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CHANGES OF MICROSCOPIC STRUCTURES AND SOUND ABSORPTION PROPERTIES OF DECAYED WOOD

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ABSTRACT

Utilizing waste decayed wood is an effective method of conservation woodresourceand protection environment.In this paper, the sound absorption property of decayed poplar wood (*Populus tomentosa*) was investigated by analyzed the changes of microscopic structure, pore characteristics and sound absorption properties. Experimental results indicated that the sound absorption coefficientof decayed poplar woodwas significantly improved compared with the health wood. The components of cell wall were decomposed after decayed resulting in the pit membrane being disappeared, even the cell wall are decomposed and formed new pores. In addition, the pore size and connectivity increased, flow resistivity and sound impedance decreasing for the decayed poplar wood. Those results revealed that propagation path and internal friction between sound wave and cell wall increased, resulting in the acoustic attenuation increasing. The decayed waste woods as a sound absorption material would become possible.

KEYWORDS: Decayed waste wood, microscopic anatomy structures, pore characteristics, sound absorption properties.

INTRODUCTION

There are approximately several million cubic meters decayed waste woods per year in China. Over time, the components of wood were degraded by insects and wood-rotting fungus (Padhiar and Albert 2011, 2012). Additionally, microscopic anatomy structures also underwent changes (Erwin et al. 2008). The porosity andinter-cell connectivity of wood pores was increased

(Blanchette et al. 1985). Those changes resulted in wood density and physical mechanical properties decreasing, but permeability and hygroscopicity properties increasing. Currently, there are main four ways to utilize these woods: 1) as fuel, 2) as raw materials for wood-based panels, 3) biological fuel (alcohol, hydrogen) extracted from waste wood after gasification or liquefaction treatment (Shethand Babu 2010. Wu et al 2006), 4) converted to activated carbon and charcoal (Tsang et al 2007). Utilizing decayed waste wood is an effective method of saving wood, and is significant in establishing an economical society and developing a recycle economy.

In general, wood is an excellent acoustic transfer material, but is not ideal for sound absorption. Previous studies have extensively investigated different treatment methods to modify its sound absorption properties (Kang et al. 2008, Wang et al. 2014). The delignification treatment could improve wood's sound absorption properties in the longitudinal direction. The results shown that intercellular substances had gushed out and formed numerous small cracks, and the treatment wood sound absorption coefficients was 20%~30% higher than those of normal wood samples in the entire frequency range (Kang et al. 2008). Microwave treatment was used to improve sound absorption capacity of pinus wood. The maximum sound absorption coefficient of the treatment wood increased 0.4 because of the pit membranes, wood ray cells and the intercellular layer destruction (Wang et al. 2014). Changes to the microscopic anatomy structure of waste woods were similar to the above treatment so that using these decayed waste woods as a sound absorption material would become possible.

Bulk density, porosity, pore characteristics, and surface impedance are important parameters that often concern the research regarding porous sound absorption materials. Variable bulk densities may result in different noise reduction behaviors since the bulk density greatly influence the porosity and sound impedance. Porosity is calculated from the normal bulk or oven-dry density and the specific (or cell wall) density of the solid (Plötze and Niemz 2011). Porosity and pore characteristics influence flow resistivity and sound absorption properties (North 1989). The sound impedance of wood can be expressed based on means density and modulus in wood. The surface sound impedance of wood has four more orders of magnitude than that of air. Those results indicate that the vast majority of sound waves are reflected back, namely, indicated poor sound absorption performance for wood.

In this paper, the sound absorption properties for different degrees of decay woodswere studied. Then, changes of microscopic anatomy structure, pore characteristics and sound impedance for decay wood were also pointed out. The relationships of between those changes and sound absorption properties were analyzed. This provided a possible method for solving problems relating to recycling and utilizing decayed waste wood.

MATERIALS AND METHODS

Materials

The dead standing decay poplar wood (*Populus tomentosa*) lag was collected from the *Xinjian* village forest farm in *Renshou* country, *Sichuan* province. The poplar wood log was rotted by insects and fungus. Its diameter and length were 20 cm, 2.4 m, respectively, and basic density distribution is shown in Fig. 4. The three longitudinal lumbers and three cross section half circular discs were taken at equal intervals along with the diameter and height direction, respectively. The letters A, B, C say longitudinal sections of different diameter direction, the arabic numerals (1, 2, 3) represent longitudinal sections of different longitudinal direction, Greek numerals (I, II, III) represent cross sections of different longitudinal direction (Fig. 1).

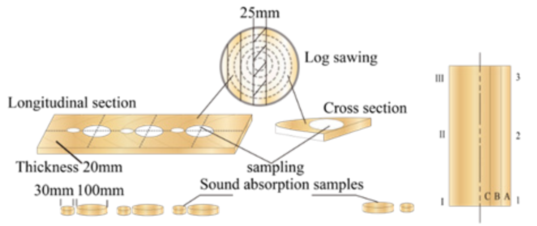

Fig. 1: Lag sawing and sampling schematic.

Those samples were oven-dried at 103 ± 2°C for 24 hours. The samples of longitudinal section sound absorption property measurements, which diameter was 100 mm and 30 mm, thickness was 20 mm, were taken at equal intervals from each piece of lumber along with height direction (Fig. 1), and the cross section samples of sound absorption property measurement were taken from each half circular disc (Fig. 1), the samples sizes were same to the longitudinal section samples. Healthy poplar wood was also collected from same forest farm that had the same tree-age as the decayed wood.

Methods

Scanning electron microscope

The changes in microstructure in decayed poplar woods were examined using a Hitachi S-4800 Field Emission Scanning Electron Microscope (SEM, Japan). The operation accelerating voltage was 10 kV. Samples were mounted on aluminum stubs with double-sided tape, sputter-coated with gold, and analyzed for changes in microstructure in the radial and tangential sections.

Mercury intrusion porosimetry (MIP)

The mercury intrusion porosimetry (MIP, AutoporeTM IV 9500 Automated Mercury Porosimeter, Micromeritics Instrument Corp., US) was used to characterize the porosity and pore size and distribution of the decayed poplar woods. Using pressure, it forced mercury into the pores; the volume of mercury that entered the pores determined the pore volume and the pressure needed determined the pore size. Measurements of the total intrusion volume, the total pore surface area, the pore size and the distribution were all possible. Certain samples with dimensions of 8 × 6 × 6 mm (L×T×R) were cut from the sound absorption sample center (Φ=100 mm). Those specimens were further oven-dried at 103 ± 2°C, and measurements were conducted by increasing the pressure on a sample immersed in the non-wetting mercury. The increasing pressure rate was automatically controlled with a lower rate at lower pressure levels. As the pressure increased, mercury progressively moved into smaller voids. The pore volume could be derived from the quantity of mercury used. The pore distribution was determined the change rate of pressure and intrusion mercury volume (Plötze and Niemz 2011).

Cantilever beam vibration apparatus and test method (Harris et al. 2002. Turk et al. 2008. Hunt et al. 2012)

The cantilever beam vibration (CBV) apparatus consists of a support base, a beam length bracket, a specimen clamp, a laser sensor, a primary displacement mechanism, and a load located within the displacement mechanism (Beijing Forestry University, China). The samples dried at 103 ± 2°C for 24 hours were taken from the C lumber root and the B lumber middle and treetop; their makers were C-1, B-1, B-2, respectively (Tab. 2). The specimens were then inserted 50 mm into the clamp and centered beneath a loading plate. On the other end of the specimen, an adjustable height laser-displacement measuring assembly is mounted perpendicular to the specimen to adjust the input signal from the laser, to apply a pre-load or displacement to the end of the specimen, and to serve as a mount for the triggering mechanism. A primary displacement screw is first used to position the laser's height and a triggering mechanism relative to the neutral specimen position (no-load). A secondary displacement screw applies an initial displacement relative to the specimen's initial no-load neutral position. Displacement in this position minus the neutral displacement is recorded as the initial deflection. Displacement is applied by the triggering mechanism, which is engaged using a spring pin. When the operator retracts the spring pin, a torsion spring causes the trigger to rotate rapidly away from the specimen, allowing the beam to enter free vibration. The result is vibration in only the first mode. The frequency of the first mode of free vibration of a cantilever beam is given in Harris et al. (2002), and the dynamic modulus of elasticity was calculated using the following Eq.:

$$E_d = \rho \frac{12}{t^2} (2\pi f)^2 (\frac{l^2}{1.875^2})^2$$

where: ρ - density of the specimen (kg·m^{-3}),
t - thickness of the specimen (m),
f - detected frequency of the first natural mode of vibration (Hz),
l - unclamped or "free" length of the cantilever beam (m).

Normal sound absorption coefficient

The sound absorption capacity of the decayed wood was tested using Type SW 422 and Type SW 477 impedance tubes (BSWA Technology Co., Ltd., China.) based on the method of ISO 10534-2 (1998). During the sound absorption measurements, the air gap between the sample and steel backing was 10 mm. The normal sound absorption coefficients at the 1/3-octave frequencies were measured using the large tube (SW 422, Φ100 mm) in the frequency range of 63 Hz to 1600 Hz. The sound absorption coefficients in the frequency range of 1000 Hz to 6300 Hz were measured using the small tube (SW 477, Φ30 mm).

DISCUSSION

The changes of microscopic structures for decayed poplar wood samples

Microscopic anatomy structures: The changes in the microscopic anatomy structures for decayed poplar wood samples were shown in Fig. 2. The pit membranes were degraded, even disappeared (Fig. 2a) for the decay poplar wood. And with decay increased, most of pit membranes had fallen off and formed larger voids.

Hyphae adhered on wood cell wall surface and decomposed wood polymers to form new voids (Fig. 2b). The size of these voids expanded constantly with the decay increased. In the late of decay, most of the wood cell wall was decomposed and became a mesh structure (Figs. 2c, 2d). Those changes led to constant increases in pore size and porosity, and were consistent with Erwin's research (Erwin, et al. 2008).

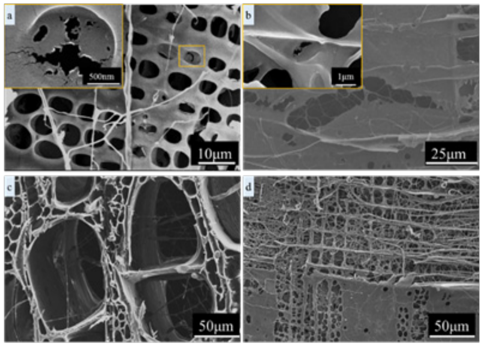

Fig. 2: The changes in microscopic anatomy structures.

Pore characteristics: The results derived from the MIP including total intrusion volume, total pore area, average pore diameter and porosity (Tab. 1).

Tab. 1: MIP test results of decayed wood.

Samples	Bulk density ($kg•m^{-3}$)	Total intrusion volume ($mL•g^{-1}$)	Total pore area ($m2•g^{-1}$)	Average pore diameter (4V/A)/nm	Porosity
Control	0.377	0.9741	2.040	1909.5	39.00
A-1	0.158	7.6286	2.495	12231.6	77.66
B-1	0.164	3.6188	1.800	8042.7	59.41
B-2	0.346	1.3169	1.191	4422.6	47.06
C-2	0.226	2.1574	1.730	4987.8	61.40

The total intrusion volume, average pore diameter and porosity for decayed poplar wood were larger than those of healthy wood, the above mentionsabout changes of microscopic anatomy structures could also prove this point. The total pore volume of the A-1 sample for decayed poplar wood was 7.63 $mL•g^{-1}$, more than that of healthy wood, and porosity was increasedby 38.66 %. As the decay aggravated, the total pore volume, porosity and average pore diameter would become enlarged. However, the total pore area reduced due to micro-voids on the pit membranes disappeared (32-313 nm, Fig. 3b). The porosity and total pore area for the C-2 sample were more than the B-2 sample (Tab. 3 and Fig. 3).

For the B-1 and B-2 samples, the porosity and total pore area for the former were increased compared with the latter (Figs. 3a, 3b). However, as shown in Fig. 3c, the cumulative pore area for healthy wood was more than that of the decayed wood because the micro-voids (32-313 nm, Fig. 3b) on the pit membrane accounted for one half of the total cumulative pore area. According to the research of Stone (Stone 1964. Stone et al. 1965), the 40-250 μm cylindrical pore might be vessel lumen, and the wood fiber lumen diameter was about 15 μm. The inter-vessel pit size was about 4-10 μm (Wheeler et al. 1989). For the A-1 sample, pores in the 7-120 μm range were significantly increased that indicated the wood cell wall substance was severely decomposed and formed lager pores (Figs. 2c, 2b). Those pores in the pit size (7 μm) were increased rapidly for the B-1 sample because pit membrane disappeared (Fig. 2a) and new pores formed (Fig. 2b).

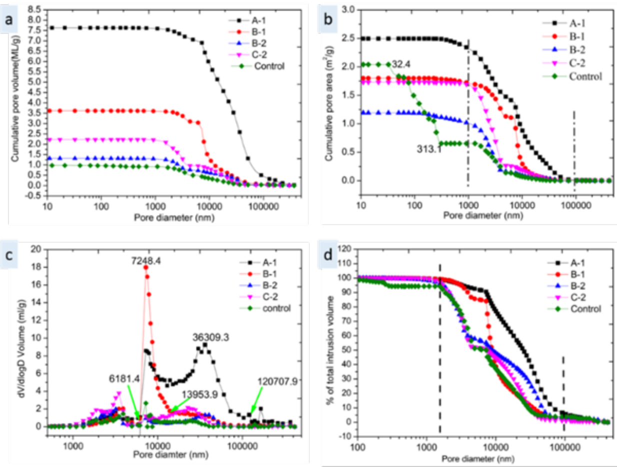

Fig. 3: Pore characteristic parameters of decayed poplar woods.

The changes of sound impedance of decayed poplar woods

The dynamic modulus of elasticity (DMOE), damping loss factor (tanδ), resonant frequency (f_r) and sound impedance (ω) of the decayed poplar wood samples were shown in Tab. 2.

Tab. 2: The acoustic impedance of decayed wood samples.

Samples	Density (g·cm^{-3})	Size (mm)	fr (Hz)	DMOE /GPa)	Tanδ	ω 10^4 (dyns·cm^{-3})
B-1	0.164	50.15×3.38×339	18.278	2.491	0.026	6.39
C-1	0.142	50.03×3.26×340	16.401	2.340	0.026	5.76
B-2	0.330	49.58×3.27×340	18.821	3.097	0.021	10.24
Control	0.377	49.69×1.52×230	33.710	6.735	0.019	25.40

As decay increased, the DMOE decreased, and the C-1 sample part of the root-pith decreased from 6.735 to 2.340GPa compared with that of the control. The similar result was proved by Jun-Li Yang (Yang, et al. 2003). The main cause of dynamic modulus of elasticity decreasing was compositions of cell wallbeing decomposed. According to above mentions and the definition of sound impedance ($\omega=\sqrt{E\rho}$), the sound impedance for decayed poplar wood was decreased from 25.40×104 to 5.76×104 dyns·cm^{-3}, and this change implied that sound waves could be much easier to enter wood for the sound impedance gap between air and wood diminution.

Inaddition, the cell wall substance decomposition and additional inter-macromolecule space production also resulted in increases in damping loss factors. According to Takemura's theory (Takemura 1966), the additional space would provide pore space of the molecular chains movement. When acoustic waves caused the vibrations of wood molecular chains, degrees of freedom and spaces of molecular chain movement were increased resulted from cell wall substance being decomposed. So this movement resulted in sound wave energy loss.

Sound absorption property of decayed poplar woods

The Ave-Abs and Max-Abs of the longitudinal sections from root to treetop were 0.167, 0.103, 0.060 and 0.386, 0.169, 0.137, respectively (Tab. 3). The closer the pith and root were, the more serious the decay was (Fig.4). The Ave-Abs and Max-Abs of cross sections for the decayed wood samples are 0.269, 0.177, 0.188 and 0.493, 0.257, 0.273 from root to treetop, respectively (Tab. 3).

Tab. 3: the sound absorption property of decayed wood samples.

Samples	Density ($g \cdot cm^{-3}$)	Ave-Abs	Max-Abs
A-1	0.158	$0.176(0.007)^{A}$	$0.357(0.030)^{B}$
B-1	0.164	$0.162(0.009)^{A}$	$0.487(0.032)^{A}$
C-1	0.142	$0.164(0.037)^{A}$	$0.313(0.127)^{B}$
A-2	0.340	$0.091(0.008)^{C}$	$0.213(0.015)^{C}$
B-2	0.346	$0.095(0.010)^{BC}$	$0.160(0.017)^{CD}$
C-2	0.226	$0.122(0.004)^{B}$	$0.133(0.152)^{CD}$
A-3	0.334	$0.069(0.013)^{CD}$	$0.177(0.074)^{CD}$
B-3	0.330	$0.054(0.013)^{D}$	$0.110(0.033)^{D}$
C-3	0.338	$0.056(0.028)^{D}$	$0.123(0.047)^{CD}$
I	0.183	$0.269(0.004)^{A}$	$0.493(0.015)^{A}$
II	0.324	$0.177(0.003)^{C}$	$0.257(0.152)^{B}$
III	0.236	$0.188(0.005)^{B}$	$0.273(0.038)^{B}$
Control-C	0.377	0.122(0.004)	0.230(0.025)
Control-L	0.377	0.057(0.001)	0.123(0.086)

Note: The confidence degree was 0.95. The dependent variables were the average sound absorption coefficient and the maximum sound absorption coefficient. The independent variable was density. Mean values with the different letters in each column were significantly different at the 5% level. Standard deviations are in parentheses

The sound absorption properties of different height direction had significant differences, but those of radial direction were not (Tab. 3). The effects of decay degrees on sound absorption property were analyzed. The sound absorption properties of the decayed poplar wood samples were superior to those of healthy wood samples (Figs. 5a, 5d). There were reasons for those changes: firstly, the cell wall substances decomposition of poplar wood caused wood density and DMOE to decrease (Fig. 4 and Tab. 2), and this change implied that sound waves could be much easier to enter wood since the sound impedance of wood diminution.

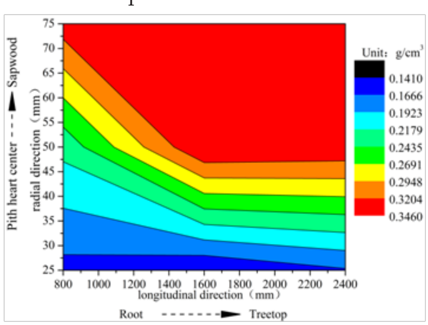

Fig. 4: The distribution of density for decayed wood samples.

Secondly, those pores became larger and formed on the cell wall, the pore connectivity increase (Fig. 2) resulted in the sound propagation pathinto wood being extended. What's more, number of pores and propagation path increase were contribution to poresspecific surface area and friction between sound wave and pore surface increasing. Finally, damping loss factor increase (Tab. 2) resulted in molecular chain movement and wood vibration damping loss increasing.

However,not was thatthe more serious the decay, the better the sound absorption performance. For the A-1 and B-1 sample, the degree of decay for the former (0.158 g·cm^{-3} was more than that of the later (0.164 g·cm^{-3}), but the sound absorption coefficient of the later was larger. Because that the cell wall of the A-1 sample was fully decomposed (Fig. 2d), number of large holes increased (Tab. 1: total pore volume was 7.6 mL/g, average pore diameter 12231.6 nm) compared with the B-1 sample (3.6 mL/g and 8042.7 nm) resulted in sound waves easy passing through the material.

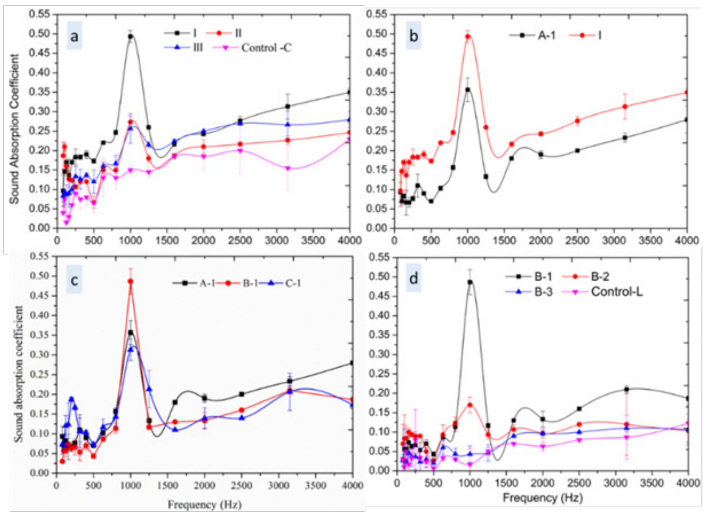

Fig. 5: The sound absorption property for decayed woods

Note: the control-C sample was a healthy poplar wood cross section, and the control-L was a healthy poplar longitudinal section.

The cross section samples of the decayed wood sound absorption coefficients are shown in Fig. 5a. The A-1 and I sample densities were 0.158 g·cm^{-3} and 0.183 g·cm^{-3}; however, the A-1 sample's Ave-Abs and Max-Abs were less than that of the I sample (Fig. 5b) due to wood cell arrangement. Numbers wood cells were distributed along the axial direction (Fig. 2c), and sound waves entered into the wood along with the cell axes for cross section samples.

CONCLUSIONS

The sound absorption properties of decayed poplar wood samples were superior to those of the health wood. Differing degrees of decay had significant sound absorption properties. Decay contributed to decreases in density and sound impedance, but the porosity, pore size, and connectivity for pit membranes disappeared and new voids increased, and even the cell wall disappeared. When the sound wave entered into the wood, the propagation path and internal friction between the sound wave and the cell wall increased, resulting in the acoustic attenuation increasing. In addition, the decayed wood internal loss increased, resulting in damping loss and acoustic attenuation increasing.

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