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Acoustic insulation properties of selected African wood species: padouk, bubinga, sapele

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Abstract: *Acoustic insulation properties of selected African wood species: padouk, bubinga, sapele*. The work determines the sound insulation properties of three wood species used in various types of acoustic partitions. The tests were carried out in a small acoustic chamber after generating white acoustic noise for 5.5 s. The level of sound intensity generated by the loudspeaker was 110 dB. The thickness of the wooden partitions was 20, 10 or 5 mm. The study was preceded by the determination of the moisture content, density and dynamic modulus of elasticity of the tested wood samples. In the 20–600 Hz frequency range, the sound insulation characteristics of the tested partitions changed dynamically but very similarly, while maintaining the mass law. In the higher frequency range, the impact of the partition thickness on insulation was individual, different for each wood species.

Keywords: African wood, acoustic insulation, density, dynamic modulus of elasticity, small acoustic chamber

INTRODUCTION

Acoustic properties of wood determine its use, among other things, for the production of sound absorbing materials. With the application of wood in various types of partitions, e.g. wall elements (facades, cladding, panelling) and flooring, the sound insulation is taken into account [Kozakiewicz et al. 2012]. Isolation, i.e. attenuation, is the ability to weaken the intensity (silencing) of sounds passing through the material, expressed in decibels. Waves with higher frequencies (high tones) are much easier to suppress than those with low frequencies. The acoustic properties of wood are significantly affected by its density and modulus of elasticity. In a simplified manner, with increasing wood density, the acoustic insulation is also increasing [Kollmann and Côte 1968, Krzysik 1978, Bucur 2006, Kozakiewicz 2012]. However, due to the diversity of wood structure and the complexity of sound phenomena, including a number of accompanying effects (e.g. reflection, deflection and penetration) [Kirpluk 2014], it is always desirable to experimentally verify its sound insulation properties. Insulation is also proportional to the increase in the mass of a partition and the sound frequency [Bucur 2006].

African species of wood have long been present on the European market and they find various applications, also resulting from specific features and properties. High natural durability of many African species, defined in EN 350:2016, and their high density transforming into high strength parameters predestine them for external applications [Kozakiewicz et al. 2010], such as sound absorbing and anti-glare screens in communication arteries. The African wood species are also the material used for solid and layered flooring materials – as horizontal partitions of buildings [Kozakiewicz et al. 2012].

The aim of the study was to determine the sound insulation properties of three African wood species – padouk, bubinga and sapele – popular on the European market.

MATERIAL AND METHOD

Samples of selected African wood species (padouk, bubinga, sapele) were used in the study. The tested wood species are used as various types of acoustic barriers in buildings, as well as in acoustic screens [Kozakiewicz 2007, Kozakiewicz et al. 2010]. Selected information on the tested wood species was compiled in Table 1. To determine the sound insulation properties, samples with planed surfaces of 500 mm (longitudinal) x 300 mm (tangential) and the final thickness of 20 mm (radial) were used – samples with a dominant tangential section were selected. After the initial determination of the insulation parameters, the samples were planed down to a thickness of 10 mm, and then to 5 mm; and the acoustic chamber test was repeated for each thickness.

Table 1. The basic information about investigated wood species from Africa [EN 13556:2003; Kozakiewicz and Szkarłat 2004; Kozakiewicz 2006, 2007; Wagenführ 2007; Richter and Dallwitz 2009]

Latin name of wood	English trade name of wood (and code) according to EN 13556:2003	Description of wood (characteristic structure attribute)
Pterocarpus soyauxii Taub., P. *osun* Craib	African padouk (PTXX)	hardwood, diffuse-porous, stored structure, small striped grain, paratracheal parenchyma - wing-like, wing-streak apotracheal - dispersed
Guibourtia tessmanii (A.Chev.) J.Léon.	bubinga (GUXX)	hardwood, diffuse-porous, stored structure, small striped grain, paratracheal parenchyma - one-sided apotracheal - diffused
Entandrophragma cylindricum (Sprague) Sprague	sapele (ENCY)	hardwood, diffuse-porous, stored structure, strong regular striped grain, paratracheal parenchyma - narrow around the vascular apotracheal - banded

After bringing the samples to air-dry condition, the wood density was determined by stereometric method in accordance with ISO 13061-2:2014, and moisture content was controlled by electric capacitive method in accordance with EN 13183-3:2005. Prior to proper sound insulation tests, the dynamic modulus of elasticity was also determined using the original ultrasonic methodology. The tests were performed using a UMT-1 material tester equipped with two cylindrical 40 kHz transmitting and receiving heads providing the required signal range. The remaining settings were as follows: 50 dB gain, 60V energy, 12 Hz pulse mode and 8.8 μs latency time. After placing the heads facing each other to the faces of the wooden element covered with ultrasound gel, ultrasound was passed (the measurement was repeated six times along the fibres, successively in lines evenly spaced from each other – determined on the width of the element). Wave time was read via the UMT-LINK program. On such basis, the following values were calculated:

– velocity of longitudinal waves:

$$c = L/t$$

where: L – sample length [m]

$t = t_1 - t_o$ – real time of longitudinal wave transition [s]

t_1 – wave transition time read from the computer monitor [s]

t_o – latency time [s]

– dynamic modulus of elasticity:

$$E = c^2 \cdot g$$

where: g – density [kg/m^3]

The testing of wood's sound insulation properties was carried out in a small chamber with full geometric similarity to large acoustic chambers (rooms). The results of the measurements in “small” model chambers do not differ significantly from the results obtained in acoustic rooms [Godinho et al. 2010, Dukarska et al. 2014, Rey et al. 2019]. The test conditions were based on the standards used for testing the sound insulation properties of building materials [ISO 10140-1:2016 and ISO 10140-2,-3,-4,-5:2010].

The test stand included the following elements: EVENT sound column (sound source), two Behringer ECM 8000 condenser microphones, FireWire 24-bit/96kHz-PreSonus3 interface, acoustic analyzer and EASERA 1.2.10 program for generating, recording and processing acoustic data. Prepared solid wood samples were placed successively in a measuring hole (partition) located between sending and receiving chambers. After placing the samples, an acoustic field stimulated by white noise was generated for 5.5 s. The EASERA program provided diagrams of the intensity of sound on both sides of the partition (samples) in the audible frequency range, i.e. from 20 Hz to 20 000 Hz. Based on the obtained data, the sound insulation (taking into account the background – the difference in the intensity of sound measured without a partition in the transmitting and receiving chamber) was calculated from the following formula:

$$\mathbf{R = S_I - S_{II} - S_o\ [dB]}$$

where: R – sound insulation [dB],

S_I – signal measured in the sending chamber [dB],

S_{II} – signal measured in the receiving chamber [dB],

S_o – difference of signal reading in the sending and receiving chamber without a partition [dB].

Based on the results of insulation performance expressed in decibels, the percentage insulation factor was calculated from the formula:

$$\mathbf{C_{R\%} = (R/S) \cdot 100\ [\%]}$$

where: $C_{R\%}$ – sound insulation coefficient [%],

S – sound level (110 dB).

RESULTS AND DISCUSSION

The moisture content of the wood to be tested ranged from 8% to 10% (typical for wood used in rooms in the temperate climate zone). Due to strong saturation with non-structural compounds, exotic species usually take lower equilibrium moisture content compared to wood from a temperate climate [Kozakiewicz et al. 2012].

The results of the density, ultrasonic wave velocity and dynamic modulus of elasticity are given in the Table 2. The density of sapele wood in the air-dry state was 694 kg/m^3, bubinga wood 858 kg/m^3, and the largest African padouk 868 kg/m^3. The marked wood densities are typical (representative) of those individual species. They are in the density ranges given in the literature [Wagenführ 2007, Richter and Dallwitz 2009].

The obtained research results indicate that the velocity of propagation of ultrasonic waves in two denser species of wood (bubinga, padouk) was similar and amounted on average to 4900 - 5000 m/s. Sapele wood containing a striped fibre pattern was characterized by a lower speed (about 4700 m/s) of ultrasonic propagation. Among the tested samples, the bubinga wood sample – 22.07 GPa – had the highest average modulus of elasticity along the fibres. Equally high value was obtained in padouk wood – 21.30 GPa, and the lowest in wood sapele – 15.16 GPa. The last of the mentioned species was also distinguished by the highest variability of the examined feature, which was most likely determined by the presence of a striped arrangement of fibres. The obtained values of the modules marked with the dynamic method are slightly higher than those found in the literature, which refer to the modulus of elasticity determined during static bending [Kozakiewicz and Szkarłat 2004, Wagenführ 2007, Kozakiewicz 2006, 2007].

Table 2. The results of the testing of the physical properties of wood

Wood species	Density [kg/m^3]	Ultrasonic transition speed average (standard deviation in parentheses) [m/s] – variation coefficient [%]	Dynamic modulus of elasticity average (standard deviation in parentheses) [MPa] – variation coefficient [%]
African padouk	868	4950 (43) – 0.87	21.30 (0.37) – 1.74
bubinga	858	5070 (55) – 1.09	22.07 (0.48) – 2.17
sapele	694	4670 (296) – 6.34	15.16 (1.89) – 12.47

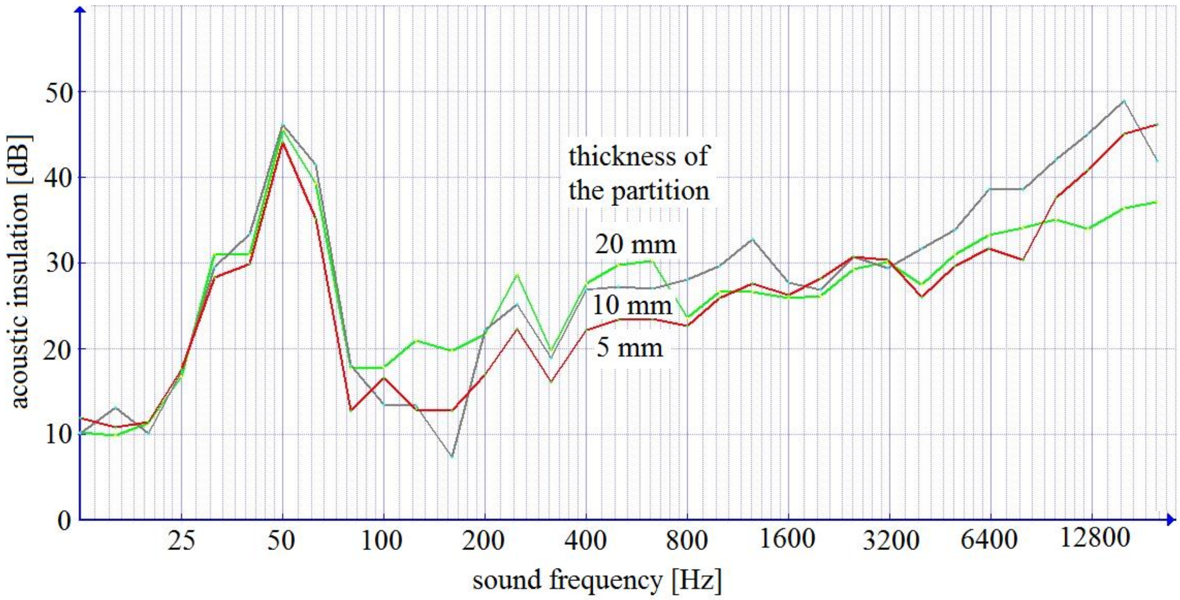

Figure 1. Acoustic insulation properties of padouk wood for three different thicknesses of the partition: 20, 10 and 5 mm

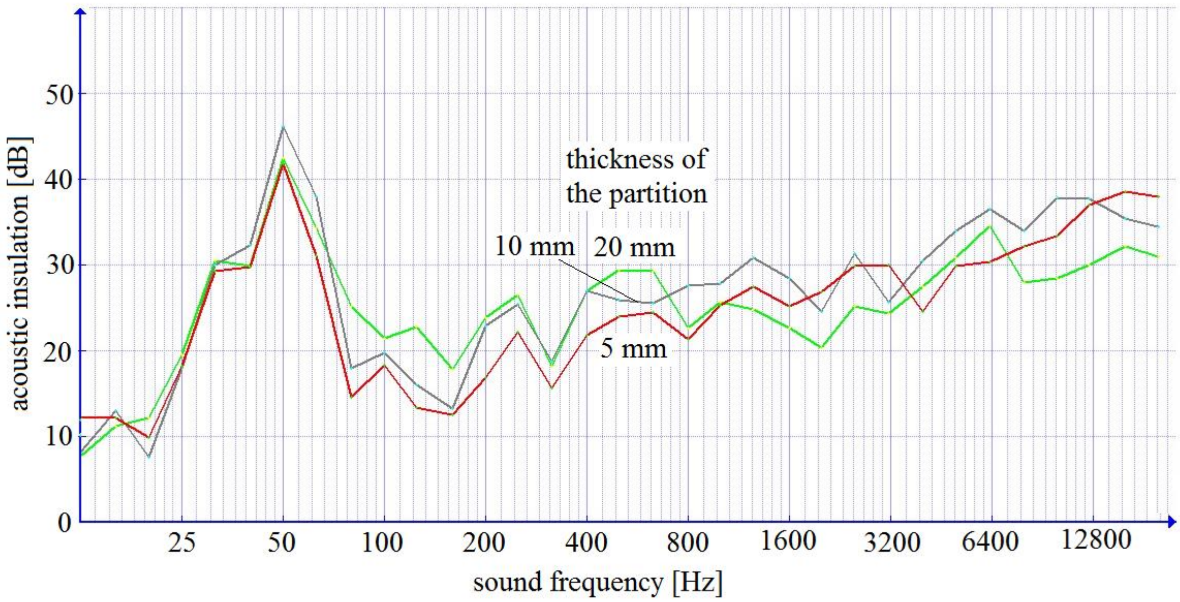

Figure 2. Acoustic insulation properties of bubinga wood for three different thicknesses of the partition: 20, 10 and 5 mm

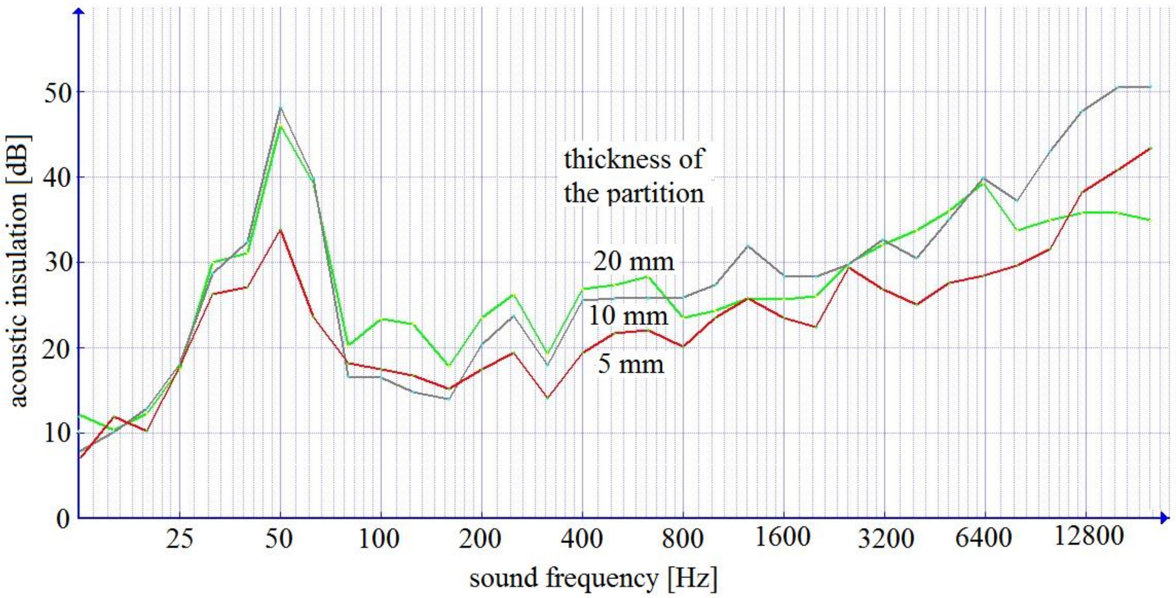

Figure 3. Acoustic insulation properties of sapele wood for three different thicknesses of the partition: 20, 10 and 5 mm

The material intended to fulfil the role of sound absorbing material must have the highest possible absorption coefficient (internal attenuation), as high as possible for the audible frequency range, i.e. 20–20 000 Hz. The law of mass allows approximation of the sound insulation of a single homogeneous partition. This law shows that the increase in insulation is proportional to the increase in bulkhead weight and sound frequency [Bucur 2006]. Generally, tested partitions show similar characteristics of the amount of sound attenuation depending on the wave frequency expressed in dB (Fig. 1, Fig 2, and Fig. 3) and in % in relation to the generated signal (Table 3). In the low frequency range, the characteristics change very dynamically and attenuation can be considered as not very effective. Above 200 Hz, a more even sound reduction characteristic begins. However, each partition is characterized by so-called limit coincidence frequency (frequency band) at which bent waves appear in the partition (resonance appears). Sounds of this frequency are suppressed to a small extent – the so-called sound window occurs (frequency band that is less attenuated compared to other frequencies) [Braune 1960]. In the conducted tests, this phenomenon is visible at a frequency of approx. 300–350 Hz (clear lower insulation of partitions). As the frequency increases further, the insulation increases, gradually reaching at least 20% efficiency in all variants for frequencies above 2 kHz (Table 3). At higher frequencies, there are also more marked differences between the tested wood species. The most effective sound insulation is provided by padouk wood. An analysis of the influence of partition thickness was also an important implication. It turns out that up to a frequency of about 600 Hz, the results were in line with the expectations. Regardless of the type of wood, the thickest partitions were the most effective in sound insulation. At higher frequencies, along with the increase in sound insulation, the effect of partition thickness was no longer so obvious; moreover, this characteristic was different for each species of wood (Fig. 1, Fig. 2, and Fig. 3). It is likely that various anatomical features, in particular fibre arrangement and wood parenchyma distribution, had an impact here. Perhaps in the case of padouk wood, the sound insulation performance (Fig. 1, Table 3) was determined not only by high density but also by the presence of banded parenchyma. Low-density parenchyma bands alternated with thick-walled fibres formed a layered system difficult to overcome by sound waves. Probably also non-straight fibre arrangement (strong, regular striped grain) in sapele wood was the reason for better insulation at high frequencies (Fig. 3, Table 3) compared to small striped fibrous bubinga wood (Fig. 2, Table 3). There was no clear relationship between sound insulation and the value of the modulus of elasticity along the fibres.

Table 3. Acoustic insulation coefficient C_R [%] in individual frequency bands

Sound frequency [Hz]	Sound insulation coefficient C_R [%]								
	African padouk			bubinga			sapele		
	partition thickness [mm]								
	20	10	5	20	10	5	20	10	5
12.5	9	9	11	7	7	11	11	7	6
16	9	12	10	10	12	11	9	9	11
20	10	9	10	11	7	9	11	12	9
25	15	16	16	18	16	17	16	16	16
31.5	28	27	26	28	27	27	27	26	24
40	28	30	27	27	29	27	28	29	25
50	41	42	40	39	42	38	42	44	31
63	36	38	32	31	34	28	36	36	21
80	16	16	12	23	16	13	18	15	17
100	16	12	15	19	18	17	21	15	16
125	19	12	12	21	15	12	21	13	15
160	18	7	12	16	12	11	16	13	14
200	20	20	15	22	21	15	21	18	16
250	26	23	20	24	23	20	24	22	18
315	18	17	15	17	17	14	17	16	13
400	25	24	20	24	24	20	24	23	18
500	27	25	21	27	24	22	25	23	20
630	27	24	21	27	23	22	26	23	20
800	21	25	21	21	25	19	21	24	18
1k	24	27	24	23	25	23	22	25	21
1.25k	24	30	25	23	28	25	23	29	23
1.6k	24	25	24	21	26	23	23	26	21
2k	24	24	26	18	22	24	24	26	20
2.5k	27	28	28	23	28	27	27	27	27
3.15k	27	27	28	22	23	27	29	30	24
4k	25	29	24	25	28	22	31	28	23
5k	28	31	27	28	31	27	33	32	25
6.3k	30	35	29	31	33	28	36	36	26
8k	31	35	28	25	31	29	31	34	27
10k	32	38	34	26	34	30	32	39	29
12.5k	31	41	37	27	34	34	33	43	35
16k	33	44	41	29	32	35	33	46	37
20k	34	38	42	28	31	34	32	46	39

CONCLUSIONS

Based on the tests of sound insulation of solid wood Afican padouk, bubinga, sapele (air-dry planed elements 20, 10 and 5 mm thick) the following conclusions were drawn:

1. The density of padouk and bubinga wood was similar and brought over 850 kg/m^3, and the sapele wood was clearly lower, less than 700 kg/m^3. The velocity of propagation of ultrasonic waves with a frequency of 40 kHz in two denser wood species (padouk, bubinga) was similar and averaged 5000 m/s. The lowest velocity (about 4700 m/s) of ultrasound propagation was found in sapele wood containing a strong striped arrangement of fibers. This also translated into the values of the dynamic modulus of elasticity.

2. In the frequency range from 20 to 600 Hz the sound insulation characteristics of the tested partitions changed dynamically, but very similarly while maintaining the law of mass. Irrespective of the type of wood, thicker partitions were more effective than thinner ones.

3. In the higher frequency range, the impact of partition thickness on insulation performance was individual, different for each type of wood. In general, the highest insulation properties were shown by the partition of padouk wood, which was probably determined not only by the high density of this wood, but also by the presence of a banded parenchyma alternated with thick-walled fibers that formed a layered system.

4. For partitions with a thickness of 10 mm and 20 mm, the largest differences in sound insulation between the tested species occurred in the frequency range 1 kHz - 20 kHz. In the case of 5 mm thick partitions in the whole frequency range, these differences were at a similar level.

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Streszczenie: *Izolacyjność akustyczna wybranych gatunków drewna afrykańskiego: paduk, bubinga, sapeli.* Afrykańskie gatunki drewna obecne na rynku europejskim znajdują różnorodne zastosowania wynikające również ze specyficznych cech i właściwości. Wysoka naturalna trwałość oraz znaczna gęstość przekładająca się na wysokie parametry wytrzymałościowe predestynuje je do zastosowań zewnętrznych między innymi na ekrany dźwiękochłonne i przeciw olśnieniowe przy ciągach komunikacyjnych. Ze względu na walory estetyczne są też stosowane w materiałach podłogowych i okładzinach ściennych. W zastosowaniach tych istotna jest również izolacyjność akustyczna. Badania przeprowadzono w małej komorze akustycznej po wytworzeniu pola akustycznego pobudzonego szumem białym w czasie 5,5 s. Poziom natężenia dźwięku generowanego przez głośnik wynosił 110 dB. W obrębie każdego gatunku grubość przegród wynosiła 20, 10 i 5 mm. Badania poprzedzono określeniem wilgotności, gęstości i dynamicznego modułu sprężystości drewna. W przedziale częstotliwości od 20 do 600 Hz charakterystyki izolacyjności akustycznej badanych przegród zmieniały się dynamicznie, ale bardzo podobnie przy zachowaniu prawa masy. W zakresie wyższych częstotliwości wpływ grubości przegrody na izolacyjność miał charakter indywidualny, odmienny dla każdego gatunku drewna. Najwyższą izolacyjnością charakteryzowały się przegrody z drewna paduka, o czym najprawdopodobniej zadecydowała nie tylko wysoka gęstość tego drewna, ale również obecność miękiszu pasmowego ułożonego na przemian z grubościennymi włóknami, które tworzyły układ warstwowy.

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