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VELOCITY OF ULTRASOUND PROPAGATION IN THE BEECH (*Fagus sylvatica* L.)[1] TENSION WOOD

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The study on ultrasonic waves velocity in tension wood and opposite wood of beech species, in the three basic anatomic directions, were carried out. The experiments wave made on wood with three moisture contents, namely on green wood, wood with moisture content 7% and on oven dry wood.

Key words: beech, tension wood, opposite wood, ultrasonic waves velocity

INTRODUCTION

Methods based on ultrasound propagation measurements have recently become most commonly used for diagnostics of different materials. They belong to the group of Non Destructive Testing methods which allow determination of the qualitative characteristics of different materials, including wood [e.g. Burmester 1965, Gerhards 1982, Dzbeński 1984]. Independence on the application, they are based on measurements of different descriptors of ultrasound waves passing through or reflected on the inner structures of the studied object. The methods based on sending the ultrasound pulse into a given object and receiving the reflected signal are known as echographic (e.g. ultrasound microscopy and defectoscopy). More sophisticated methods using the information carried by the pulses passing through the object studied in which the acoustic parameters are locally differentiated are known as Ultrasound Transmission Tomography (UTT).

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The ultrasound technique uses such parameters of the acoustic signals as the propagation velocity, decrease in the amplitude, decrease in the frequency, total power of reflected pulses – the so-called back-scattering.

For material quality testing without the need of getting images of its structural features, measurements of one of the above descriptors are usually sufficient. The most often parameter measured is the time of the ultrasound wave passing, so the velocity of its propagation in a given object.

In the hitherto studies it has been established that the ultrasound velocity propagation in wood depends on the anatomical direction, [e.g. Burmester 1965], the angle of fibres inclination [e.g. Kabir et al. 1997], the length of the anatomical elements [e.g. Dzbeński 1984, Buks 1998], wood density [Dzbeński 1984, Yamamoto et al. 1998, Gibson and Ashby 1997], the presence of defects [e.g. Bernatowicz 1990, Karyś and Stawiski 1996], and moisture content [Burmester 1965, Krzysik 1978, Gerhards 1982, Mishiro 1996].

To the best of our knowledge there have been no reports on ultrasound propagation in the reaction wood. As it seemed to us an important question from the point of view of the full diagnostics of growing trees and timber, a study was undertaken to establish and analyze ultrasound propagation in the tension and opposite wood of beech.

METHODS

Since the macroscopic identification of tension wood is difficult and not always possible in growing trees, the material to be studied was selected in a storing yard at a sawmill in Mroczeń LZD-Siemianice. The structure of logs of the freshly cut beech trees, seen on the crossections could indicate the presence of reaction wood [Datswell and Wardrop 1955, Hejnowicz 1973, Panshin and de Zeeuw 1980, Ternard 1983] were selected. The reaction wood was moreover identified with the help of a zinc chloride water solution (66 g) and potassium iodide (6 g) with a small addition of crystalline iodine [Gindl 1998]. The tension wood, which contains more cellulose than the normal wood, on contact with this solution changes colour from dark blue to dark brown. The normal wood changed from yellow to light brown. On the basis of the macro structural features and colour changes observed after 20 min. from the solution application on the front surfaces of the log, we have chosen one log of beech wood (*Fagus sylvatica* L.). It was 3 m long and had a diameter of 40 cm at a height of 1.3 m from the butt. In the zone of a longer radius of this log the tension wood of the maximum width of 40 mm was identified. The mean width of annual increments of the tension wood was 2.56 mm, while that of the opposite wood (on the opposite side of the tension wood) was 1.86 mm. Prior to cutting out samples, the log was cut into 1 m sections.

On the front surfaces of these sections the zones of the tension wood and the opposite wood corresponding to the same annual increments were marked. Samples in the shape of a hexagon of 30 mm long edge were cut out from the zones marked.[2]

[2] Experimental materials were prepared with the help of graduate student Rafał Browarski

The measurements of time of the ultrasound wave passage through the samples were made with an ultrasound probe type 543, made by UNIPAN in Lubawa, equipped with a head emitting and receiving waves of 0.5 MHz frequency. The head was adhering to the sample through a layer of silicon oil.

The measurements were made in three anatomical directions with accuracy to 0.1 μs for the samples in the green state (as obtained), dried (W = 6-8%) and oven dry state. In total the measurements were performed for 32 samples of the tension wood and the same number of samples of the opposite wood. Moreover, the wood density the oven dry state and the maximum contraction in particular anatomical directions were determined.

RESULTS

The density of the tension wood was in the range from 658 to 695 kg/m^3 (mean value 676 kg/m^3), while that of the opposite wood ranged from 662 to 685 kg/m^3, (mean value 674 kg/m^3). The practically insignificant differences in the density of these two kinds of wood are a consequence of the fact that the density of wood of the diffuse-porous-wood species does not depend on the width of annual increments. In spite of a similar density of tension and opposite wood, the values of the maximum contractions longitudinal direction are drastically different. The maximum contraction of the tension wood longitudinal direction is over 2.2 times greater (β_{lmax}= 0.74%) than that of the opposition wood (β_{lmax}= 0.33%). In the transversal directions the maximum contractions for the two kinds of wood are similar: in the radial direction 5% and 4.85% and in the tangential direction 11.64% and 11.43% for the tension and opposite wood, respectively. These results are in agreement with those reported for *Fagus* by [Čunderlik et al.1992].

The results of ultrasound velocity measurements in all anatomical directions are presented in Tab.1-3.

Analysis of the data from Tab. 1 shows that the mean velocity of ultrasound propagation longitudinal direction is somewhat greater for the tension wood (about 2%) than that in the opposite wood, irrespective of the moisture content.

The mean velocity of ultrasound propagation in the radial and tangential directions in the tension wood is lower than in the opposite wood, see Tables 2 and 3. The greatest differences in the ultrasound propagation have been noted in the wet state: (8.5% in the radial direction and 11% in the tangential direction). In the oven dry wood in these two anatomical directions the differences reach about 4%. This fact can be explained as follows. A characteristic feature of the tension fibres is that they are covered with a non-lignified gelatinous layer. This gelatinous layer (G layer) is loosely bound to the deeper layers of the cell wall and it is often undulated thus allowing a formation of voids and gaps in the cell wall of the fibres. When the acoustic wave encounters obstacles of this kind, the time of its passing increases which means that its velocity decreases. The ultrasound wave propagates along a path of the lowest acoustic resistance,

Table 1

Tabela 1

Selected parameters characterising ultrasound propagation longitudinal direction in the tension and opposite beech wood.

Niektóre wielkości statystyczne charakteryzujące prędkość propagacji ultradźwięku wzdłuż włókien w napięciowym i opozycyjnym drewnie buka

Kind of wood Rodzaj drewna	Moisture content Wilgotność [%]	Ultrasound propagation velocity in longitudinal direction V_L [m/s] Prędkość ultradźwięku wzdłuż włókien V_L [m/s]			Standard deviation Odchylenie standardowe ± S [m/s]	Variation coefficient Współczynnik zmienności V [%]
		min. min.	mean średnia	max. max.		
Tension Napięciowe	W=0	4733	5075	5475	160	3.2
	W=7	4500	4946	5306	180	3.6
	W>PNW	3868	4086	4297	105	2.6
Opposite Opozycyjne	W=0	5850	4975	5148	150	3.0
	W=7	5630	4819	4992	137	2.8
	W>PNW	4680	4061	4221	115	2.8

Table 2

Tabela 2

Selected parameters characterising ultrasound propagation in the radial direction in the tension and opposite beech wood.

Niektóre wielkości statystyczne charakteryzujące prędkość propagacji ultradźwięku w kierunku promieniowym w napięciowym i opozycyjnym drewnie buka

Kind of wood Rodzaj drewna	Moisture content Wilgotność [%]	Ultrasound propagation velocity in the radial direction V_R [m/s] Prędkość ultradźwięku w kierunku promieniowym V_R [m/s]			Standard deviation Odchylenie standardowe ± S [m/s]	Variation coefficient Współczynnik zmienności V [%]
		min. min.	mean średnia	max. max.		
Tension Napięciowe	W=0	2243	2375	2482	66	2.8
	W=7	2143	2288	2386	62	2.6
	W>PNW	1750	1820	1955	57	3.1
Opposite Opozycyjne	W=0	2320	2486	2758	74	2.9
	W=7	2368	2421	2582	39	1.6
	W>PNW	1908	1990	2077	45	2.3

Table 3

Tabela 3

Selected parameters characterising ultrasound propagation in the tangential direction in the tension and opposite beech wood.

Niektóre wielkości statystyczne charakteryzujące prędkość propagacji ultradźwięku w kierunku stycznym w napięciowym i opozycyjnym drewnie buka

Kind of wood Rodzaj drewna	Moisture content Wilgotność [%]	Ultrasound propagation velocity in the tangential direction V_T [m/s] Prędkość ultradźwięku w kierunku stycznym V_T [m/s]			Standard deviation Odchylenie standardowe ±S [m/s]	Variation coefficient Współczynnik zmienności V [%]
		min. min.	mean średnia	max. max.		
Tension Napięciowe	W=0	1612	1672	1785	45	2.7
	W=7	1570	1642	1740	41	2.5
	W>PNW	1421	1482	1556	41	2.8
Opposite Opozycyjne	W=0	1656	1740	1847	48	2.8
	W=7	1626	1724	1872	47	2.8
	W>PNW	1493	1660	1886	113	6.8

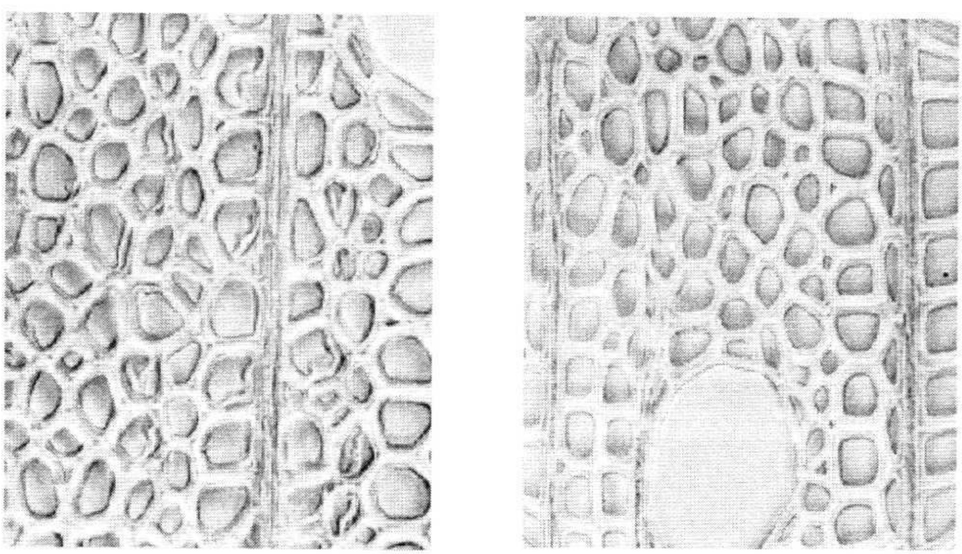

Fig. 1. Microscopic images of cross-sections of the tension wood (a) and opposite (b) beech wood (*Fagus sylvatica* L.)

Rys.1. Obrazy mikroskopowe przekrojów poprzecznych napięciowego (a) i opozycyjnego (b) drewna buka (*Fagus sylvatica* L.)

although it is not the shortest one. This interpretation is supported by the analysis of the microscopic images of the cross-sections of the tension and opposite wood of beech tree, shown in Fig. 1.

As follows from the Fig. 1, the gelatinous layer in the tension wood is often separated from the deeper layers of the cell wall.

The differences in the ultrasound velocity between the two kinds of wood are also related to the presence of rays. Because of their presence the differences in the ultrasound propagation in the radial direction between the tension and the opposite wood are smaller than in the tangential direction.

The results collected in Tab. 1-3 also confirm a well known fact of increasing the ultrasound propagation velocity with a decrease of the moisture content, in both kinds of wood. However, it should be noted that a change in the moisture content does not significantly affect the relations between the mean ultrasound velocities in the opposite wood longitudinal direction and in transversal directions.

CONCLUSIONS

1. The mean density of the tension beech wood is practically the same as that of the opposite wood.
2. The mean value of the maximum contraction of the tension wood longitudinal direction is over twice greater than that in the opposite wood. In the transversal directions no differences in the maximum contraction have been noted between the two kinds of wood.
3. With decreasing moisture content the ultrasound propagation velocity increases in both kinds of wood.
4. The mean velocity of ultrasound propagation longitudinal direction is somewhat greater in the tension than in the opposite wood. In the transversal directions it is greater in the opposite wood. In the wet state the differences in the ultrasound velocity between the two kinds of wood reach about 10% and decrease with decreasing moisture content to 4% in the oven-dry state.

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PRĘDKOŚĆ PROPAGACJI ULTRADŹWIĘKU W DREWNIE NAPIĘCIOWYM BUKA (*Fagus sylvatica* L.)

Streszczenie

Przeprowadzono badania nad prędkością ultradźwięku w napięciowym i opozycyjnym drewnie buka w trzech podstawowych kierunkach anatomicznych. Badania wykonano na drewnie mokrym, o wilgotności 7% i w stanie zupełnie suchym.

Wykazano, że prędkość propagacji ultradźwięku wzdłuż włókien w tkance napięciowej jest nieznacznie wyższa od prędkości ultradźwięku w tkance opozycyjnej. W kierunkach poprzecznych ultradźwięki rozprzestrzeniają się szybciej w tkance opozycyjnej. Różnica w prędkościach dźwięku pomiędzy drewnem napięciowym i opozycyjnym wynosi w stanie mokrym około 10% i zmniejsza się ze spadkiem wilgotności drewna do 4%.

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