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INFLUENCE OF THE MAIN COMPONENTS CONTENT OF *PICEA JEZOENSIS* ON ACOUSTIC VIBRATION PROPERTIES

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ABSTRACT

The main chemical composition content of *Picea jezoensis* (holocellulose, lignin, and extractive content) was measured using the traditional chemical experiment method, and the vibrational parameters including of dynamic elastic modulus E, specific dynamic elastic modulus E/ρ, acoustic impedance $Z(\omega)$ and sound radiation coefficient R, of the spruce samples were measured using the multi-channel fast Fourier transform analyzer. The relationship between the different components and wood acoustic vibration properties were analyzed by simple linear regression analysis and bivariate regression models. The results showed that the holocellulose content significantly affected on the acoustic properties of the wood. The vibrational properties first increase and then decrease with the increase in holocellulose content. The best vibration properties is achieved when the holocellulose content is 62% to 65%. Lower lignin content and benzyl alcohol extractive content are beneficial in improving the acoustic properties of wood.

KEYWORDS: *Picea jezoensis*; holocellulose; fast Fourier transform analyzer; acoustic vibration properties.

INRODUCTION

Wood is an important part of musical instruments; hence the properties of wood provide a powerful basis for the production of instruments and directly determine instrument quality (Zheng 2003). However, excellent wood materials are increasingly scarce, that seriously influences the rapid development of the instrument industry. Wood with good acoustic quality has excellent acoustic resonance and vibration frequency spectrum. It can spread acoustic energy through impacting action, and provides the beautiful tone. Excellent acoustic vibration requires good radiation ratio, middle density, faster sound transmission speed, higher specific dynamic elastic modulus, lower damping coefficient, and lower acoustic impedance, among others (Liu et al. 2006).

The acoustic properties of wood are related to its structural characteristic and physical properties, as well as its chemical properties (Traore et al. 2010). To improve acoustic vibration properties, researchers had tried to improve the acoustic properties of wood by reducing density and damping factor, and enhancing the radiation ratio. Decay fungi in wood have chemical selectivity (brown rot fungi mainly involved in the degradation of cellulose and hemicellulose in soft wood) that mainly occurs in the secondary wall S3 layer (Spycher 2007). Yano (1993) tried to improve that the quality of wooden string instruments by impregnating various concentrations of saligenin solution in Sitka spruce specimens and allowed to react with gaseous formaldehyde using SO2 as a catalyst. The values of specific dynamic elastic modulus ($/\rho$) significantly increased and the value of loss tangent was reduced with the increase in density, thereby improving the acoustic converting efficiency. Meanwhile, the wood dimensional stability was also improved because the formaldehyde reacted with holocellulose hydroxyl (Yano and Minato 1993). Jia (2010) analyzed the effect of high temperature treatment on the wood acoustical properties, and found out the density was decreased and the rate of acoustic emission was increased after high temperature process because that the internal chemical composition degraded. Part of the hemicellulose decomposition reduces the moisture absorption and then enhance the dimensional stability (Jia 2010). Wood is mainly composed of cellulose, hemicellulose, and lignin, which account for more than 90% of wood quality. The molecular structure, properties, and relationship of these components are used as material basis for various wood properties and chemical basis for wood properties improvement. The secondary components of wood include ash extractive, which comprise a small part, but has significant effect on wood properties (Akitsu et al. 1991). Studies about acoustic modification have often neglected the effects of chemical content on acoustic vibration properties. Therefore, studying the influence of the chemical properties of wood and their impact on acoustic properties, as well as clarifying the inner mechanism of acoustic vibration characteristic with chemical properties, could provide reliable basis for modification of musical vibration.

MATERIAL AND METHODS

Materials

A series of 40 spruce (*Picea jezoensis*) specimens with dimensions of 500 (longitudinal direction) × 30 (radial direction) × 10 mm (tangential direction) were used in this study. The surface of the samples was sanded after air drying. The vibrational properties of the samples were measured at equilibrium moisture content in atmosphere at 20°C and 65% relative moisture content. Prior to the measurement of the vibrational properties, five blocks of approximately 20 mm were intercepted from the end of the sample, then the blocks were prepared to powder which passed the 40 – 60 mesh screen for wood chemical properties measurement.

Methods

The vibration of the acoustic properties was tested using a fast Fourier transform (FFT) spectrum analyzer based on the beam theory of the free boundary conditions at both ends (Akitsu et al. 1991). An elastic tripod was used for hanging the specimen horizontally on the vibrational node of sample, as shown in Fig. 1.

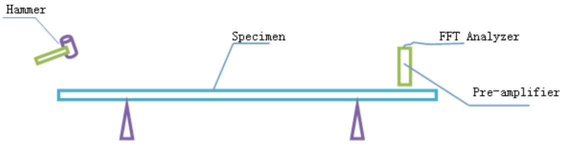

Fig. 1: Schematic of the wood vibration characteristic parameter test.

The node location was determined based on the theory of vibration. The vibrational mode of the fundamental wave was 0.224 times of length from the node to the end. A small wooden hammer was used to knock on one end of the specimen, while a microphone was placed at the other end to receive the signal. After the signal passed the preamplifier and filter, the FFT analyzer was used to process the time domain signal and frequency domain signal during the vibration of the specimen. The acoustic vibration parameters (such as specific dynamic elastic modulus E/ρ, acoustic impedance Z (ω), and sound radiation coefficient R et. al) were calculated as follows:

$$E = \frac{48\pi^2 \rho L^4 f_m^2}{m^4 T^2} \tag{1}$$

where: E - flexural dynamic MOE (GPa),
L - length of sample (m),
T - thick of sample (m),
f_m - flexural resonant frequency (Hz),
ρ - density of sample ($kg \cdot m^{-3}$),
m - the coefficient of vibration.

$$R = \frac{v}{\rho} = \sqrt{\frac{E}{\rho^3}} \tag{2}$$

$$Z(\omega) = \rho v = \sqrt{\rho E} \tag{3}$$

where: v - the surface wave velocity (longitudinal direction) ($m \cdot s^{-1}$),
R - sound radiation coefficient,
Z (ω) - acoustic impedance.

The chemical contents of the cellulose, lignin and extractive were measured following the GB/T 2677 -2011 standard.

RESULTS AND DISCUSSION

Wood is an important material for making instrument soundboard. The quality of musical instrument not only depends on the technological conditions during production; but also the acoustic properties of the material (Liu and Liu 2012). As is well-known, the acoustic properties of the trees under the same species significantly varies because of the different chemical composition contents of each tree. To clarify the relationship of chemical properties and acoustic properties, the relationships between wood chemical composition content (extractive content, holocellulose content, and lignin content) and acoustic vibration parameters (specific dynamic elastic modulus *E/ρ*, acoustic impedance Z (ω), and sound radiation coefficient R) were analyzed using different simple linear regression analysis and bivariate regression models.

Relationship between holocelluose content and vibration properties

Figs. 2, 3 show the significant correlated between the holocellulose content and dynamic elastic modulus E, specific dynamic elastic modulus *E/ρ*. The maximum dynamic elastic modulus E and specific dynamic elastic modulus *E/ρ* occurred at 62% to 65% holocellulose content. With the increase in holocellulose content, the E, *E/ρ* first increased and then exhibited a decreasing trend, indicating that the maximum E, *E/ρ* could be obtained under certain holocellulose contents.

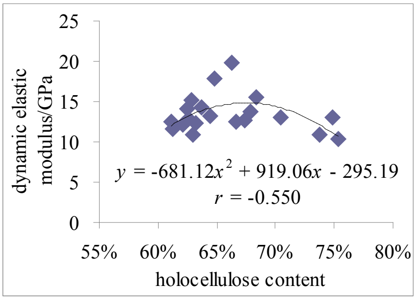

Fig. 2: Relationship of E and holocellulose content.

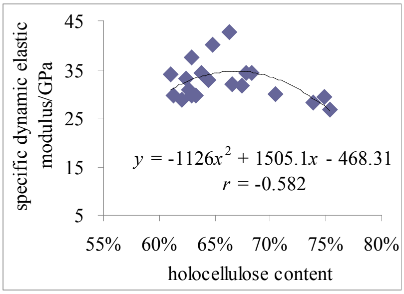

Fig. 3: Relationship of E/ρ and holocellulose content.

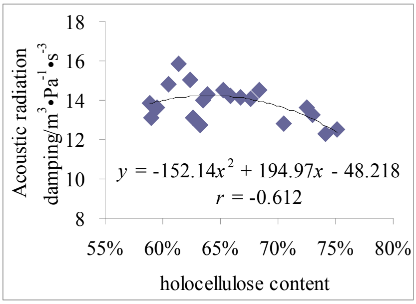

Fig. 4: Relationship of g R and holocellulose content.

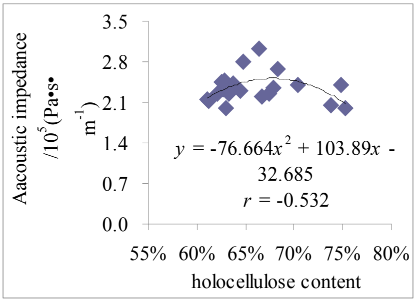

Fig. 5: Relationship of Z (ω) and holocellulose content.

To obtain high vibration efficiency, the value of sound radiation coefficient *R* should be larger according to the theory of vibration (Yano et al. 1993). Larger constant *R* indicates the vibrational energy of wood would be radiated, and loud sound and strong persistence would be obtained. As shown in Fig. 4, the holocellulose content had a negative correlation on the sound radiation coefficient *R*; that is, constant *R* decreased with increasing holocellulose and reached the highest value when the holocellulose content was around 62%.

Lower acoustic impedance *Z (ω)*, the acoustic properties would be better. As shown in Fig. 5, the highest *Z (ω)* appears at the 62% to 65% holocellulose content. To obtain lower *Z* (ω), the *E*, *E/ρ* and *R* would decrease. It would lead to poor comprehensive acoustic properties of wood.

To obtain better acoustic vibration properties, all parameters would be considered comprehensively.

The above analysis indicated that the vibration properties of bar was the best when the content of holocellulose is between 62% and 65%, but the content of spruce holocellulose was between 60% and 80% commonly. Holocellulose is mainly composed of cellulose and hemicellulose. Holocellulose could absorb more vibration energy because of the hemicellulose, which contains several branched-chain structures that are arranged irregularly, and the non-crystalline cellulose with irregular arrangement. Higher holocellulose content leads to an increase in the hemicellulose and the non-crystalline region in cellulose, which consequently reduces the vibration energy radiation.

Relationship between lignin content and vibration properties

Fig. 6 and 9 show that lignin content is negatively correlated with E, E/ρ, R and Z (ω). The vibration parameters decreased with increase in lignin content. That means lower lignin content leads to greater E, higher E/ρ and R. So lower lignin content is beneficial in improving the acoustic properties of wood. For the *Picea jezoensis*, 24% – 26% of the lignin content is expected.

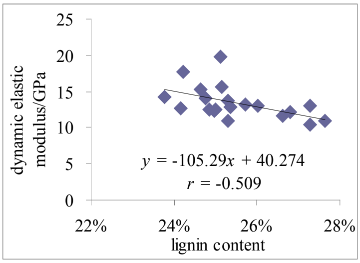

Fig. 6: Relationship of E dynamic elastic modulus and lignin content.

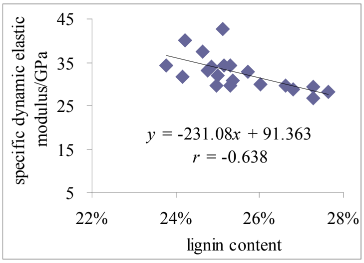

Fig. 7: Relationship of E/ρ specific dynamic elastic modulus and lignin content.

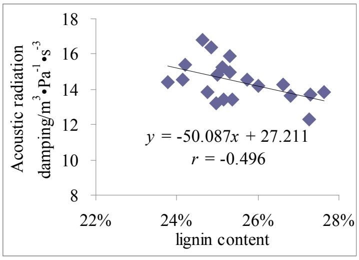

Fig. 8: Relationship of acoustic radiation damping R and lignin content.

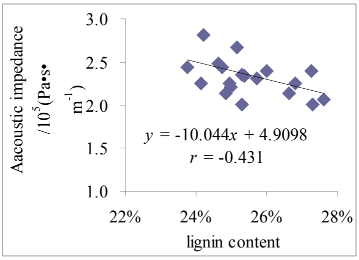

Fig. 9: Relationship of Z(ω) acoustic impedance and lignin content.

Relationship between extractive content and vibration properties

The result of wood extractive on the impact strength of wood showed that the bending strength of North American red fir and extractive content had no obvious linear relationship; however, the elastic modulus decreased with the increase in extractive content (Peng et al. 2004). The quality of instruments largely depends on the acoustic resonance of the soundboard. We found that a few years aging of wood is necessary to produce high quality musical instruments. The acoustic properties of wood could be improved because the extractive are broken down or removed under long-term storage (Liu and Zhao 2004). Masahiro analyzed the vibrational property properties changes of spruce wood by impregnation with water soluble extractives of Pernambuco. The loss tangent (tan δ) of the impregnated specimens decreased by nearly half of its original value, suggesting that the decrease in tan δ results is caused by impregnation of the extractive components into the amorphous region of the cell walls (Matsunaga 2000). For the *Picea jezoensis*, the relationship between the benzyl alcohol extractive content and vibrational properties are shown as in Figs. 10 – 13.

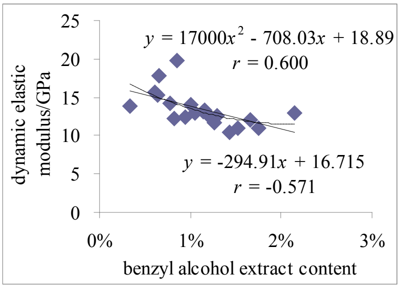

Fig. 10: Relationship of E and benzyl alcohol extractive content.

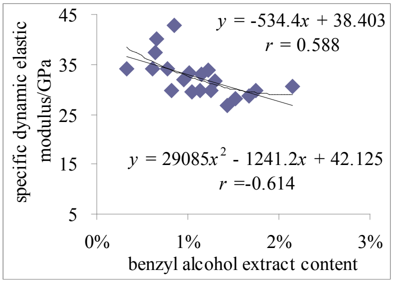

Fig. 11. Relationship of E/pand benzyl alcohol extractive content.

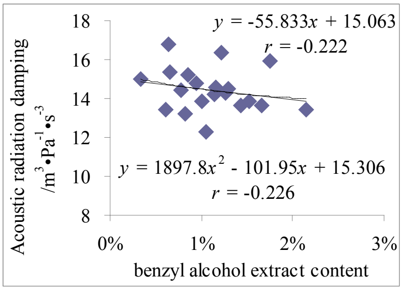

Fig. 12. Relationship of R and benzyl alcohol extractive content.

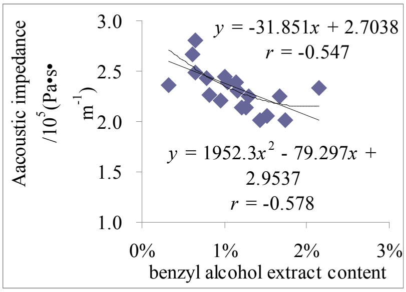

Fig. 13. Relationship of Z(ω) and benzyl alcohol extractive content.

These figures show the relationship between benzyl alcohol extractive content and *E*, *E/ρ* and *Z*(*ω*) are obvious, but the relationship between benzyl alcohol extractive content and *R* is not obvious. To obtain better acoustic vibration properties, Less than 1% of benzyl alcohol extractive content is expected based on comprehensive consideration.

CONCLUSIONS

In this study, we showed that the chemical components have different influences on vibration properties of wood.

Holocellulose content is closely related to the acoustic properties of wood. The vibrational properties first increase and then decrease with the increase in holocellulose content. The best vibration properties is achieved when the holocellulose content is 62% to 65%.

Lower lignin content is beneficial in improving the acoustic properties of wood. For the *Picea jezoensis*, 24%-26% of the lignin content is expected.

To obtain better acoustic vibration properties, less than 1% of benzyl alcohol extractive content is expected based on comprehensive consideration.

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