

Wąsik R. [2007]: Zmienność cech makrostruktury i gęstości drewna daglezji zielonej (*Pseudotsuga menziesii* var. *viridis* Franco) na terenie Polski (Variability of the features of macrostructure and wood density of Douglas fir (*Pseudotsuga menziesii* var. *viridis* Franco) in Poland). Drewno 50 [178]: 57-85

Witkowska J., Lachowicz H. [2012]: Analiza zmienności gęstości umownej drewna sosny zwyczajnej (*Pinus sylvestris* L.) wzdłuż wysokości pnia w zależności od wybranych czynników (Analysis of variation in pure density of Scots pine wood (*Pinus sylvestris* L.) along a trunk height depending on selected factors). Przegląd Papierniczy 68: 1-6

Witkowska J., Lachowicz H. [2013]: Zmienność gęstości umownej drewna sosny zwyczajnej (*Pinus sylvestris* L.) w zależności od wybranych czynników (Variability of conventional wood density of Scots pine (*Pinus sylvestris* L.) depending on the selected factors). Sylwan 157 [5]: 336-347

List of standards

PN-77/D-04100:1978 Drewno – Oznaczanie wilgotności (Wood – Determination of Moisture Content)

PN-77/D-04103:1978 Drewno – Oznaczanie wytrzymałości na zginanie statyczne (Wood – Determination of ultimate strength in static bending)

Acknowledgements

This research was financed by the Ministry of Science and Higher Education of the Republic of Poland