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Study of selected properties of red maple wood (*Acer rubrum*) from the experimental plot of the forest arboretum in Rogów

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Abstract: *Study of selected properties of red maple wood (Acer rubrum) form the experimental plot of the forest arboretum in Rogów*. As part of the work, investigation on the dendrometric, physical and mechanical properties of red maple trees and its wood from the Forest Experimental Plant in Rogów has been carried out. The obtained results of the research on the species experimentally introduced in Rogów were compared with the features of the *Acer rubrum* from the area of natural occurrence in North America. The results of the investigation showed that the trees from the Arboretum area have a lower height, a much smaller trunk diameter and their physical and mechanical properties are weaker than the maple wood grown in native conditions. Despite the above statements, the significant influence of the location of the wood in the trunk (distance to the core) on its density, acoustic properties and static modulus of elasticity, bending and compression strength along the fibers are noted.

Keywords: *Acer rubrum*, dendrometric features, wood density, modulus, acoustic properties, bending strength, compression strength

INTRODUCTION

Red maple (*Acer rubrum* L.) is more common in the northeastern part of the United States and Canada in mixed deciduous forests. Mainly found in lowlands, river banks and wetlands, in combination with black and red ash, thuja and American larch in the eastern part of North America. In Europe Acer rubrum is mostly used for ornamental purposes where it is planted in parks, gardens and public spaces. Under native conditions, it takes the form of a tall tree, reaching ca. 30 m in height and ca. 0,6 to 1 m in trunk circumference (Hough 2013). In Central Europe climate, it reaches ca. 10 to 20 m in height (Porter 2012).

Red maple wood belongs to diffuse - porous wood species. The sapwood is creamy white to greyish, strongly demarcated from the heartwood of various shades, from light to dark reddish brown, commonly with a faint of purplish or greyish hue (Hoadley 1990, Porter 2012).

Dendrochronological research for red maple carried out by Justin Pszwaro in America proved that the place and climate in which the tree is grown is important. These factors clearly affect the growth and development of the species (Reed 1992, Fekedulegn 2003, Pszwaro 2015). This hypothesis was tested in Poland to see how exactly the European climate affects Acer rubrum and how its properties will change. Average dried weight of red maple is 610 kg/m^3 in air drying condition. Its lumber is easy to work with both hand and machine tools (Meier 2015). It has good bending and crushing strength, but low stiffness and shock resistance.

Red maple is defined as unstable and perishable in terms of resistance to decomposition by external factors, such as outdoor use, immersion in water, attacks of pests, fungi or bacteria (Internet 1). Probably the wood of red maple has the lowest natural resistance to fungi (class 5), as does the wood from other *Acer* species mentioned in EN 350:2016. The stands from the Arboretum area, from which samples were collected for research, had relatively little contact with the taxa of fungi and plants. The presence of dangerous species of fungi for exotic trees was noted in a very small amount, therefore the tested samples should not have any changes in the composition of the wood and it should not be weakened (Wojerska i in. 2012). As red maple is a non-persistent species, its use should be restricted to indoor implementation. Therefore, it is widely used in the production of furniture, especially in upholstered elements and as secondary wood (Porter 2012).

Research on the red maple in 2014 focused on determining the elastic characteristics. Moisture content of Acer rubrum was 9% and its level of density was 651 kg/m^3. Modulus of elasticity (MOE) for the species was in the range of bibliographic data dispersion, where the average value was 11879 MPa (Hernández-Maldonayot 2014).

AIM AND SCOPE OF STUDY

The aim of the study is to determine the dendrometric features of the acquired arboretum trees, and to obtain information on selected physical and mechanical properties of red maple wood, to be able to compare its properties with conventional red maple wood and evaluation of optimal wood disposal based on its properties.

MATERIAL AND METHODS

The test samples were taken from the Forest Experimental Plant in Rogów where, in 1973, on an area of 0.14 ha, 541 tree grafts originally from the Argonne Experimental Forest in Wisconsin were planted. The cultivation was established in an open area after cutting a 50-year-old stand in a depressed area (Fig.1). Of all the trees planted after the last thinning, only 74 of them remained (Chronicle of the experimental plot 1970-2020).

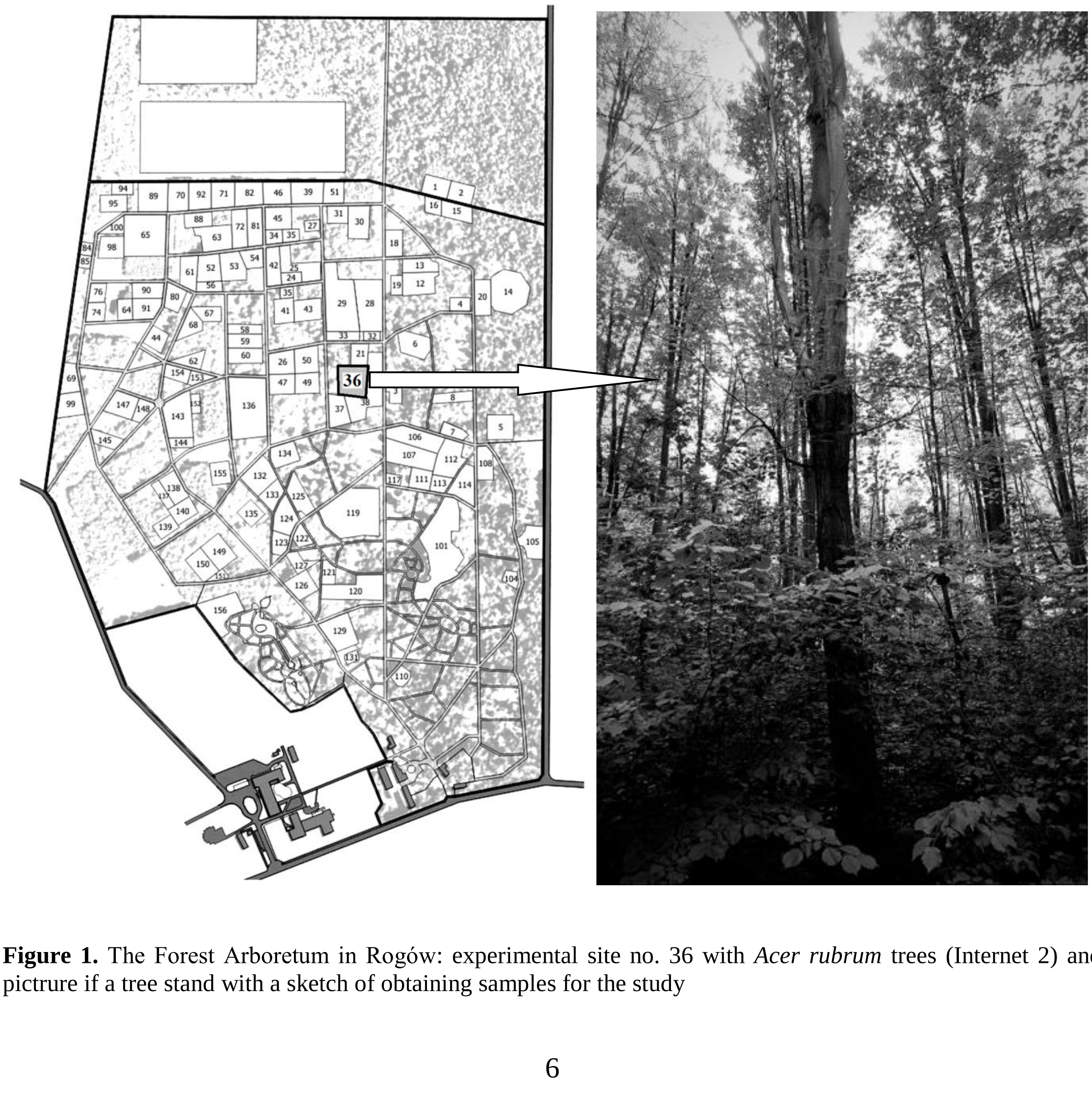

Figure 1. The Forest Arboretum in Rogów: experimental site no. 36 with *Acer rubrum* trees (Internet 2) and pictrure if a tree stand with a sketch of obtaining samples for the study

The trees were selected taking into account their biosocial position in the stand. Seven trees (class II according to Kraft's classification) were selected for the study - dominant trees - forming the main ceiling of the stand, with a well-developed crown.

As part of the work, the dendrometric features of the harvested trees will be determined (height, diameter, thickness, trunk shape), and then selected physical and mechanical properties of the wood (moisture content, density, modulus of elasticity, acoustic properties, bending and compressive strength along the fibers), taking into account the location on the transverse section of the trunk. Most of the tests were carried out according to the international standards (ISO 4471:1982, ISO 13061-1:2014, ISO 13061-2:2014, ISO 13061-3:2014 ISO 13061-4:2014, ISO/DIS 13061-17:2014). A deviation from the standards was the testing of wood with a moisture content close to the fiber saturation point. Thanks to this, the strength of wood was determined as it has in living trees. After strength tests, the appearance of damages was analyzed in accordance with American standard (ASTM D 143-94:2000). The samples (slices and bars) for individual tests were indented and numbered according to the scheme in Figure 2.

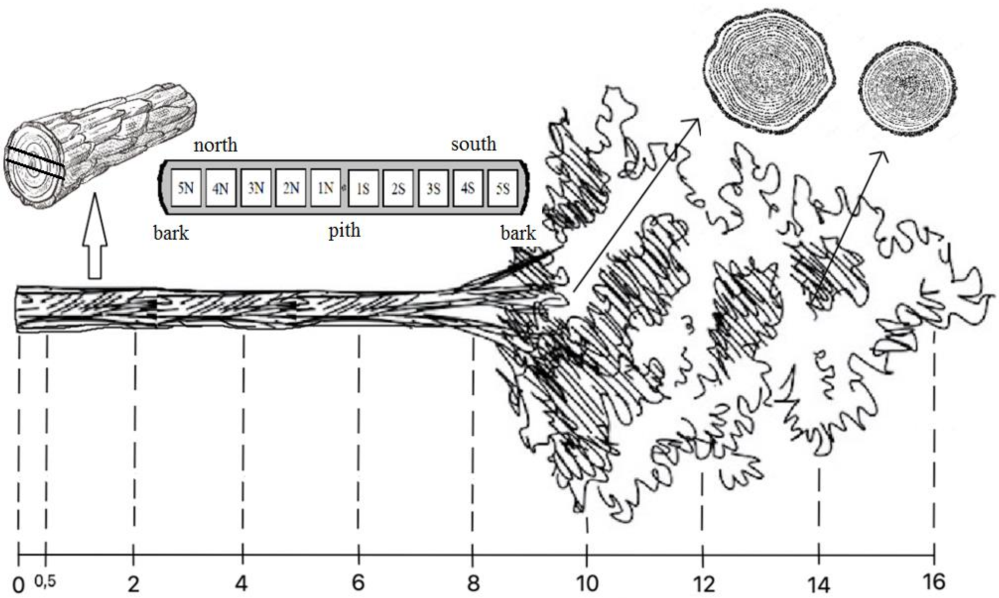

Figure 2. The method of obtaining samples (slices and bars) to test the individual characteristics of wood

The exception was the study of acoustic properties of wood using the original methodology and specialized equipment UMT-1 materials tester. The ultrasound tests were performed with the transition method using the impulse mode and polyacrylic gel as a coupling substance. A 40 kHz frequency head with the face radius of 40 mm was used. On the basis of previous research (e.g. Hadinata and Kozakiewicz, 2020), appropriate settings of the device were adjusted: 40 dB gain, repulsion of 12Hz, signal amplification at 60V. After running ultrasound waves parallel to the grain (samples 300 mm long), the time of the main echo was read and the results were used to calculate some acoustic properties of red maple wood:

$$c_{||} = \frac{L}{t} \tag{1}$$

where: c - velocity of the longitudinal ultrasound waves parallel to the grain [m/s]

L - sample length [m] (assuming that $L >> \lambda$)

$t = t_1 - t_0$ - real time of the passing through of the longitudinal wave [s]

t_1 – time of the passing through of the wave read from the computer screen [s]

t_0 – lag time [s]

$$MOE_d = 0.74286 \cdot c_{\|}^2 \cdot d \tag{2}$$

where: MOE_d – dynamic modulus of elasticity parallel to the grain [GPa]

0.74286 – reduced Poisson's ratio for wood

d – density of wood of a known moisture content [kg/m^3]

$$T = \frac{5 \cdot 10^{-8} \cdot c}{g} = \frac{5 \cdot 10^{-8} \sqrt{\frac{E}{g}}}{g} \tag{3}$$

where: T - damping of ultrasound radiation

$$Z = g \cdot c = g \cdot \sqrt{\frac{E}{g}} = \sqrt{g \cdot E} \tag{4}$$

where: Z - ultrasound wave resistant

RESULTS AND DISCUSSION

Dendrometric parameters

Figure 3 shows dendrometric data such as tree height, its diameter every 2 meters and the false heartwood diameter also measured in such intervals of the trunk height.

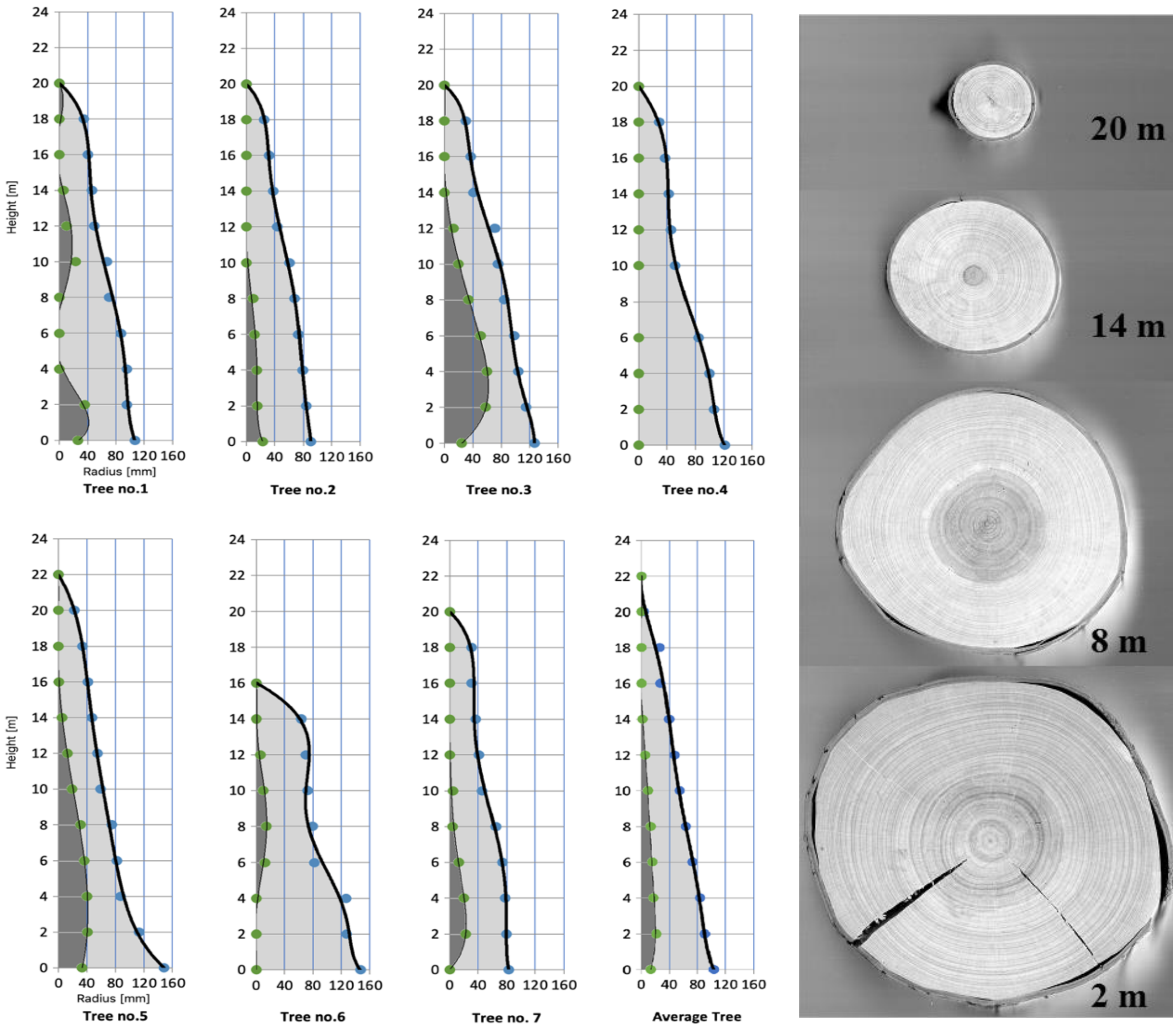

Figure 3. Radius length and radius length in hardwood in all obtained trees and a scanned wood discs (exemplary from tree no.5) of red maple

Acer rubrum in its native conditions reaches a height of 19-27 meters, and its trunk diameter is about 46-76 cm (Smith and Dudzik 1997). This species often has a defect called false heartwood, which manifests itself in some parts of the trunk with a darker, often glaucous-green shade. The size of the heartwood diameter was examined in relation to the age and radial growth rate of trees, which was related to the number and size of scars from dead branches (Belleville and others 2011). The studied samples from Rogów mostly fit into the height of the red maple in native conditions, reaching an average of 20 m, while their diameter turned out to be much smaller, reaching only 24 cm.

The grain of the wood

The collected wood rings of 50-year-old red maple trees were examined in terms of average growth in width. The analysis of the average annual growth was carried out on the basis of scanned wood discs that were cut every two meters from the height of the tree. Table 1 shows a greater and faster growth of annual rings on a tree height of 8 m. The tested samples show that the average annual increase in red maple volume decreased with age.
This means that in the initial stage of development, Acer rubrum gains almost twice as much growth in width as in the final stage of tree growth.

Table 1. Width of annual rings of red maple wood

The height of the tree	Tree number							Average value
	1	**2**	**3**	**4**	**5**	**6**	**7**	
0	2,2	1,8	2,8	2,5	3,0	2,8	1,7	2,4
2	2,2	2,0	2,7	2,4	2,6	3,0	1,9	2,4
4	2,3	1,9	2,4	2,3	2,0	3,1	1,9	2,3
6	2,2	1,9	2,6	2,0	2,0	2,1	2,0	2,1
8	1,9	1,9	2,4	-	2,0	2,1	1,8	2,0
10	2,0	1,8	2,2	1,4	1,5	2,1	1,4	1,8
12	1,6	1,4	2,4	1,4	1,6	2,2	1,2	1,7
14	1,6	1,5	1,6	1,3	1,4	2,1	1,2	1,5
16	1,7	1,3	1,6	1,3	1,4	-	1,2	1,4
18	1,6	1,2	1,6	1,2	1,3	-	1,3	1,4
20	-	-	-	-	1,0	-	-	1,0

Research in North America shows that during the first 10 years of growth, the tree on average gains 5.7 cm larger diameter (Walters and Yawney 1990). Red maple from the experimental plot in Rogów produced narrow-grained wood. It seems that the decisive influence here is the high density of the stand and the deficit in access to sunlight, which reduces the efficiency of photosynthesis.

Physical properties (density, moisture content)

Based on the research, the average density of the tested red maple wood samples was determined, and their value was 683 kg/m^3 (Fig.4). The density reported by Porter (2012) of red maple wood from Canada was 630 kg/m^3, and for wood tested by Hernández-Maldonado (2014) 651 kg/m^3. The pieces tested for mechanical properties were sampled for drying and tested for moisture content. The moisture content of the tested samples was about 25%. It was wood in a state close to the moisture of the fiber saturation point.

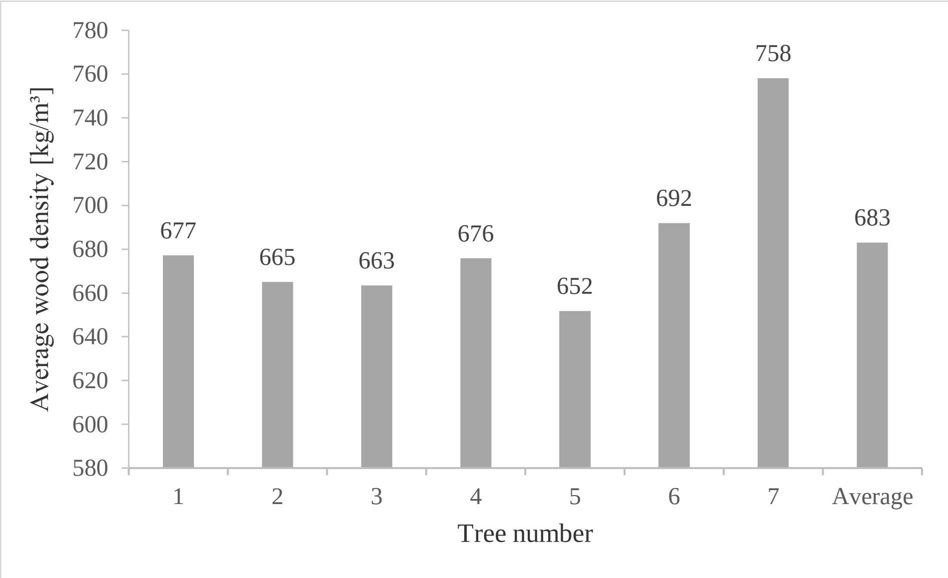

Figure 4. Average wood density of red maple obtained from the Rogów Arboretum

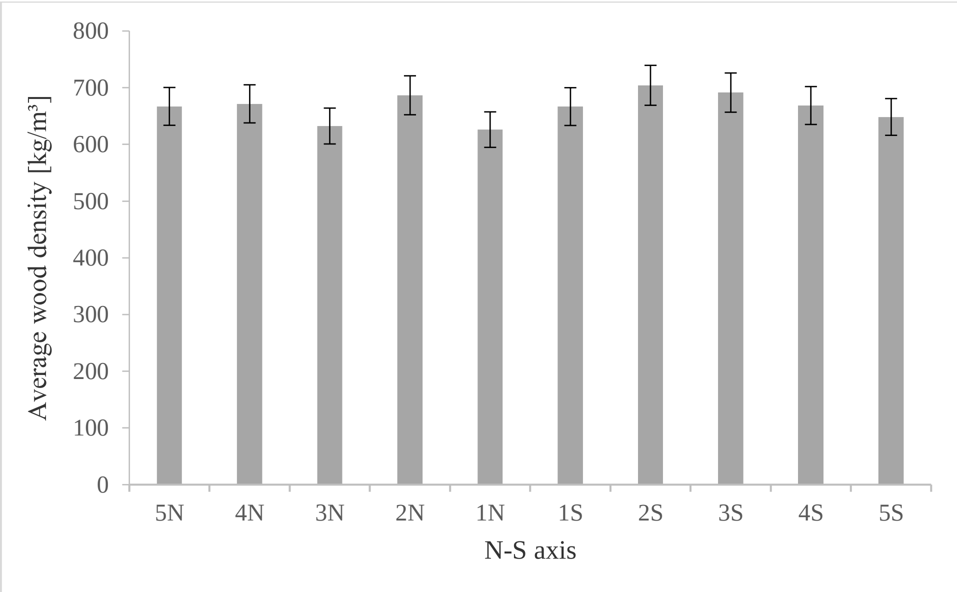

Figure 5. Average wood density variation on the cross-section of the trunk of red maple on the N-S axis

Acoustic properties

The results of ultrasound tests for 7 acquired red maple trees from the Rogów Arboretum showed that the average value of the speed of sound was 4770 m/s. The highest average value was recorded for the tested samples from north side of the trees, which reached 5064 m/s (3N). Stanciu (2007) emphasizes in his research that the higher the value of the speed of sound, the purer its clarity. The values of the tested samples from red maple wood are within the range of optimal values of acoustic properties of resonance wood (Fig. 6.) which means that they could be used for parts of instruments such as violin backs and ribs (3500-4500 m/s), and for piano actions (4200-5200 m/s) (Wegst 2006).

As shown in figure 7 the average value dynamic modulus of elasticity (MOE_d) varies between 13-17,5 GPa. According to Wegst (2006) red maple can be used for parts of instruments such as: violin backs and ribs (MOE_d 8-19 GPa), wind instruments (MOE_d 7–18 GPa) and for piano actions (MOE_d 15–19 GPa). Because of its different correlation between dynamic modulus of elasticity and wood density it cannot be used as soundboards, xylophone bars, violin bows and strings.

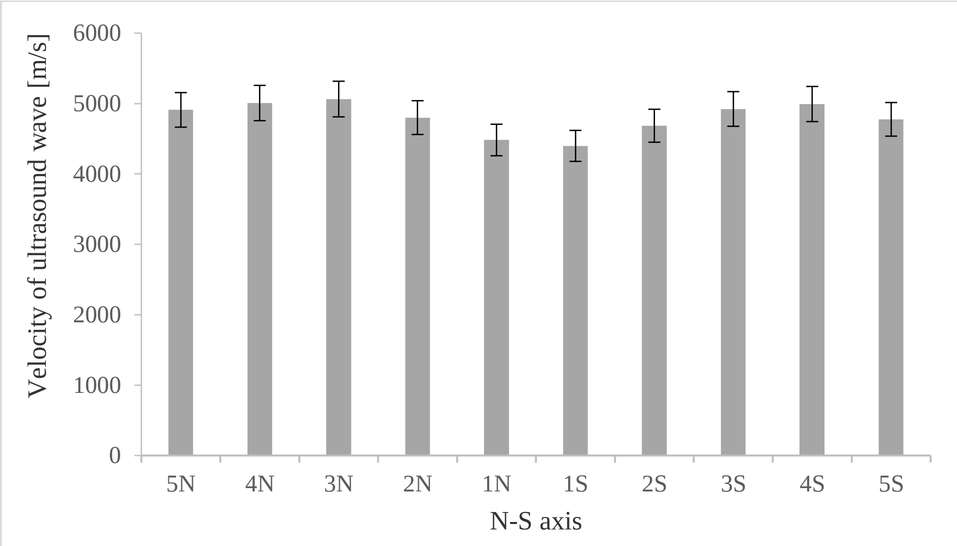

Figure 6. Velocity of sound wave (c) in red maple wood obtained from the Rogów Arboretum.

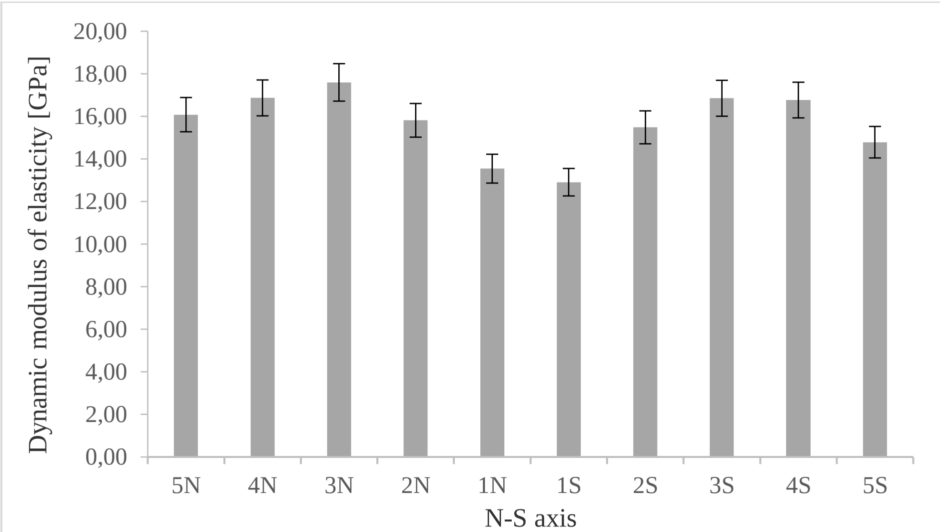

Figure 7. Dynamic modulus of elasticity (MOE_d) in red maple wood obtained from the Rogów Arboretum.

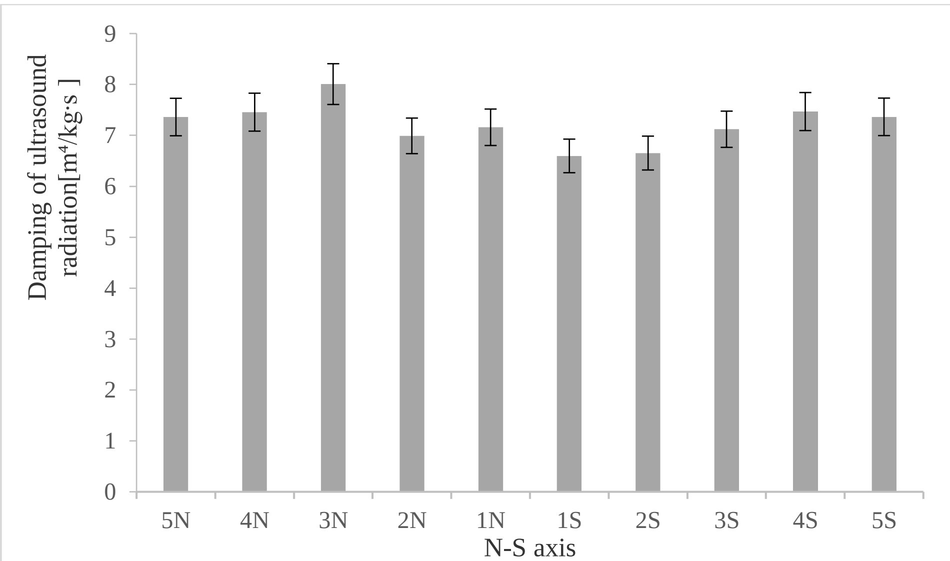

Figure 8. Damping of ultrasound radiation (T) in red maple wood obtained from the Rogów Arboretum.

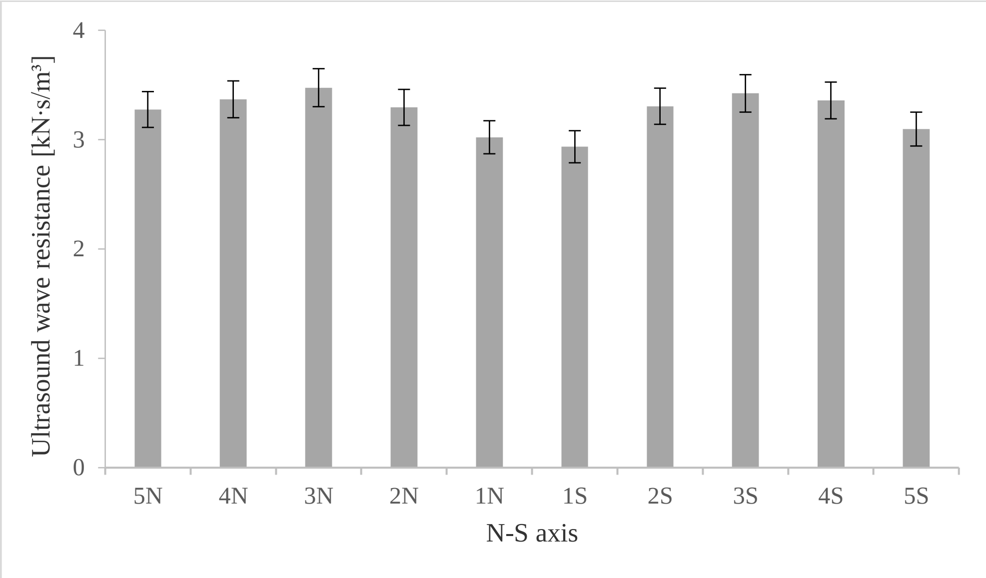

Figure 9. Ultrasound wave resistance (Z) in red maple wood obtained from the Rogów Arboretum.

Maple wood is suitable as a material for making musical instruments due to the low speed of sound and the high degree of internal damping it possesses. Because of its properties it's commonly used in guitar building (Internet 3).

The examined acoustic properties of wood depend on its location on the trunk cross-section (Fig. 6, 7, 8 and 9). The wood near the pith and the wood near the perimeter of the trunk have reduced acoustic properties. Juvenile wood, made of shorter cells, is located near the pith (Fabisiak 2005), which reduces the speed of acoustic waves. The zone at the side of the trunk is the wood with the narrowest rings (less than 1 mm wide). Annual rings produced by a tree with a deficit of sunlight increasing from year to year (increasing density of the stand), probably also contain weaker (thin-walled) structural elements.

Mechanical properties

Standard samples with dimensions of 20x20x300 mm were used for testing the mechanical properties. Figure 10 shows the samples tested to check their static modulus of elasticity (MOE_s).

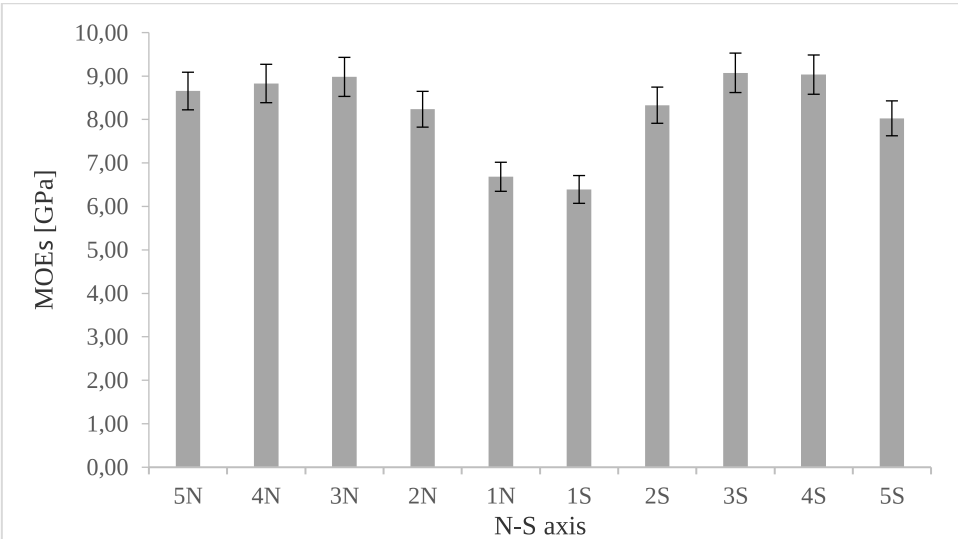

Figure 10. Static modulus of elasticity (MOE_s) in red maple wood obtained from the Rogów Arboretum.

The average MOE$_s$ value for the tested red maple wood was 8,1 GPa. The tested samples had a fairly large divergence in terms of the MOE$_s$ value. The results showed that these values are in the range 3,7-12,4 GPa. In the literature, the modulus of elasticity reaches 11,31 GPa with a wood moisture content of 12% (Internet 4).

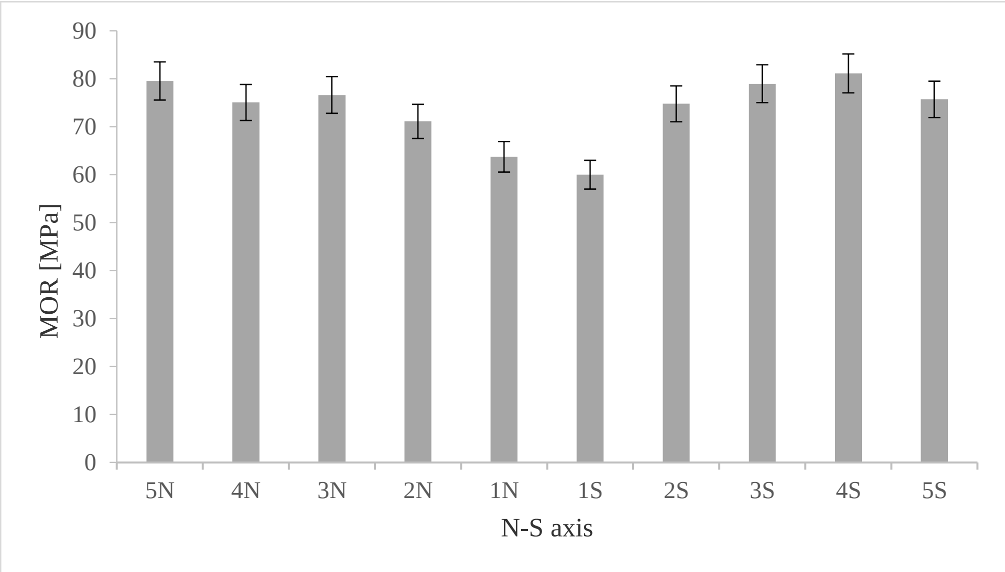

Figure 11. Modulus of rapture (MOR) in red maple wood obtained from the Rogów Arboretum.

Figure 11 shows the bending strength also known as the breaking modulus (MOR) for red maple wood. The average modulus of rapture of the tested samples was 73,7 MPa and was slightly lower than the value reported in the literature, where the MOR is 92,4 MPa with a wood humidity of 12% (Internet 4).

Samples tested for bending strength show cross-grain tension pattern (Fig.12) according to ASTM D 143-94: 2000 classification. In the pith area also known as the juvenile wood there was a noticeable difference in the damage pattern. Because of the lower density and strength in that area of wood a compression pattern can be observed.

Figure 12. Samples broken as a result of wood bending test of red maple on the N-S axis of tree no.5.

Based on the conducted research, Han (1995) found that parameters such as age, environment, species and tree position had a significant impact on the modulus of elasticity and the breaking modulus (bending strengths). Age did not play a major role in the studied trees from the Arboretum area because it did not have a significant influence on MOE and MOR in the maturity phase. In a study by Korkut and Büyüksari (2006), MOE_s and MOR Acer rubrum differed depending on the habitat. The values tested in the wet environment were higher than those in the dry area.

As shown in Figure 13, for the red clone obtained from Rogów Arboretum, compression strength (Rc) ranged from 35-45 MPa. The average given value of the compressive strength for red maple in the literature is 35,9 MPa, so the obtained result for the compressive strength is consistent with the assumptions (Internet 5).

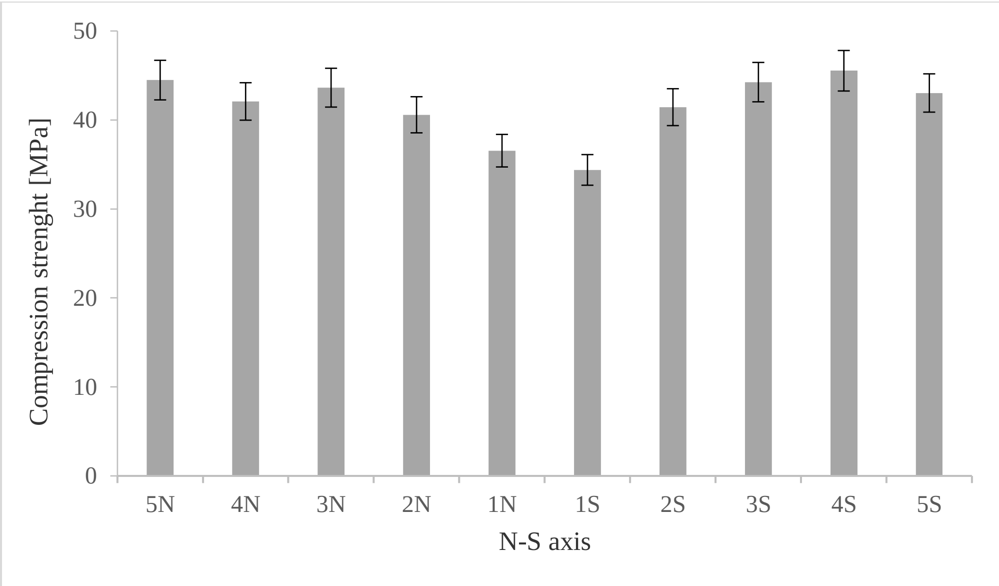

Figure 13. Compression strength (Rc) in red maple wood obtained from the Rogów Arboretum.

Figure 14 shows a damage pattern of splitting and brooming, according to ASTM D 143-94: 2000 classification after a compression strength test. This is a typical type of failure for wet samples and wood of medium or low density (Kozakiewicz 2010).

As in the case of acoustic features, the influence of the position of the wood (distance from the pith) on the tested mechanical properties is noticed. The lowest mechanical parameters have juvenile wood right next to the pith and mature wood right next to the trunk bark.

Figure 14. Samples squeezed as a result of wood compression strength test of red maple on the N-S axis of tree no.6.

CONCLUSIONS

On the basis of the conducted research on the red maple collected from the Forest Experimental Plant in Rogów, the following conclusions were made:

1. The height of red maple grown in Rogów reaches dimensions that fall in the lower range of the height of wood from the parent areas. A similar situation applies to its trunk diameter, where the average value is two times lower than for non-European *Acer rubrum*.
2. The average growth in width decreases with age. Acer rubrum gains almost twice as much growth in width in the initial stage of development in comparison to the final stage of tree growth.
3. Wood density does not differ significantly from trees of other origin (e.g from natural range in North America). Despite the lower density, the compressive strength does not differ from the typical level noted for the discussed type of wood.
4. The study of acoustic properties of red maple wood showed that it falls within the range of optimal values of acoustic properties of resonance wood. This means that it can be used for the production of musical instruments due to the low speed of sound and the high degree of internal damping it possesses.
5. Recorded values of modulus of elasticity (MOE_s), modulus of rapture (MOR) were lower than those for red maple wood from natural range in North America. Wood samples destroyed during strength tests showed poorer properties in the part of juvenile wood due to the lower density and strength in that area of wood.

REFERENCES

1. ASTM D 143-94:2000 Standard Test Methods for Small Clear Specimens of Timber.
2. Belleville B., Cloutier A., Achim A. 2011: Detection of red heartwood in paper birch (*Betula papyrifera*) using external stem characteristics. Can. J. For. Res. 41(7): 1491–1499.
3. Chronicle experimental plot of Acer rubrum in the Forest Experimental Plant in Rogów 1970-2020 (unpublished material).
4. Fabisiak E., 2005: Variation of fundamental anatomical elements and wood density of selected tree species. Wydawnictwo Akedemii Rolniczej im. Augusta Cieszkowskiego. Poznań. (in Polish).
5. EN 350:2016 Durability of wood and wood-based products - Testing and classification of the durability to biological agents of wood and wood-based materials.
6. Hadinata M.E., Kozakiewicz P., 2020: An investigation of selected properties of teak wood from 9-year-old plantation forest in Indonesia. Annals of Warsaw University of Life Sciences – SGGW No. 110, 2020:61-72 DOI: 10.5604/01.3001.0014.3929
7. Han Y. 1995: The site and age effects on the selected physical and mechanical properties of red maple in Maine. University of Maine, p. 151.
8. Hoadley R.B. 1990: Identifying Wood Accurete Rusults with Simple Tools. The Taunton Press.
9. Hough R. 2013: The Woodbook. The Complete Plates. Taschen.
10. Internet 1: https://www.americanhardwood.org/pl/american-hardwood/miekki-klon-amerykanski?species=30 (access: November 2020).
11. Internet 2: http://arboretum.sggw.pl/lpd.html (access: March 2021).
12. Internet 3:https://www.soundpure.com/a/expert-advice/guitars/tonewood-spotlight-maple/
13. Internet 4: https://www.wood-database.com/red-maple/ (access: May 2021).
14. Internet 5: http://matweb.com/search/datasheet_print.aspx?matguid=67e57f907bc842259 e268a5c8e4a7457
15. ISO 4471:1982 Wood. Sampling sample trees and logs for determination of physical and mechanical properties of wood in homogeneous stands.

16. ISO 13061-1:2014 Physical and mechanical properties of wood. Test methods for small clear wood specimens. Part 1: Determination of moisture content for physical and mechanical tests.
17. ISO 13061-2:2014 Physical and mechanical properties of wood. Test methods for small clear wood specimens. Part 2: Determination of density for physical and mechanical tests.
18. ISO 13061-3:2014 Physical and mechanical properties of wood. Test methods for small clear wood specimens - Part 3: Determination of ultimate strength in static bending.
19. ISO 13061-4:2014 Physical and mechanical properties of wood. Test methods for small clear wood specimens. Part 4: Determination of modulus of elasticity in static bending.
20. ISO/DIS 13061-17:2014 Physical and mechanical properties of wood. Test methods for small clear wood specimens. Part 17: Determination of ultimate stress in compression parallel to grain.
21. Korkut, S., Büyüksarı, Ü. 2006: Some mechanical properties of red-bud maple (Acer trautvetteri Medw.) wood grown in different districts . Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi, 2 (2) , p. 24-31
22. Kozakiewicz P., 2020: Effect of temperature and moisture content on compression strength parallel to the grain of selected species of wood with variable density and anatomical structures. Wydawnictwo SGGW. Warsaw (in Polish).
23. Meier E. 2015: Wood! Identifying and Using Hundreds of Woods Worldwide. The Wood Database.
24. Porter T. 2012: Wood Identifivation and Use, A Field Guide to More Than 200 Species. Taunton Press.
25. Pszwaro J. 2015: Growth and Stand Dynamics of Red Maple-Dominated Forests in the Upper Great Lakes Region. Graduate School of the University of Minnesota, p. 4-8.
26. Smith K., Dudzik K. 1997: *Acer rubrum*. Enzyklopädie der Holzgewächse – 10. Erg.Lfg.12/97.
27. Stanciu D. M. 2007: Researches concerning the acoustic properties of tone wood used on musical instruments structures. 11th International Research/Expert Conference ”Trends in the Development of Machinery and Associated Technology”. Hammamet, p. 807-810.
28. Walters, Russell S. and Harry W. Yawney. “Red Maple.” *Silvics of North America*. Ed. Russell M. Burns and Barbara H. Honkala. Washington, DC: Forest Service, United States Department of Agriculture, December 1990. 60-69
29. Wegst U. 2006: Wood for Sound. American Journal of Botany, p.1439-1448.
30. Wojerska M. I in. 2012: Species diversity related to red maple (*Acer rubrum* L.) occurred on experimental stands in Rogów Arboretum (Poland). Folia Forestalia Polonica, series A, 2012, Vol. 54 (4), 233–240.

Streszczenie: *Badanie wybranych właściwości drewna klonu czerwonego (Acer rubrum) z powierzchni doświadczalnej leśnego arboretum w Rogowie*. Klon czerwony najczęściej spotykany jest w północno-wschodniej części Stanów Zjednoczonych i Kanady w mieszanych lasach liściastych. W Europie używany jest w większości do celów zdobniczych, gdzie sadzi się go w parkach, ogrodach i przestrzeniach publicznych. W ramach pracy przeprowadzono badania cech dendrometrycznych drzew wymienonego wyżej gatunku z powierachni doświadczalnej leśnego arboertum w Rogowie (Leśny Zakład Doświdczalny SGGW), oraz wybranych właściwości fizycznych i mechanicznych tworzonego drewna. Uzyskane wyniki badań doświadczalnie introdukowanego w Rogowie gatunku porówano z cechami klonu czerwonego z obszaru nartualnego wystepowania w Ameryce Północnej. Wyniki badań wykazały, że hodowane w Rogowie 50-o letnie drzewa mają mniejszą wysokość, a w szczególności zdecydowanie mniejszą pierśnicę w porówaniu z naturalnym zasiegiem występowania. Również właściwości fizyczne i mechaniczne drewna klonu czerwonego z

Rogowa są słabsze niż dla drewna klonu hodowanego w warunkach rodzimych. Niezależnie od powyższego zaznacza się istony wpływ umiejscownienia drewna w pniu (odległość do rdzenia) na jego gęstość, właściwości akustyczne oraz statyczny moduł sprężystości, wytrzymałość na zginanie i ściskanie wzdłuż włókien.

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