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https://doi.org/10.5109/4103900

出版情報：九州大学大学院農学研究院紀要. 65 (2), pp.351-355, 2020-09. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **65** (2), 351–355 (2020)

Studies of the Relationship Between Sound Absorption Coefficient and Air Permeability of Wood

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(*Received April 2, 2020 and accepted May 27, 2020*)

The longitudinal sound absorption capability and air permeability of three species of Japanese wood were investigated. The air permeability values of Sugi, Chanchin-modoki, and Yurinoki were 0.5, 0.06, and 0 (air flow not detected) darcy for the heartwood and 18.2, 0.92, and 0.91 darcy for the sapwood, respectively. The noise reduction coefficients of those three species were 0.04, 0.04, and 0.09 for the heartwood and 0.11, 0.05, and 0.14 for the sapwood, respectively. The mean sound absorption coefficients of those sample specimens in the frequency range of 50–6400 Hz were 0.08, 0.06, and 0.20 for the heartwood and 0.16, 0.09, and 0.30 for the sapwood, respectively. The sound absorption capability of the sample specimens increased with increase in air permeability.

Key words: Air permeability, Sound absorption coefficient, Sugi, Chanchin-modoki, Yurinoki

INTRODUCTION

Wood is a porous material with numerous longitudinal cylindrical pores, although not all species are highly permeable. The permeability variations among wood species are large because the pore structures of woods are very different. Permeability of wood is a topic of interest for many wood researchers because it affects the wood's chemical treatability and drying characteristics. Chemical treatments of wood, such as with preservation chemicals or fire–retardant resin, are generally recognized to increase its permeability. Many researchers have reported the relationship between permeability and drying characteristics (Kanagawa *et al.,* 1992; Hayashi *et al.,* 1995; Lee and Luo, 2002; Lee *et al.,* 2004). Jang and kang (2019) investigated content of three pore types (through pore, blind pore, and closed pore), as defined by IUPAC, and gas permeability of yellow poplar and Korean red pine wood and reported the increasing of through pore content and air permeability in longitudinal direction by heat treatment.

Only a few studies have investigated the relationship between air permeability and sound absorption capability of wood on the surface of a cross–section. Kang *et al.* (2010, 2012) reported that steam explosion treatment improved wood permeability in the longitudinal direction; in addition, the sound absorption capability of a cross–sectional surface of Yurinoki wood increased compared with the control wood. However, the available information on the relationship between sound absorption properties and permeability of wood is insufficient. In this study, the sound absorption capability and air permeability of several Japanese wood species were investigated. Based on these results, the relationship between air permeability and sound absorption capability on a cross–sectional surface of wood are discussed.

MATERIALS AND METHODS

Specimen Preparation

Three kinds of Japanese wood were investigated: Sugi (*Cryptomeria japonica*), Chanchin–modoki (*Choerospondias axillaris*), and Yurinoki (*Liriodendron tulipifera*). Wood specimens 28.9 mm in diameter and 10 mm length were dried at room temperature. Five sample specimens of sapwood and heartwood from each of the 3 species were used for estimation of sound absorption coefficient and air permeability in the longitudinal direction (Figure 1).

Gas Permeability Measurement

Permeability of the specimens was measured with a capillary flow porometer (Porous Material Inc, Model : CFP–1200AEL) using the method described in ASTM 316–03.

Air pressure was applied in the vertical direction to the dried sample. The flow rate was measured, and a graph of flow versus pressure was generated. The relationship between air pressure and permeability is shown in equation [1]:

$$V = -\left(\frac{k}{\mu}\right) \cdot \frac{dP}{dx} \qquad [1]$$

where
v = linear flow rate
k = specific or simple permeability

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μ = viscosity of the fluid
P = pressure
x = displacement in the direction of flow

Sound Absorption Coefficient Measurement

The sound absorption rate of each specimen was measured by a two–microphone transfer function method using an impedance tube (B&K Company, kit type 4706), pulse analysis equipment, and a spectrum analyzer (B&K company), as described previously (Kang *et al.,* 2012). When sound absorption rate was measured, the diameter of the impedance tube was limited by frequency. Generally, the diameter was 29 mm for the high–frequency range and 99 mm for the low–frequency range. In this study, variations in sound absorption rate were measured as a change of frequency in the range of 500 Hz to 6400 Hz using an impedance tube with a diameter of 29 mm. The temperature, relative humidity, atmospheric pressure, velocity of sound, air density, and acoustic impedance were measured to be 26.30℃, 57.00%, 1013.25 hP, 346.91 m/s, 1.177 kg/m^3, and 408.20 Pa/(m/s), respectively.

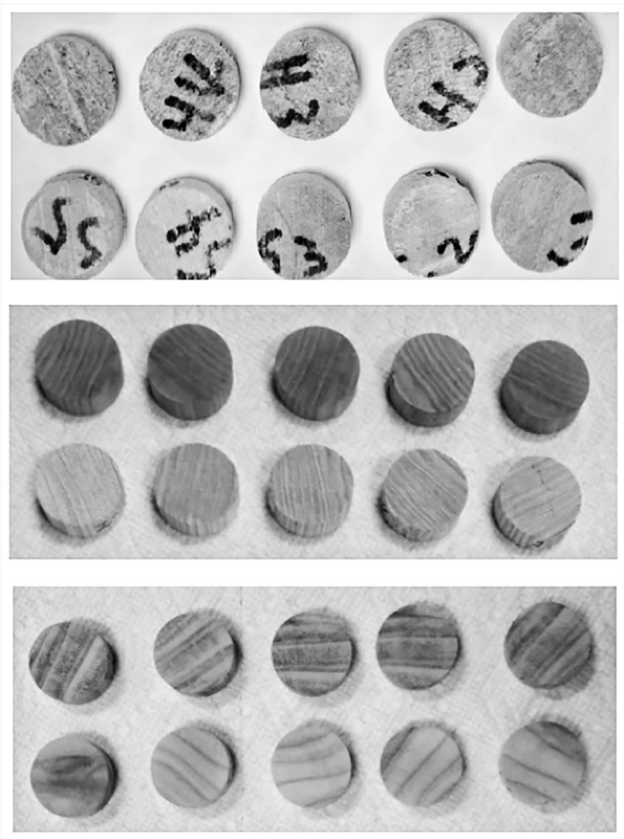

Fig. 1. Sample specimens.

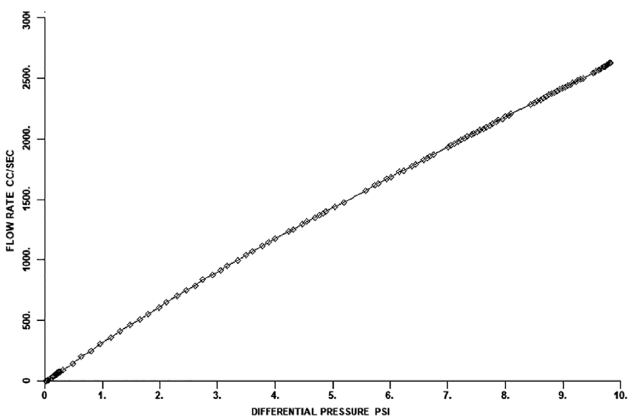

Fig. 2. Typical results of gas permeability obtained using a filtration medium (Jena and Gupta. 2002).

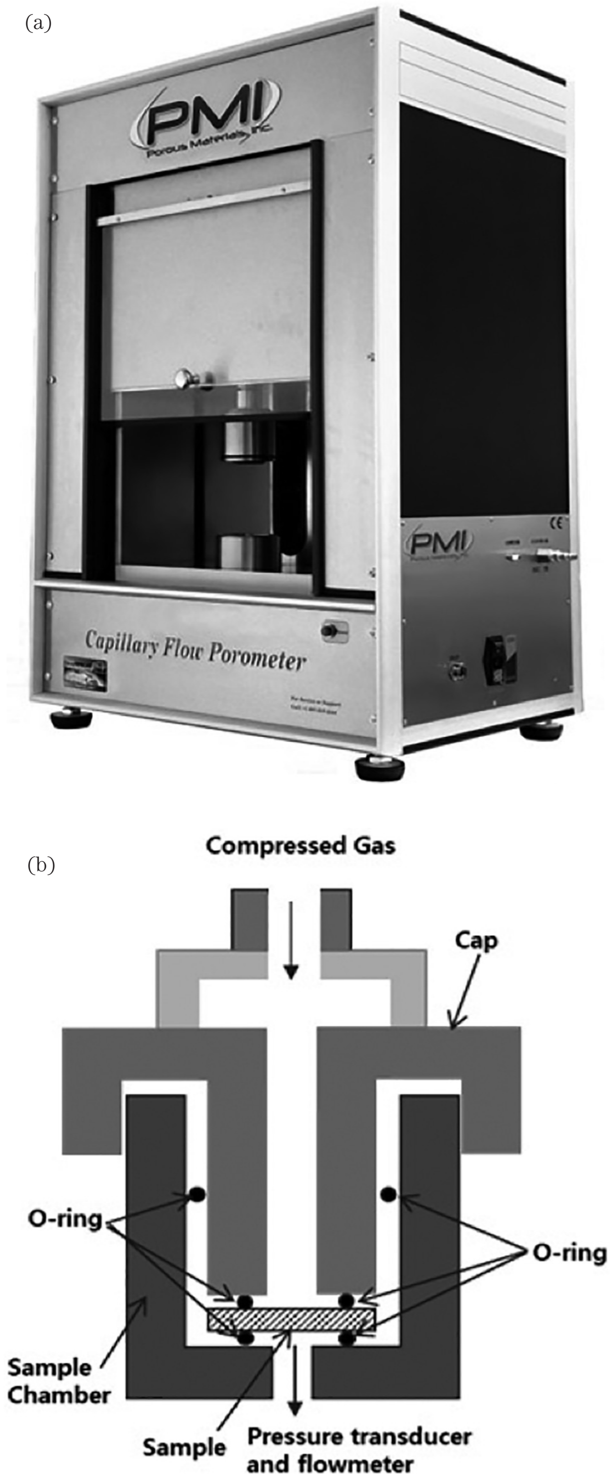

Fig. 3. Permeability estimation equipment: (a) CFP-1200AEL and (b) sample chamber.

RESULTS AND DISCUSSION

Permeability

The permeabilities of the sapwood and heartwood specimens for the 3 species are presented in Figures 5–7. The average permeabilities of Sugi heartwood, Sugi sapwood, Chanchin–modoki heartwood, Chanchin–modoki sapwood, Yurinoki heartwood, and Yurinoki sapwood were 0.5, 18.2, 0.06, 0.92, 0 (air flow not detected), and 0.91 darcy, respectively. The air permeability of the Yurinoki sapwood specimens was 18.2 darcy, which is more than 36 times higher than that of the heartwood specimens (0.5 darcy).

The pore size of Chanchin–modoki sapwood was the largest among the three species; however, its permeability was less than that of Yurinoki, which might be attributed to presence of tylosis blocking the passageway for fluid movement. The permeability was highest for Yurinoki and lowest for Chanchin–modoki, and it was higher in sapwood than in heartwood.

Sound absorption coefficients

The sound absorption coefficients of the specimens in the frequency range of 500–6400 Hz are shown in Figures 8–13.

As shown in the figures, the sound absorption rate of the specimens was highest for Yurinoki and lowest for Chanchin–modoki. The coefficients was also higher in sapwood than in heartwood; in particular, it was almost two times higher in sapwood than in heartwood for Yurinoki in the frequency range of 1500–2000 Hz.

As shown in the figures, the sound absorption coefficients of the highly permeable Yurinoki sapwood specimens had higher values than those of Yurinoki heartwood or the other species of wood in almost all frequency ranges. The sound absorption coefficients of all estimated wood specimens increased with increase in frequency, which is a typical characteristic of a porous sound absorber.

The noise reduction coefficients of Sugi heartwood, Sugi sapwood, Chanchin–modoki heartwood, Chanchin–modoki sapwood, Yurinoki heartwood, and Yurinoki sapwood were 0.04, 0.11, 0.04, 0.05, 0.09, and 0.14, respectively. In addition, the mean sound absorption rates of Sugi heartwood, Sugi sapwood, Chanchin–modoki heartwood, Chanchin–modoki sapwood, Yurinoki heartwood, and Yurinoki sapwood were 0.08, 0.16, 0.06, 0.09, 0.20 and 0.30, respectively.

Based on our results, it can be concluded that the sound absorption coefficients of highly permeable wood specimens are greater than those of less permeable wood specimens because the increased air flow assists with sound wave attenuation.

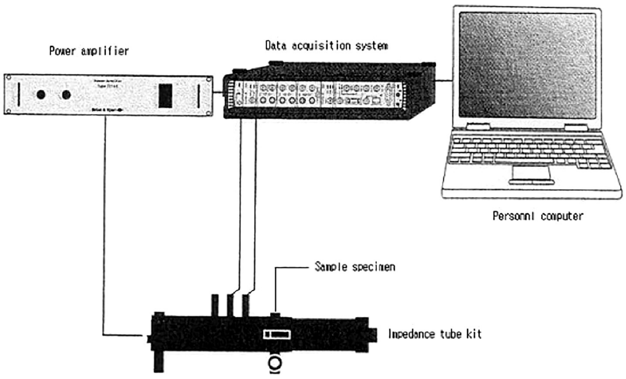

Fig. 4. Sound absorption estimation equipment.

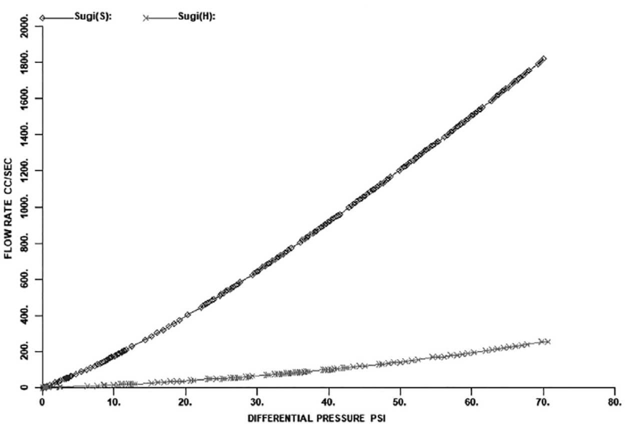

Fig. 5. Gas permeability of Sugi heartwood (H) and sapwood (S).

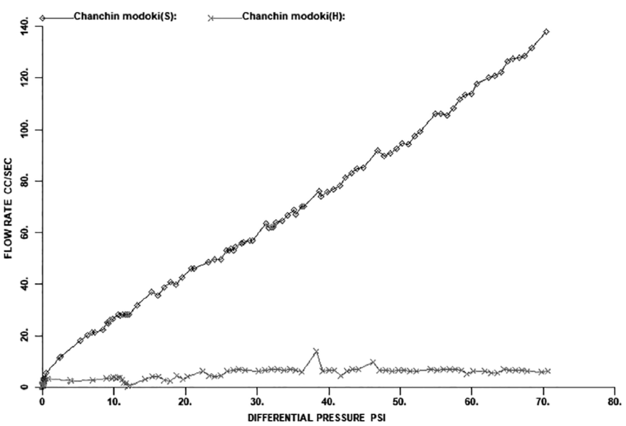

Fig. 6. Gas permeability of Chanchin-modoki heartwood (H) and sapwood (S).

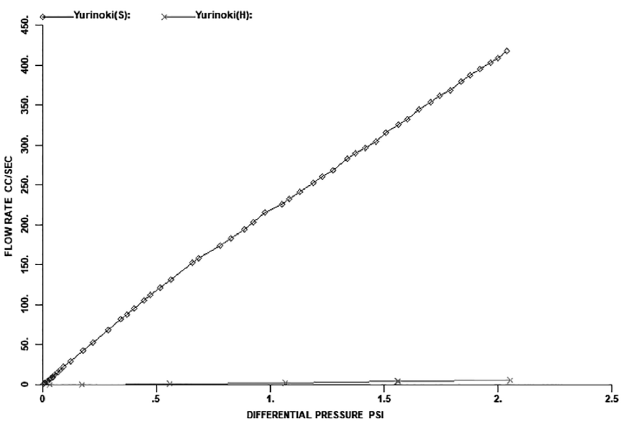

Fig. 7. Gas permeability of Yurinoki heartwood (H) and sapwood (S).

CONCLUSIONS

To determine the relationship between sound absorption coefficients and permeability, the sound absorption coefficients and permeability of several wood specimens were measured in this study. The results of this study were as follows:

1. The sound absorption coefficients was highest for the highly permeable wood specimens in almost all frequency ranges.
2. The air permeability of sapwood was greater than that of heartwood, as estimated by capillary flow porometer.

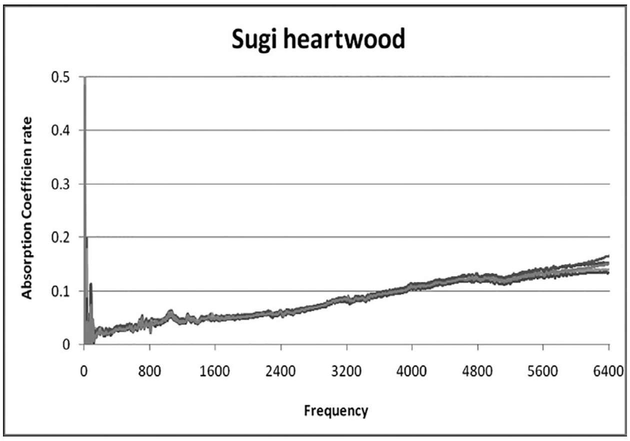

Fig. 8. Frequency versus sound absorption coefficients of heartwood (H).

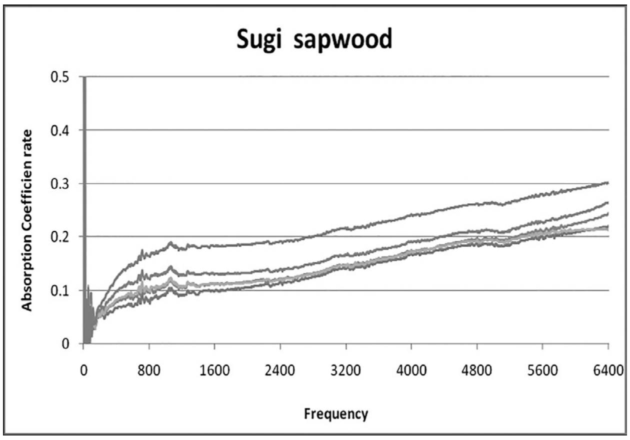

Fig. 9. Frequency versus sound absorption coefficients of sapwood (S).

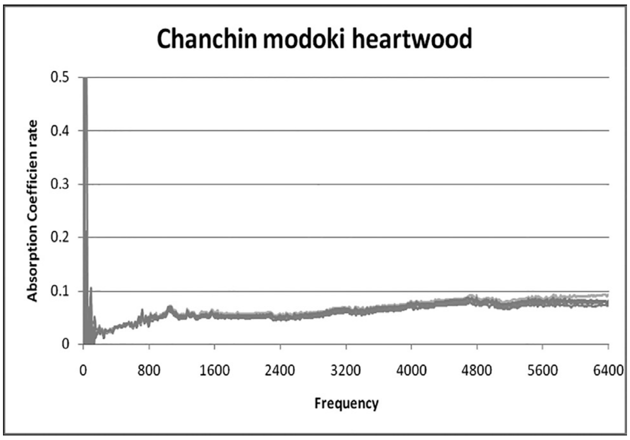

Fig. 10. Frequency versus sound absorption coefficients of Chanchin-modoki heartwood (H).

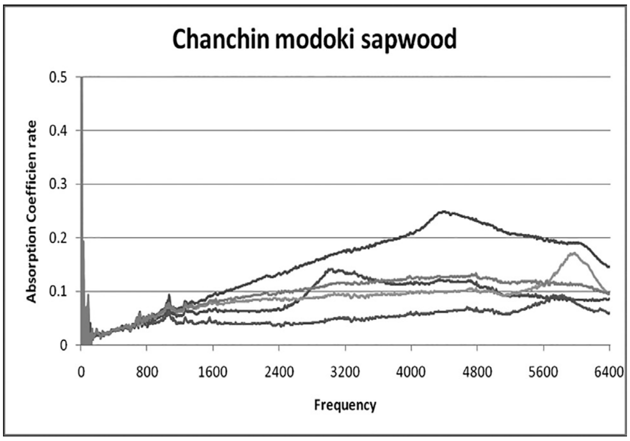

Fig. 11. Frequency versus sound absorption coefficients of Chanchin-modoki sapwood (S).

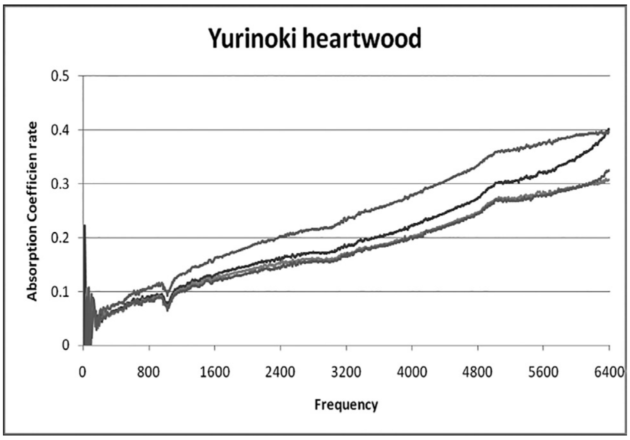

Fig. 12. Frequency versus sound absorption coefficients of Yurinoki heartwood H).

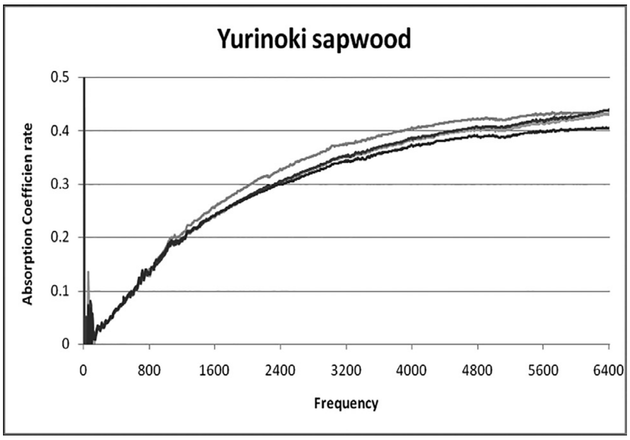

Fig. 13. Frequency versus sound absorption coefficients of Yurinoki sapwood (S).

ACKNOWLEDGMENTS

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (NRF–2019R1I1A3A02059471).

AUTHORS' CONTRIBUTIONS

C. W. Kang designed the study, performed the experiments and wrote the paper. E. S. Jang, S. S. Jang, M. Hasegawa and J. Matsumura provided important comment. All authors assisted in editing of the manuscript and approved the final version.

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