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SOUND INSULATION AND MECHANICAL PROPERTIES OF WOOD DAMPING COMPOSITES

Meihong Liu, Limin Peng, Zhengqiang Fan, Dong Wang
Research Institute of Wood Industry Chinese Academy
of Forestry
Beijing, China

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ABSTRACT

The sound insulation performance and mechanical properties of medium density fiberboard (MDF) and rubber multilayer panels were studied. The MDF and rubber materials were compounded under certain conditions of hot pressing, temperature and amount of glue. The weighted sound reduction was 28.0 dB for 6 mm MDF, while it was 37.4 dB for 6 mm wood composite damping material, increased by 25.1%. Compared to the monolayer MDF, the composite panels showed increased sound insulation at the resonant frequency, and the critical frequency moved to a higher frequency. The coincidence valley became shallow, effectively suppressing the anastomosis effect. As the rubber thickness increased, the multilayer composite material exhibited enhanced sound insulation efficiency and mechanical properties, and the damping properties of the composite increased, making the composite resistant to bending deformations caused by incident sound waves.

KEYWORDS: Wood materials, rubber, composite panels, dynamic mechanical properties, sound insulation performance.

INTRODUCTION

The continued developments of modern industry, civil construction, and transportation have brought about serious noise pollution, which is considered to be one of the most lethal forms of pollution arising from industrial and technological advancement in recent years (Babisch 2011, Chen et al. 2010, Maderuelo-Sanz et al. 2012, Zhu et al. 2013). Thus, noise prevention and control have attracted worldwide attention as a research and engineering topic. Concerning transportation noise, one option of mitigation is the alteration of the noise propagation path (Chobeau et al. 2017, Han et al. 2015). There are three different approaches to curb these pollution effects: turning off the source, preventing the sound from entering the ears, and altering the noise propagation path and impeding the sound propagation using soundproof materials.

Sound insulation is one technique used to reduce the effects of noise in previously cited cases (Di Bella et al. 2012, Georgiadis et al. 2008, Wareing et al. 2015, Zergoune et al. 2017) and is an extremely pragmatic approach when it comes to making soundproof structures. However, this problem has not been completely solved and merits further research in order to find new materials capable of improving conventional soundproofing solutions (Queheillalt and Wadley 2005).

Single-layer homogeneous materials, with their poor sound insulation performance, cannot achieve the desired sound insulation effects. Traditional methods of improving sound insulation performance involve increasing the surface density and thickness of the material in question. This method is neither economic nor convenient in terms of the processing and utilization of materials (Li et al. 2011). At present, there is a need for new and innovative materials capable of satisfying new requirements for lightness, minimal thickness, and superior sound insulation performance (Chen et al. 2009, Kim et al. 2004, Yungwirth et al. 2008). The concept of damping composite materials is an extremely active research field and the source of many recent engineering solutions (Ghofrani et al. 2016, Wang et al. 2005), and the modification of polymer damping multilayered composites for high noise reduction performance have been studied previously. Han et al. (2015) investigated the effects of foaming processing, acoustic impedance mismatching, and using different numbers of layers on the soundproofing properties of polyvinyl chloride (PVC)-based, multilayered composites. Yoon et al. (2000) investigated the sound insulation properties of both confined and extensional layer configurations in steel/polyurethane composites. They reported that both the extensional and confined structures presented better soundproofing properties than pure steel of the same thickness. Ghofrani (2016) presented the acoustical performance of plywood/waste tire rubber (PWTR) composite panels. The study found that the damping factor and acoustical coefficient of PWTR were significantly improved. Arunkumar (2016) presented the acoustic vibration performance and sound transmission loss behavior of aluminum honeycomb core sandwich panels with fiber-reinforced plastic (FRP) facings. Their results revealed that with high stiffness, inherent material damping significantly affected the acoustical coefficient of PWTR. Shen (2016) studied sound transmission loss (STL) of composite laminate sandwich structures, demonstrating that both stiffeners and laminate layup have significant effects on the vibration and sound radiation behaviors of the structure.

Ng et al. (2008) showed that changing the hardness and stiffness of the material improved the composite damping structure board's sound insulation performance. It has also been shown that maintaining the material quality and thickness of each layer while increasing the number of layers of composite materials changes the nature of the composite structure and greatly improves the sound insulation performance. Wang et al. (2017) investigated the STL through sandwich structures with pyramidal truss cores immersed in acoustic fluids and found that sound insulation generally improves with increasing compactness of the structure.

Many researchers have used composite damping materials with good sound insulation and noise reduction properties, but the damping materials in the damping multi-layer composite structure can weaken the strength of the bending vibrations in the plate (Arunkumar et al. 2016, Reixach et al. 2015, Zhao et al. 2010). When the laminated structure undergoes flexural vibration, energy is quickly transferred to the damping material that is closely adhered to the surface of the structure, causing friction and mutual misalignment within the damping material. Extensive elastic deformation occurs when macromolecular polymers are subjected to alternating stresses from vibrations and sound waves due to the movement of rubber molecule chains. This effect is characterized by a remarkable lag of deformation after stress changes (Hackley and Ferraris 2001, Li et al. 2010, Liang et al. 2012, Lu et al. 2016, Yin et al. 2007). The movement of lagged deformation works by overcoming high resistance before converting to heat energy and dissipating into the environment. According to this theory, viscoelastic materials should have better soundproofing properties when compared to non-viscoelastic materials. These macromolecular polymeric materials cannot only save energy but also dissipate energy, consuming more sound energy in the process (Chen et al. 2014, Lu et al. 2016, Yin and Cui 2009).

In this paper, medium-density fiberboard (MDF) is used as the substrate. The damping material is then laminated with the substrate using an isocyanate adhesive in form of sandwich structure. The damping effect of the sandwich material can further attenuate the acoustic energy, and at the same time, weaken the anastomosis and resonance effects, making the anastomosis valley shallow. If different materials are interlaced into a multilayer structure, the sound insulation of composite material increases at the critical frequency and resonant frequency. The wood damping composite material is used in sandwich structure's interior, both to retain the advantages of wood materials and to improve their sound insulation properties.

MATERIALS AND METHODS

Materials

The thickness of the MDF board was 2.0 mm ± 0.15 mm, supplied by Hubei Bao Yuan Wood Industry Co., Ltd. The rubber damping material had a thickness of 0.8 mm ± 0.2 mm, 1.2 mm ± 0.2 mm, or 2 mm ± 0.2 mm, with a density of 2,300 $kg \cdot m^{-3}$. This rubber damping material can withstand temperatures of -20-100°C, and was supplied by Tianjin Rubber Industry Research Institute Co., Ltd.

The isocyanides adhesive was methylene diphenyl isocyanate (MDI) with a hot pressing temperature of 100°C and sizing for 10% of the total mass. The density at 25°C was 1.240 $kg \cdot m^{-3}$, with a viscosity of 275 cps. These resins were obtained from Shanghai Huntsman Polyurethane Co., appearing as a brown liquid with industrial grade viscosity.

Preparation of wood damping composite

The samples were arranged into dimensions of 500 mm × 500 mm, with alternating layers of MDF board and rubber board (see Fig. 1). The single surfaces of MDF were glued using MDI resin with a glue spread rate of 64 $g \cdot m^{-2}$ before hot pressing for 10 min at a hot pressing pressure of 3 MPa. The types of materials represented by samples 1-8 in the article are shown in Tab. 1:

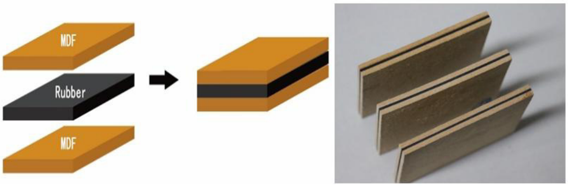


Fig. 1: Structure of composite sample.

Tab. 1: The number of this study sample.

NO	MDF thickness (mm)	Rubber thickness (mm)	Rubber density ($kg\cdot cm^{-3}$)
1	2.0	-	-
2	6.0	-	-
3	2.0	0.8	2,300
4	2.0	1.2	2,300
5	2.0	2.0	2,300
6	2.0	2.0	2,000
7	2.0	2.0	2,300
8	2.0	2.0	2,500

Test methods

Areal density test

Specimen density tests utilized Vernier caliper measurements on the sample length and width of the three tests to find the average dimensions. Three different samples were weighed to obtain an average weight. The formula for the surface density is:

$$G_0=\frac{G\times 10^4}{L\times B} \tag{1}$$

where: G - the sample density (g),
L - the sample length (cm),
B - the sample width (cm).

Mechanical characterization

The Young's modulus was obtained using an extensometer, determined from the average of at least six samples. The bending stiffness was also measured, as flexural bending stiffness is a crucial factor affecting the soundproofing efficiency. The stiffness of the composite was tested according to Eq. 5, the results of which are available in Tab. 2.

Damping loss factor measurement

Dynamic mechanical analysis was conducted using a DMA Q800 system. Samples 25 mm in length and 10 mm in width were heated from 20°C to 36°C at a heating rate of $3°C\cdot min^{-1}$ under a single cantilever mode. The measurements were fixed at 10 Hz and an amplitude of 15 μm, using a dynamic mechanical analyzer to measure the dynamic modulus of elasticity, storage modulus, loss modulus, loss factor, and damping ratio of the materials.

Measurement of sound transmission loss

The impedance tube could measure the sound waves that are incident vertically. However, the sound waves are incident irregularly. Thus, the result measured by the impedance tube is higher. The reverberation chamber method has higher requirements on test site construction as it requires two reverberation chambers and requires the size of the sample to be 10 m^2. As a result, this method is not conducive to the early development of new materials and research in the laboratory. In recent years, researchers proposed that one of the reverberation chamber can be replaced by an anechoic chamber or a semi-anechoic chamber (Xie et al. 2006). Then, the acoustic function of the test components is equivalent to a large-area sound source, allowing the sound waves to simply radiate outward from the sound chamber. Considering the influence of the near-field effect, the sound intensity level cannot be estimated from the sound pressure level measurement result directly. In order to eliminate the influence of the near-field effect, the sound pressure measurement can instead be substituted by the sound intensity measurement, forming a new sound insulation measurement method described as the 'reverberation chamber-muffler box method'. By using this method to test the sound insulation performance of components, not only is the difficulty of installing large specimens avoided, but the test results are closer to the actual sound insulation and noise reduction effect of components in practical application.

The principle of measuring sound insulation performance of composite structure using the 'reverberation chamber-muffler box method' is as follows. The noise signal generated by the white noise signal source is amplified by the power amplifier, driving the reverberation indoor loudspeaker system to emit broadband white noise. Then, a steady state uniformity sound field is formed in the reverberation chamber; the sound pressure signal in the sound source chamber and the muffler box is amplified by the preamplifier by the microphone and sent to the spectrum analyzer for 1/3 octave analysis, producing the test results. Seen below, L_1 is the average effective sound pressure level of the reverberation indoor reverberation zone. L_2 is the average effective sound pressure level of a certain plane in the muffler box. After theoretical derivation, the sound transmission loss of the test piece can be obtained as follows (Xie et al. 2006):

$$R = L_2 - L_1 + 10\log_{10}(1/4 + s_1/r_2) \tag{2}$$

s_1 is defined as the sound receiving area of the test sample (0.26×0.26m^2). r_2 is defined as the room constant in the muffler box.

$$r_2 = A_2 / \left(1 - \bar{a}_2\right) \tag{3}$$

A_2 is the total sound absorption of the muffler box.
a2 is the average sound absorption coefficient in the muffler box.

Several test points are selected in the reverberation chamber and the muffler box, measuring L_1 and L_2, respectively. Then, the sound absorption correction item is determined.

$$\delta = 10\log_{10}(1/4 + s_1/r_2) \tag{4}$$

Finally, according to Eq. 2, the R value of the tested piece is obtained. The test setup is shown in Figs. 2 and 3.

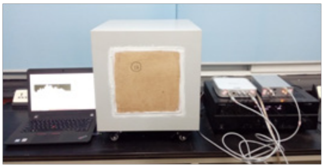


Fig. 2: Small reverberation chamber–silencer box sound insulation test setup.

(a) (b) (c)

Fig. 3: Experimental test setup showing (a) the acoustic test box (b) the inner space of the test box and (c) omnidirectional sound source.

The sound insulation of the small reverberation chamber sound insulation box is then analyzed. The test results are expressed according to the national standardization organization ISO 717 and the national standard GB/T 50121-2005 "Building sound insulation evaluation standard" in the weighted sound reduction index R_w. It is determined by comparing a standard curve with the sound insulation frequency characteristic curve of the component.

The specific determination method of R_w involves comparing the air acoustic sound insulation reference curve and the sound insulation member sound intensity frequency characteristic curve, with the 500 Hz sound insulation amount satisfying the 32 dB principle of the maximum sound insulation reference curve being defined as R_w. The principle of 32 dB is defined as when the sum of the sound insulation of 16 1/3 octave components of 100 to 3150 Hz is less than 32 dB than the reference curve. The standard curve is shown in Fig. 4:

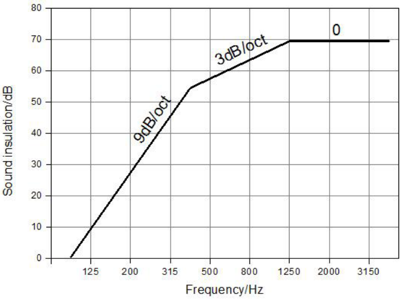


Fig. 4: Determination of the standard curve of the weighted sound barrier R_w.

RESULTS AND DISCUSSION

The composite material was composed of MDF board and rubber material. The sound insulation properties of composite materials must better than MDF board and rubber material. The sound insulation properties of the composites should be better than that of a single-layer MDF of the same thickness. Fig. 5 shows the sound insulation performance of monolayer MDF (2.0 mm or 6.0 mm in thickness). Fig. 8 shows samples 1 and 2, representing the weighted sound reduction index of monolayer MDF, with values of 19.3 dB and 28.0 dB, respectively. The sound insulation performance curve indicated that MDF with a thickness of 2 mm presents a series of resonant frequencies. This material has the lowest coincidence frequency of any of the materials investigated in this study, having a value of approximately 1,000 Hz. MDF with a thickness

6 mm had a critical frequency of 2,000 Hz, displayed an anastomosis valley, and featured the lowest sound insulation among these.

The dependence of the sound transmissions loss STL on rubber thicknesses of 0.8 mm, 1.2 mm, and 2.0 mm is shown in Fig. 6. All samples exhibited the same relationship between frequency and STL value. As the thickness increased, the STL of the rubber samples gradually increased. In order to get a comprehensive comparison of the soundproofing efficiency among the samples, the weighted sound insulation indexes of (Rw) the samples are plotted in Fig. 8. Samples 3, 4, and 5 featured a single layer of rubber plating, with weighted sound insulation values of 20.5 dB, 23.1 dB and 27.2 dB, respectively. From this figure, the resonance frequency of the rubber material was 400 Hz. Also, the amount of noise went down from 32 dB to 5dB. Finally, the rubber featured poor sound insulation performance at the resonant frequency. Both materials are considered to be defective as separate sound insulation materials, but the rubber-MDF multi-layer composite can effectively improve the insulation performance of these types of structures.

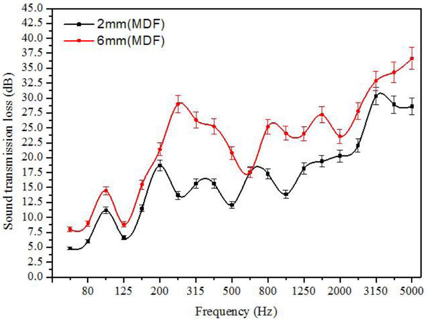


Fig. 5: Sound insulation performance of single layer MDF.

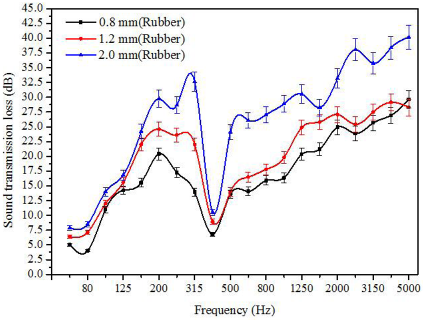


Fig. 6: Sound insulation curve of rubber veneer.

Fig. 7 shows the sound insulation properties of wood damping composite panels with varying rubber thicknesses. The composites studied here featured an MDF thickness of 2 mm, a rubber density of 2,300 kg·cm^{-3}, and rubber thicknesses of 0.8, 1.2, or 2.0 mm. As the rubber thickness increases, the sound insulation properties increase considerably. The STL values for all tested samples were influenced by the frequency in a manner that was similar to each other. These results can be divided into three zones. The first area is the stiffness control area, where in the low frequency range, the composites panels were controlled by their own stiffness (in this instance the board quality and damping were not important). Here, the sound insulation performances of the composite panels were mainly controlled by the stiffness. As the thickness of rubber increases, the stiffness of the composite increases. The STL of composite materials increases with increasing stiffness. For the low frequency noise regime, damping materials can reduce the amplitude of the material's vibration, weakening the resonance phenomenon.

As the frequency continues to increase, the sound insulation performance of composite material is controlled by its mass and stiffness. The composite material generates a series of resonance frequencies. With the increasing of the rubber thickness, the damping performance of the plate was improved, and the resonant and anastomotic effects were suppressed. In the frequency range 500-1,250 Hz, the sound insulation performance of the composites was mainly controlled by the surface density. Here, the material complies with the mass law. The sound insulation performance of the composites increases with increasing arel density. At this time, the mass effect is offset by the bending stiffness effect of the plate, with the impedance of the composite being extremely small. The acoustic properties of the composites mainly arise from the co-damping properties of the material and the quality effect. As the thickness of the rubber increases, the damping properties of such composite materials improve, shifting the critical frequency to higher frequencies. As the damping performance increases, the critical frequency of the sound insulation increases, making the anastomosis valley of the composite material shallower. Therefore, increasing the thickness of rubber can effectively the sound insulation performance of composite materials.

As shown in Fig. 8, the weighted sound reduction index of the 5, 6, and 7 group numbers represents a different rubber thickness for the composite sample, with weighted sound insulation values of 30.6 dB, 34.5 dB and 37.4 dB, respectively. As the rubber thickness increases, the weighted sound insulation of the composite material increases from 30.1 dB to 37.4 dB, a growth of 24.3%. Compared with the fiberboard of the same thickness and density, the sound insulation performance of the composite material increased as the resonant frequency of the sound insulation increased. The coincidence frequency of MDF was 2,000 Hz, while the critical frequency of the composite material was 3,150 Hz. The addition of the rubber material makes the critical frequency of the material increase. Also, the coincidence valley becomes shallow and effectively suppresses the anastomosis effect.

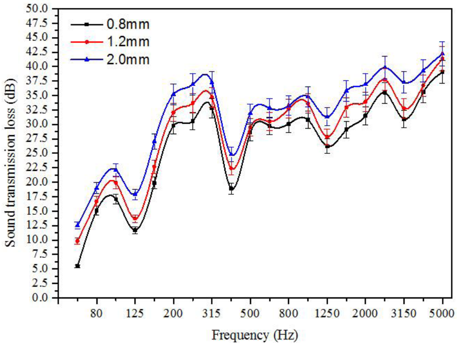


Fig. 7: Sound insulation performance of composite materials.

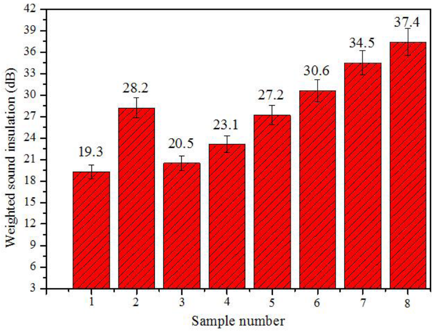


Fig. 8: Weighted sound reduction index.

Fig. 9 shows the effect of density ρ on the sound insulation performance of wood damping composites. As the density increases from 2,000 kg·m^{-3} to 2,500 kg·m^{-3}, the three curves tend to be uniform. The sound insulation performance of the composite material is not significantly improved with increasing R density, which is consistent with the conclusions of former research. As the R density increases, the areal density, stiffness, and elastic modulus of the composite material have relatively small variation, shown in Tab. 2, yet the sound transmission loss with a resonant frequency of 400 Hz increases from 21.4 dB to 28.3 dB.

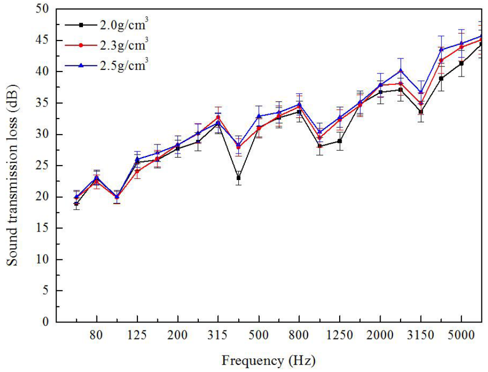


Fig. 9: Sound insulation performance of composite materials with different rubber densities.

In general, the stiffness, areal density, and damping loss factor are the main factors that affect the soundproofing efficiency of these composites. Stiffness plays a vital role in the control area, areal density mainly affects the quality control area, and the damping loss factor plays a key role in the damping control area. The STL of composites increases with increasing stiffness, areal density, and damping loss factor. The stiffness formula can be written as:

$$S= \frac{Eh^3}{12(1-\mu^2)} \tag{5}$$

where: S - the stiffness ($N{\cdot}m^{-1}$)
E - the modulus of elasticity (Pa),
h - the thickness (m),
μ - Poisson's ratio (-).

The potential parameters and the test results are listed in Tab. 2. Increasing the rubber thickness causes the stiffness and modulus of elasticity of the composites to increase as well. Compared to single layer MDF specimens, the stiffness of MDF/Rubber composite with different rubber thickness improved by 47.6%, 93.5% and 218%, respectively and surface density of MDF/Rubber composite with different rubber thickness improved by 116%, 168% and 236%, respectively and surface The improved stiffness, areal density, and damping loss factor led to improvement of the STL of the composites.

Tab. 2: Modulus of elasticity, stiffness, and areal density of composites

Sample	Elastic modulus (MPa)	Stiffness (10–2 N·m)	Areal density (kg·m^{-2})
MDF/Rubber (0.8 mm)	3,364 ± 3	31.0	5.4 ± 0.01
MDF/Rubber (1.2 mm)	3,552 ± 5	41.6	6.7 ± 0.01
MDF/Rubber (2.0 mm)	3,769 ± 8	68.4	8.4 ± 0.01
MDF (2.0 mm)	2,779 ± 2	21.5	2.5 ± 0.01

Tab. 3 shows the modulus of elasticity, sound speed, and logarithmic attenuation coefficient of 6 mm MDF and 6 mm wood damping composites. Compared to single MDF specimens, the elastic modulus, sound speed, and logarithmic attenuation coefficient of the composite samples improved by 8.6%, 49.6% and 29.0%, respectively. The logarithmic attenuation coefficient is an important parameter in the dynamic measurement of viscoelastic materials, and describes the energy loss of the material. The greater the logarithmic decay rate, the stronger the acoustic energy dissipation ability of the material.

Tab. 3: Modulus of elasticity, sound speed, and logarithmic attenuation coefficient of MDF and MDF/rubber.

	Elastic modulus (MPa)	**Sound speed ($m\cdot s^{-1}$)**	**Logarithmic attenuation coefficient**
MDF (6.0 mm)	3,470 ± 6	397.2	0.107
MDF/Rubber (6.0 mm)	3,769 ± 8	594.4	0.138

As illustrated in Fig. 10, when the sound waves were incident on the surface of the monolayer material, the sound waves passed only twice. However, when the sound waves are incident on the surface of the multilayer composite structure, the impedance mismatch between the three layers led to the partial reflection of acoustic waves at the interface and increased the propagation path of sound waves in the multilayered materials, leading to acoustic energy loss. Multi-layer composite sound insulation boards consist of three or more layers of three or more materials with multi-layer interface characteristics. The multi-layer material sound reduction mechanism involves sound waves moving into the laminated composite structure of the surface, undergoing reflection and transmission processes, and the reflected waves being transmitted through the interface between the multiple reflections (Chen et al. 2009, Kim et al. 2004, Yungwirth et al. 2008). As a result, the sound is largely consumed, achieving effective sound reduction.

The rubber material of the core layer can weaken the strength of the bending vibrations in the plate due to acoustic waves. Its vibrational energy is quickly transmitted to the damping material sandwiched in the core layer, causing friction inside the damping material and mutual misalignment. Extensive elastic deformation occurs when macromolecular polymers are subjected to the alternating stresses of vibrations and sound waves (due to the movement of rubber molecular chains) and is characterized by a remarkable lag of deformation behind the stress change. This lagged deformation movement overcomes great resistance to be converted into heat energy, then dissipates into the environment. According to this theory, viscoelastic materials should have better soundproofing properties when compared to non-viscoelastic materials. These macromolecular polymeric materials can not only store energy, but can also dissipate energy, allowing for more sound energy to be consumed. As mentioned earlier, soundproofing is a common method for noise control, with the multilayered composite material showing much better sound insulation performance than the single layer version.

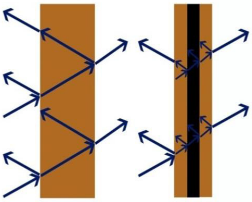
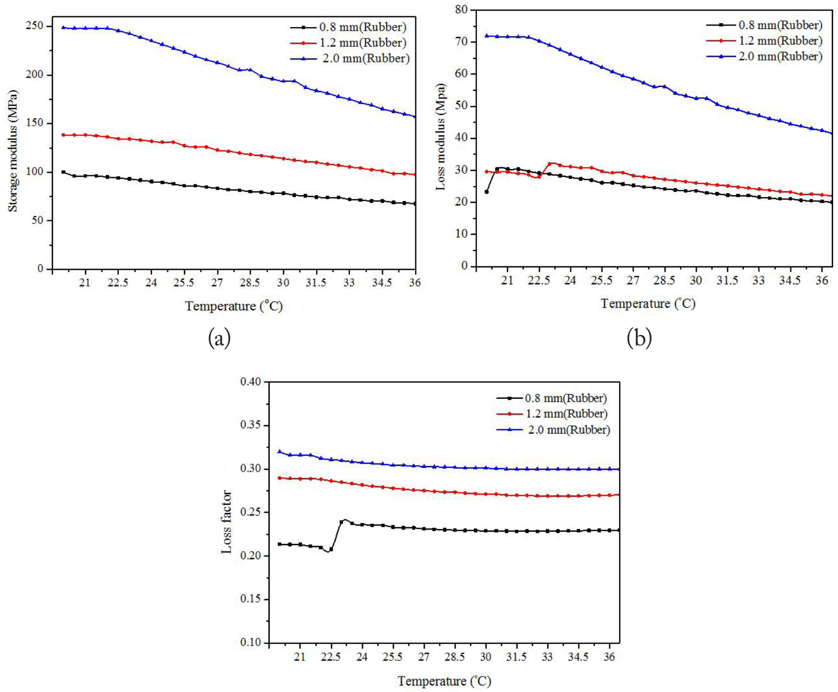


Fig. 10: Schematic of sound wave transmission.

The energy loss capacity of the wood damping composite material was evaluated based on the loss modulus and the loss factor of the composite material. The storage modulus, loss modulus, and loss factor were measured using dynamical mechanical properties analysis (DMA). Fig. 11a shows three curves representing the storage modulus of the single layer rubber material with a rubber thickness of 0.8 mm, 1.2 mm, or 2.0 mm. As the rubber thickness increases, the storage modulus increases, while, over a temperature range of 20-36.5°C, the storage modulus of the rubber material declined to a small degree. Fig. 11b shows that the loss modulus of the rubber was improved by increasing the rubber thickness. As shown in Fig. 11c, the loss factor of the material varies over a temperature range of 20-36.5°C. As the rubber thickness increases, so too does the rubber loss factor. The loss factor of rubber was greatest at a rubber thickness of 2 mm. The greater the rubber loss factor, the better the damping properties of the material, and the stronger its ability to resist bending vibrations due to sound waves.

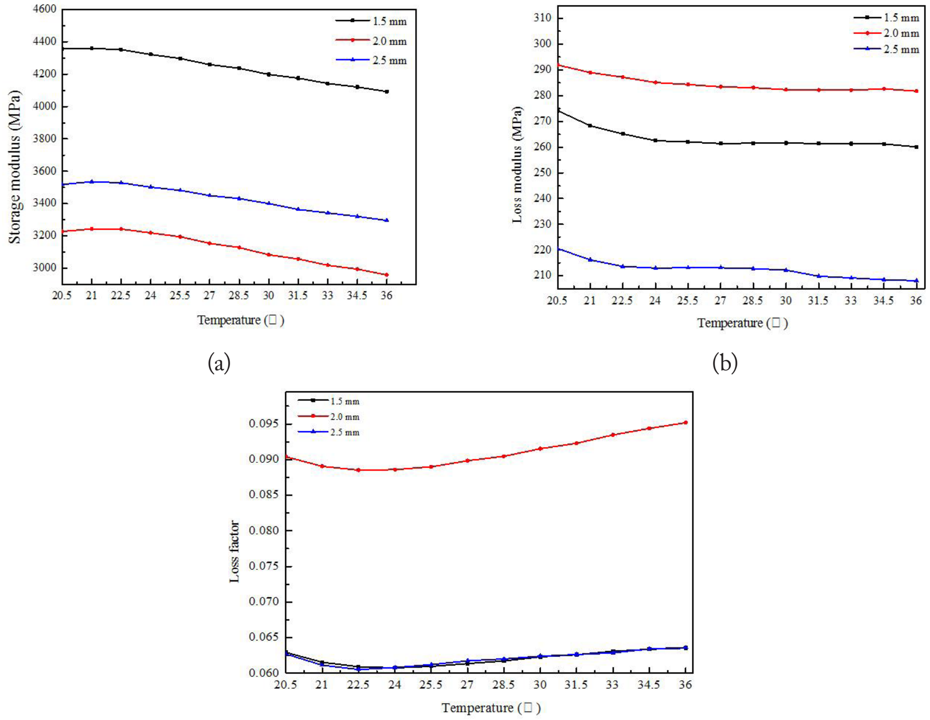


(a) (b)

(c)

Fig. 11: Storage modulus, loss modulus, and loss factor-temperature curves of rubber materials

The dynamic modulus of elasticity and loss factor of MDF are the important indicators for evaluating the acoustic performance of MDF. Fig. 12 shows the dynamic mechanical properties of MDF thicknesses of 1.5 mm, 2.0 mm, and 2.5 mm. Figs. 12a, b and c represent the storage modulus, loss modulus, and loss factor of the MDF, respectively. It can be seen from Fig. 12 that the energy storage modulus of MDF is maximized at a thickness of 1.5 mm, while the loss modulus and loss factor of MDF are largest at a thickness of 2.0 mm. The loss modulus and loss factor of MDF are not linear with its thickness. The damping performance of MDF is better at a thickness of 2.0 mm.

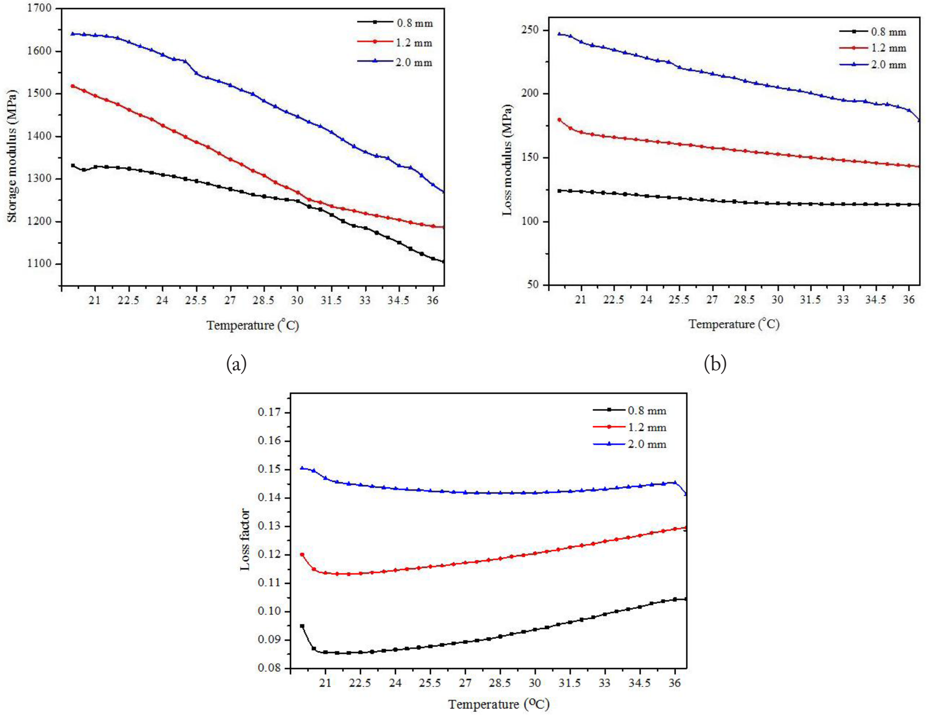


(a) (b)

(c)

Fig. 12: Dynamic mechanical properties of MDF.

Fig. 13 (a) shows three curves representing the storage modulus of the composite material at rubber thicknesses of 0.8 mm, 1.2 mm, and 2.0 mm. As the thickness of the rubber increases, the storage modulus of the composite increases. Increasing the temperature from room temperature causes the storage modulus to decrease. As shown in Fig. 13b, as the thickness of the rubber increases, the loss modulus of the composite increases; the greater the loss modulus of the composite, the better its damping performance and stronger its sound reduction capability. The loss modulus of the composite material does not noticeably increase over this same temperature range. As shown in Fig. 13c, the loss factor of the composite increases with increasing temperature within this test temperature range. As the thickness of the rubber increases, the loss factor of the composite material increases accordingly. The greater the damping loss factor, the greater the energy loss, making the composite material resistant to sound waves caused by stronger vibrations. Increasing the thickness of the rubber, therefore, can effectively improve both the sound insulation properties of composite materials and their mechanical properties. Compared to the rubber samples, the multilayered composites showed higher storage modulus and loss modulus values. Since the loss modulus is an indication of a material's energy dissipation ability, the higher loss modulus of the multilayered composite denotes that more acoustic energy would be dissipated during sound wave propagation in the material (Ghofrani et al. 2016). Therefore, the sound insulation properties of the composites can be enhanced by controlling the rubber thickness to maintain a good balance between the sound insulation ability and the mechanical properties of the composite.

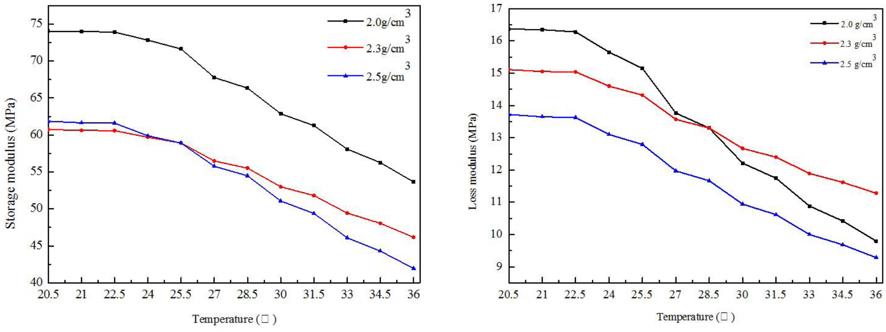


(a) (b)

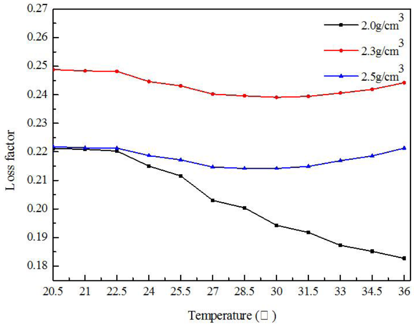
(c)

Fig. 13: Storage modulus, loss modulus, and loss factor–temperature curves of wood damping composites with varying rubber layer thicknesses.

The increase of density has a certain influence on the dynamic mechanical properties of the composite. It can be seen from Fig. 14 that the smaller the density is, the larger the storage modulus of the composite is. The greater the density is, the greater the loss modulus of the composite is. When the density of R is 2,300 kg·m^{-3}, the loss factor of the composite is the largest, the damping property of the composite is better, the anastomosis effect is suppressed, the critical frequency is shifted to a higher frequency, and the sound insulation performance is increased.



(a) (b)



(c)

Fig. 14: Dynamic mechanical properties of wood damping composites with different rubber densities.

CONCLUSIONS

By using rubber-based composite materials, it is possible to create a sandwich structure with superior acoustic performance while retaining the same thickness of the single-layer density fibreboard for sound insulation performance. Using MDF face sheets with a rubber core increases the sound insulation at the resonant frequency and causes the coincidence frequency to move to higher frequencies, effectively inhibiting the anastomosis effect and making the coincidence valley shallower. Moreover, core materials with high damping performance corresponded to multi-layered composites with improved acoustic performance. As the thickness of the rubber layer increased, so too did the loss modulus of the composite. The weighted sound insulation of single-layer MDF was 28.0 dB, which increased to 37.4 dB for the wood damping composite material, increased by 25.1%. As the thickness of the rubber increased, the storage modulus and loss factor of the composite both increased accordingly. The greater the damping loss factor, the greater the energy loss, making the composite material more resistant to sound waves caused by stronger vibrations. Compared to the rubber samples, the multi-layered composites showed higher storage modulus and loss modulus values. Since the loss modulus is a measure of the energy dissipation, a higher loss modulus of the multi-layered composite denotes that more acoustic energy would be dissipated during sound wave propagation in the material. Therefore, the sound insulation ability of the composites can be enhanced by controlling the rubber thickness, keeping in mind that a good balance between the sound insulation ability and the mechanical properties is required. The density of rubber is not significant for the sound insulation performance of composite materials.

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Meihong Liu, Limin Peng*, Zhengqiang Fan, Dong Wang
Research Institute of Wood Industry Chinese Academy
of Forestry
Beijing
China
Phone: +86 010 62889429
*Corresponding author: penglm@caf.ac.cn