Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology № 83, 2013: 24-28
(Ann. WULS - SGGW, For. and Wood Technol. 83, 2013)

Axial variation in modulus of elasticity (MOE) in wood of Scots pine (*Pinus sylvestris* L.) growing in stands particularly exposed to wind

TOMASZ JELONEK, ARKADIUSZ TOMCZAK, WITOLD PAZDROWSKI
Department of Forest Utilisation, Poznan University of Life Sciences

Abstract: *Axial variation in modulus of elasticity (MOE) in wood of Scots pine (Pinus sylvestris L.) growing in stands particularly exposed to wind*. The study comprised an analysis of axial variation in modulus of elasticity (MOE) in wood of Scots pine growing in mature stands particularly exposed to wind. Investigations were conducted on 72 trees growing in eight different localities in northern Poland (the Regional Directorate of the State Forests in Szczecinek). Axial variation in modulus of elasticity was analysed in wood of the tested trees. The highest values of the examined property were recorded in the butt end section of stems in trees growing in the high (A) and medium (B) wind load zones. The lowest values were recorded in the tree top parts of trees growing in zone A.

Keywords: Scots pine, tree stability, wind, slenderness ratio

INTRODUCTION

Stress factors influencing the forest environment are complex in nature and typically they are characterised by synergism. One of the main abiotic factors affecting the forest is connected with mechanical stress caused by the action of wind, which annually causes damage in several dozen to several hundred thousand hectares of forests (Raport…2011).

The effect of wind on forest ecosystems is unique, because it continuously affects the forest community and through its violent character it causes considerable economic losses in commercial forests. For this reason it is an object of interest of many researchers (Fournier 2006; Peltola 2006; Quine and Gardiner 2007; Jelonek et al. 2011, 2013).

Wind-induced damage in forests is not limited only to tree damage resulting from its high velocity. There may be damage to wood tissue caused by the response of trees to moderate dynamic load (Mayer 1987; Peltola et al. 1993; Kerzenmacher and Gardiner 1998; Flesch and Wilson 1999). In order to alleviate the effects of the action of high winds many studies focus on the understanding in what manner wind influences trees (Mayer 1987; Gardiner 1994; Wood 1995). Many contemporary studies attempt to develop biomechanical models of trees or models used in the prediction of wind damage to stands (Bruchwald and Dmyterko 2012; Jelonek et al. 2013).

The factor determining tree resistance to the action of wind is related with the so-called biomechanical system, which combines both morphological traits of trees and properties of wood tissue (Jelonek 2013). Wood is a biological conglomerate with exceptional properties, such as e.g. low density at a simultaneous high strength. However, despite numerous advantages wood is characterised by very high variability (Perré and Badel 2003). Variation in properties of wood inside pine stems was analysed by Mahado and Crus (2005). They found a gradual deterioration of mechanical properties of wood in the direction from the stem base to its top. Similar conclusions were drawn by Jelonek 2013 and Jelonek et al. 2012 when investigating variation in wood tissue in pines growing on former farmland soils.

The study analysed adaptation growth of pines exposed to wind. Axial variation in modulus of elasticity (MOE) was investigated in stands particularly exposed to wind.

METHODS

Investigations were conducted in 8 pine stands of age class V growing in the fresh mixed coniferous forest site in the Regional Directorate of the State Forests in Szczecinek (tab. 1). Stands were selected to ensure their similarity in terms of taxation traits, while at the same time they were adjacent to open space from the west. In each of the stands one experimental site was established in the form of a rectangle, which one side (100 m) was adjacent to the edge of the stand neighbouring with open space. The second side reached deep into the stand to a distance equivalent to three mean tree heights in the stand. Next each experimental site was divided into three zones of wind load imposed on trees. Zone A – the strongest loads, the zone adjacent to open space. Zone B – average load. Zone C – the smallest loads, the zone located farthest from the edge of the stand.

In all plots all breast height diameters and tree heights were measured and on this basis 9 sample trees were selected, with three in each wind load zone. Samples trees were felled and from each five 0.5-m blocks were cut, corresponding to breast height (1.3 - 1.8 m) as well as 20, 40, 60 and 80% tree height, respectively. Collected material was cut into strips of 20 x 20 x 300 mm, which were further analysed in terms of modulus of elasticity. Tests were conducted on wood with a moisture content exceeding fibre saturation point, since such a wood tissue is found in the living tree, which corresponds to its actual elasticity and resistance to the action of external factors causing mechanical stress.

Collected empirical data were analysed using statistical methods with the application of the *STATISTICA 10PL* software package.

Tab. 1 Location and selected taxation traits of analysed stands

Forest districts	Compartment	Forest site type	Composition	Age	Stand stocking	Quality class	Crown closure
Miastko	193b	BMśw	10So	84	0,9	I	PRZ
Miastko	125d	BMśw	10 So	89	0,7	I	PRZ
Warcino	106c	BMśw	10So	86	0,9	I	PRZ
Czaplinek	231f	BMśw	8So2So	87	1,1	I	PRZ
Łupawa	291a	BMśw	10So	83	0,7	I	PRZ
Swidwin	7a	BMśw	10 So	83	1,1	I	PRZ
Złotów	43d	BMśw	10 So	82	0,9	I	PRZ
Czarnobór	129g	BMśw	10 So	82	0,8	I	PRZ

RESULTS

On average modulus of elasticity of wood at static bending was 5018 [MPa] and it was characterised by variation of 28% (Tab. 1). In the axial distribution the highest values (5712 MPa) of modulus of elasticity were recorded in the first, butt end zone of the stem and they decreased gradually with the passage to higher stem sections, reaching its minimum, i.e. 3887 [MPa], in the last, tree top section of the stem. The greatest variation in the analysed properties, amounting to 31%, was recorded at level II, while the lowest variation (22%) was found for level III, i.e. 40% tree height. Moreover, statistically significant differences were observed between each of the levels compared in this study. These differences were significant at $p < 0.01$ (Tab. 1).

Tab. 2 Basic statistical characteristics of modulus of elasticity of wood and results of HSD RIR test

	MOE [MPa]			
Level	**Mean**	**Standard deviation**	**Coefficient of variation**	**p**
I	5712.45	1366.11	23.91	0.01
II	5290.69	1626.86	30.75	
III	4776.84	1032.27	21.61	
IV	4314.74	990.67	22.96	
V	3887.25	902.08	23.21	
Total	5018.47	1419.10	28.28	

Next modulus of elasticity (MOE) was analysed in each of the three wind load zones. In each of the zones a gradual decrease was observed in the values of this modulus with the passage to higher parts of the stem (Fig. 1). The highest values of modulus of elasticity were recorded in the bottom section of stems with the greatest mechanical loads in pines growing in zones A (5762 MPa) and B (5766 MPa). In turn, the values were lowest in the upper stem sections of trees growing in the zone of high wind load (3651 MPa).

Modulus of elasticity in wood at static bending differed statistically significantly at each of the examined levels in all the compared zones (A, B and C). In contrast, no significant differences were found between the same stem levels in trees growing in different wind load zones.

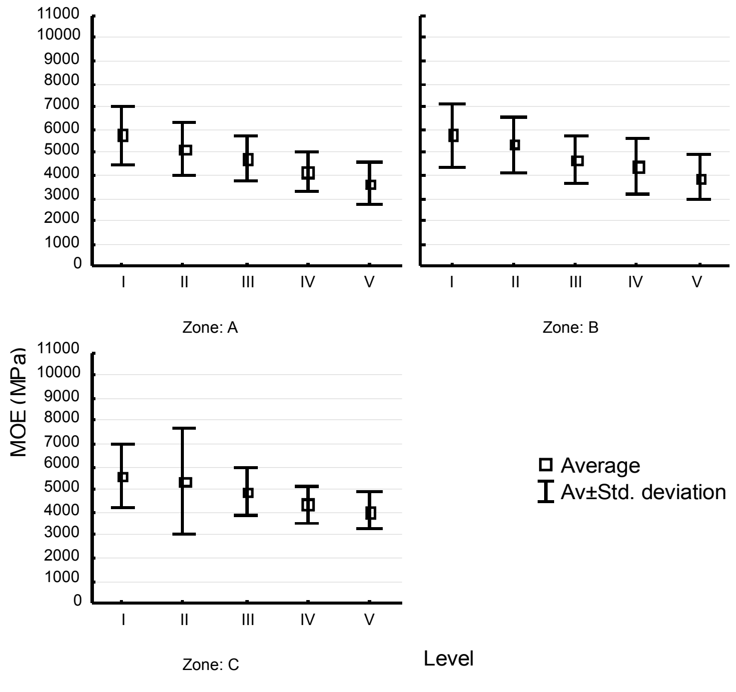

Fig. 1 Axial variation in modulus of elasticity in wood of trees growing in different wind load zones

CONCLUDING REMARKS AND DISCUSSION

Wind significantly modifies forest ecosystems and it is one of the factors determining the formation of trees, landscape and forest sites (Mitchell 2012).

Moreover, it continuously causes considerable economic losses in commercial forests and for this reason its effect has been investigated by many researchers (Zajączkowski et al. 1991, 2004, Fournier et al. 2006, Peltola 2006, Quine and Gardiner 2007).

In this study modulus of elasticity was determined in wood of trees growing in different wind load zones. Values of modulus of elasticity in wood of tested pines ranged from 1588 to 30204 MPa and they were consistent with the results supplied by Gurau et al. (2008) and Lindström et al. (2009). In turn, axial variation was found in all moduli of elasticity in wood within a single tree is mainly connected with the proportion of late wood as well as juvenile wood tissue in tree stems (Perrson et al. 1995).

In their studies conducted on wood properties in trees exposed to wind load Brüchert and Gardiner (2006) found variation both in the form and properties of wood depending on tree exposure to wind. Trees with the greatest wind exposure growing at the edge of the stand were characterised on average by a lower height and greater tapering in relation to trees, which were growing inside the stand. A greater rigidity of the stem at its base and its greater elasticity in the crown zone were recorded in this group of trees. Results reported by Brüchert and Gardiner (2006) to a considerable degree are consistent with those obtained in this study. The highest modulus of elasticity was found in the lower stem part of pines growing in zones A and B, while they were lowest in the upper section of trees growing in the zone of high wind load (A).

REFERENCES

1. BRÜCHERT F., GARDINER B. 2006: The effect of wind exposure on the tree aerial architecture and biomechanics of Sitka spruce (*Picea sitchensis*, Pinaceae). Am. J. Bot. 93(10): 1512–1521.
2. BRUCHWALD A., DMYTERKO E. 2012: Ryzyko powstawania szkód w drzewostanach poszczególnych nadleśnictw Polski. Sylwan. 156 (1): 19-27.
3. FLESCH T.K., WILSON J.D. 1999: Wind and remnant tree sway in forest cutblocks. II. Relating measured tree sway to wind statistics. Agric. Forest Meteorol. 93, 243–2
4. FOURNIER M., STOKES A., COUTAND C., FOURCAUD T., MOULIA B. 2006: Tree biomechanics and growth strategies in the context of forest functional ecology. *In* A. Herrel, T. Speck, and N. Rowe [eds.], Ecology and biomechanics: A mechanical approach to the ecology of animals and plants, 1 – 33. CRC Press Taylor & Francis, Boca Raton, Louisiana, USA.
5. GARDINER B. A. 1994: Wind and wind forces in a plantation spruce forest. Boundary-Layer Meteorology 67: 161 – 186.
6. GURAU L., CIONCIA M., Mansfield-Williams H., Sawyer G., Zeleniuc O. 2008: Comparison of the mechanical properties of branch and stem wood for three species. Wood Fib. Sci. 40(4): 647 – 656.
7. JELONEK 2013: Biomechaniczna stabilność drzew a wybrane właściwości fizyczne, mechaniczne i strukturalne ksylemu sosny zwyczajnej (*Pinus sylvestris* L.) wyrosłej w warunkach gruntów porolnych i leśnych, Rozprawy naukowe 455, Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu, Poznań 2013.
8. JELONEK T., JAKUBOWSKI M., TOMCZAK A. 2011: The effect of wind exposure on the selected stability parameters of the Scots pine stands. Ann. Warsaw Univ. of Life Sci. – SGGW, For. and Wood Technol. 74: 143-149.
9. 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.

10. JELONEK T., WALKOWIAK R., JAKUBOWSKI M., TOMCZAK A. 2013: Wskaźniki stabilności drzew w drzewostanach sosnowych uszkodzonych przez wiatr. Sylwan 157 (5):323-329.
11. KERZENMACHER T., GARDINER, B.A. 1998: A mathematical model to describe the dynamic response of a spruce tree to the wind. Trees 12, 385–394.
12. LINDSTRÖM H., REALE M., GREKIN M. 2009: Using non-destructive testing to assess modulus of elasticity of *Pinus sylvestris* trees. Scan. J. For. Res. 24: 247-257.
13. MAYER , H. 1987: Wind-induced tree sways. Trees (Berlin) 1: 195 – 206.
14. PELTOLA H. 2006: Mechanical stability of trees under static loads. Am. J. Bot. 93 (10): 1501–1511.
15. PELTOLA H., KELLOMÄKI S., HASSINEN A., LEMENTTINEN M., AHO J. 1993: Swaying of trees caused by wind: analysis of field measurements. Silva Fennica. 27 (2): 113–126.
16. PERSSON B., PERSSON, A., STAHL E.G., KARLMATS U. 1995: Wood quality of *Pinus sylvestris* progenies at various spacings. For. Ecol. Manage. 76: 127–138.
17. RAPORT O STANIE LASÓW 2011: Centrum Informacyjne Lasów Państwowych, Warszawa.
18. QUINE C. P., GARDINER B. A. 2007: Understanding how the interaction of wind and trees results in windthrow, stem breakage, and canopy gap formation. In: Johnson, E.A., Miyanishi, K. (Eds.), Plant Disturbance Ecology—The Process and the Response. Elsevier, Amsterdam.
19. WOOD C. J. 1995: Understanding wind forces on trees. *In* M. P. Coutts and J. Grace [eds.], Wind and trees, 133 – 164. Cambridge University Press, Cambridge, UK.

Streszczenie: *Osiowa zmienność modułu sprężystości (MOE) drewna sosny zwyczajnej (Pinus sylvestris L.) wyrosłej w drzewostanach szczególnie narażonych na działanie wiatru.* W pracy przeprowadzono analizę osiowej zmienności modułu elastyczności (MOE) drewna sosny zwyczajnej wyrosłej w drzewostanach rębnych szczególnie eksponowanych na działanie wiatru. Badania przeprowadzono na 72 drzewach wyrosłych na ośmiu różnych stanowiskach w północnej Polsce (RDLP Szczecinek). Stwierdzono osiową zmienność modułu sprężystości drewna badanych drzew. Najwyższe wartości badanej właściwości stwierdzono w odziomkowej części strzał drzew wyrosłych w dużej (A) i średniej (B) strefie obciążenia wiatrem. Najniższe zaś w wierzchołkowej partii drzew wyrosłych w strefie A.

ACKNOLEDGEMENT: *The study was financed from funds for science in the years 2011-2014 as research project no. N N309 108240*

Corresponding author:

Tomasz Jelonek
Poznan University of Life Sciences
Department of Forest Utilisation
Wojska Polskiego 71A,
60-625 Poznań,
Poland
e-mail: tomasz.jelonek@up.poznan.pl
Phone +48 61 8487754
Fax +48 61 8487755