

Sound Insulation Property Study on Nylon 66 Scrim Reinforced PVF Laminated Membranes and their Composite Sound Proof Structure

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Abstract. In this paper, we investigated the sound insulation property of nylon 66 scrim reinforced PVF laminated membranes and their corresponding composite structures with glass fiber felt and carbon fiber board. Sound transmission loss (STL) was measured by standing wave tube method. The results show that, with the decrease of nylon 66 gridlines spacing, STL of nylon 66 scrim reinforced PVF laminated membranes was improved. The sound insulation performance of laminated membranes with gridlines spacing of 3mm is the best, whose STL was up to 10dB at 6.3 kHz. Besides, STL was improved effectively as air layers were embedded into the composite sound proof construction consist of laminated membrane, glass fiber felt and carbon fiber board.

1. Introduction

Since the 21st century, the issue of noise has become increasingly serious and has become one of the major environmental problems facing mankind. For this reason, noise reduction materials have become the focus of researchers [1, 2]. Fiber materials such as glass fiber, are widely used as sound-absorbing and sound-proofing materials for construction and transport. However, fiber materials are scattered and limited by the effect of the mass law, which caused their application is suffering more and more restrictions [3, 4].

In recent years, a number of studies have been carried out to develop new materials, technology and composite structure to improve the acoustic properties. Christina et al. studied sound insulation characteristics of a membrane-type acoustic metamaterial based on the local resonance mechanism and found that the peak value of STL could be affected by adjusting the additional weight [5]. Yang et al. investigated the effect of the number and stacking sequence of membranes in different glass fiber felt composite structures on acoustic properties and found that the addition of films could effectively improve the sound insulation performance [6]. Mei et al. explored a kind of elastic membrane with asymmetric hard metal inlays, which could provide an effective method to control low-frequency noise, because the membrane system could efficiently reflect low-frequency sound waves and the subwavelength waves can be absorbed by metal border [7]. Zhong et al. measured the sound absorption performance of glass fiber felts as they were sealed packaged by PVF film, and found the PVF membrane coating has the characteristics of lower high frequency absorption coefficient [8, 9].



PVF film is widely applied in building decoration, solar battery back, anticorrosion surface materials, and other fields due to many great properties such as stain resistance, corrosion resistance, wear resistance, resistance to ultraviolet radiation, and excellent weather resistance, etc. However, it is prone to mechanical damage, therefore, it is always used in combination with PET film [10, 11, 12]. In particular, nylon fiber scrim and polyester fiber scrim serve as reinforcement of PVF laminated membrane in the insulation materials for aviation, and the reinforcement greatly enhanced the tear strength and puncture strength of the laminated membranes [13].

Refer to the above research results, lightweight laminated membranes with cyclical mass changes were prepared, which were comprised of PVF film, PET film and nylon 66 scrim. The motivation of this study is to explore the effect of the gridlines spacing of nylon 66 scrim on sound insulation performance of laminated films. The acoustic property of composite sound proof structures was also investigated, which were fabricated by laminated membrane, glass fiber felt, and carbon fiber board.

2. Materials and Measurement

The laminated membranes were produced by three steps. The first step was compounding PVF film and PET film with dry composite method, the second step was attaching the nylon 66 scrim dipping glue to the PET film with hot-pressing process, and at last kept them at constant temperature until they were stable. The schematic diagram of nylon 66 scrim reinforced PVF laminated membrane is shown in Figure 1.



Figure 1. Schematic diagram of nylon 66 scrim reinforced PVF laminated membrane

2.1. Surface Morphology Test

Nylon 66 scrim played the part of the reinforcement of the laminated membrane, and it was inevitable that nylon 66 yarns got a larger degree of deformation after dipping glue and hot pressing. In order to study the configuration status and microstructure of nylon 66 scrim and crossing area after compounding, ProX scanning electron microscope (SEM) was used to observe the surface of nylon 66 scrim reinforced PVF laminated film.

2.2. Areal Density Test

The surface of the laminated membrane presented a periodic arrangement of nylon 66 yarns, which caused the structure of the laminated membrane was not uniform completely. This paper measured areal density on the basis of GB/T9914.3-2013, using electronic balance. The areal density was computed with the following formula.

$$\rho = m/S \quad (1)$$

where “ ρ ” is the areal density of laminated membrane, “ m ” is the quality of laminated membrane and “ s ” is the area of laminated membrane. Select 10 samples from different positions randomly, and measure the average as the experimental data.

2.3. Sound Insulation Performance Test

Sound insulation property was measured by AWA6290T sound absorption coefficient test system (Hangzhou Aihua Instruments Co., Ltd.). Figure 2 shows the principle diagram of the sound insulation performance testing equipment. On the basis of ASTM C384-98, the diameters of

impedance tube and sample were 29mm. The acoustic measurements were carried out at the frequency of 500Hz, 630Hz, 800Hz, 1 000Hz, 1 250Hz, 1 600Hz, 2 000Hz, 2 500Hz, 3 150Hz, 4 000Hz, 5 000Hz, 6 300Hz.

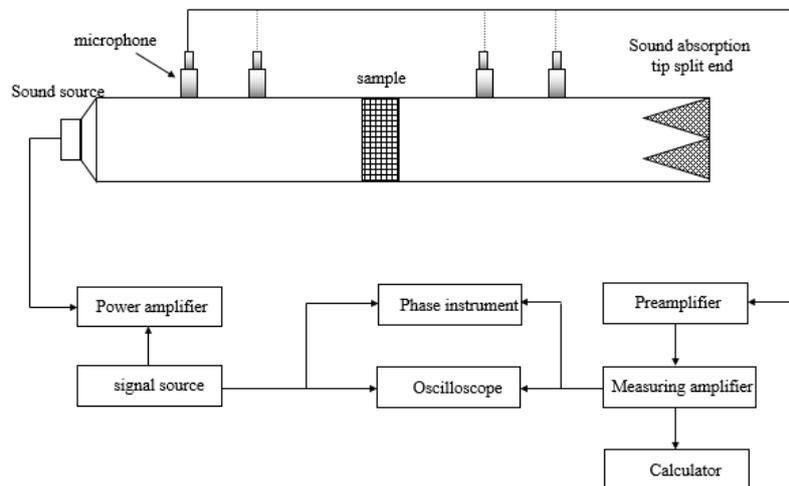


Figure 2. Schematic diagram of sound insulation property testing apparatus

3. Results and Discussion

3.1. Surface Morphology and Areal Density

The nylon 66 scrim reinforced PVF laminated membranes could be divided into three layers, including PVF film, PET film and nylon 66 scrim. The nylon 66 yarns were directly attached to the surface of PET film in the form of orthogonality, and the yarns in the same direction were arranged neatly. The SEM images of nylon 66 scrim reinforced PVF laminated film were shown in Figure 3.

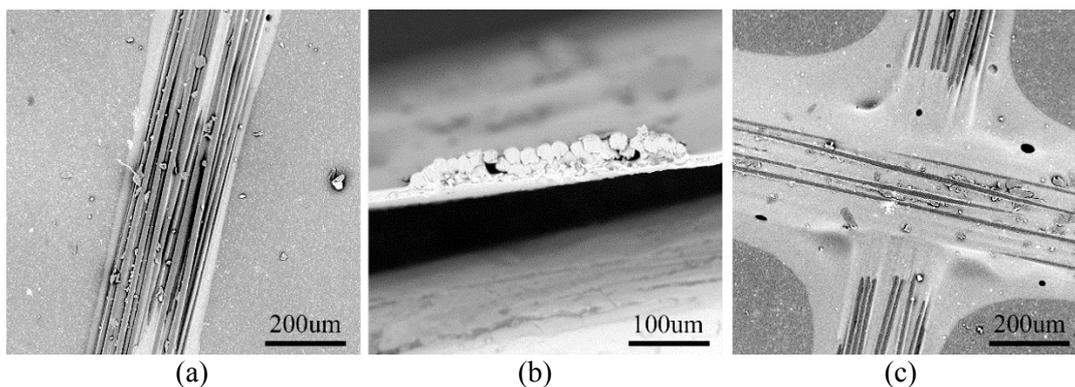


Figure 3. SEM images of laminated membrane

(a) nylon 66 scrim; (b) section of nylon 66 fibers; (c) the intersecting zone of the warp and weft

As shown in Figure 3, the nylon 66 yarns were formed as raised stiffeners on the surface of PET film after hot-pressing process, which were about 250 μm wide and 50 μm high. In addition, the weight of the intersecting zone of warp and weft yarns is higher than other areas because of the overlapping of gridlines and the aggregation of glue, which restricted the vibration of laminated membrane. Compared to the film without nylon 66 scrim, the laminated membranes reinforced by nylon 66 scrim were separated by the raised gridlines, forming a number of neatly arranged sag units.

With the decrease of spacing of the gridlines, the density of the mesh unit increased, and the damping of the surface of laminated membranes increased as well. This paper selected samples with different gridlines spacing for research, and the gridlines spacing was 3mm, 4mm, and 5mm. Table 1 provides the related parameters of samples.

Table 1. Related parameters of laminated membranes

Sample	Spacing of nylon 66 gridlines / (mm)	Grid density / (/m ²)	Areal density / (kg/m ³)
W3	3	1.11×10^5	82
W4	4	6.25×10^4	76
W5	5	4.00×10^4	71

3.2. Acoustic Properties of Laminated Membranes with Different Gridlines Spacing

In this section, STL of laminated films with different gridlines spacing was compared, and the testing results were shown in Figure 4. It reveals that there is a great volatility in the 500-2 000Hz range in the acoustic characteristic curve, because the resonant frequency band of the composite membrane was in the low frequency zone, and a series of resonant motions occurred within this band. What is more, it is obvious that STL of the laminated membranes increased with the decrease of the gridlines spacing when the frequency is more than 2000Hz. The possible reason is that, on the one hand, as the gridlines spacing decreased, the areal density of the whole laminated membrane increased, so that the sound insulation property improved due to the effect of the mass law. On the other hand, with the shrink of gridlines spacing, more and smaller units were formed on the surface of the laminated membrane, and they were arranged in two-dimensional periodic array structure, which resulted in the increase of surface damping.

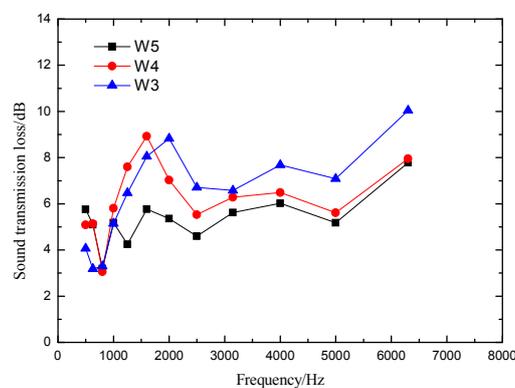


Figure 4. Sound insulation property of laminated membranes with different gridlines spacing

3.3. Sound Insulation of Sandwich Structure of Laminated Membrane, Glass Fiber Felt and Carbon Fiber Board

Yang et al. studied the sound insulation performance of different glass fiber sandwich structures, and found that sandwich structure had the best sound insulation effect [14]. In this section, sample W3, glass fiber felt and carbon fiber board were combined to form a sandwich structure, along with changing the number and position of air layers. Sample W3 was the acoustic incident surface, and glass fiber felts was in the middle of the sandwich structure, as shown in Figure 5. Table 2 lists the stacking sequence of the sandwich structure.

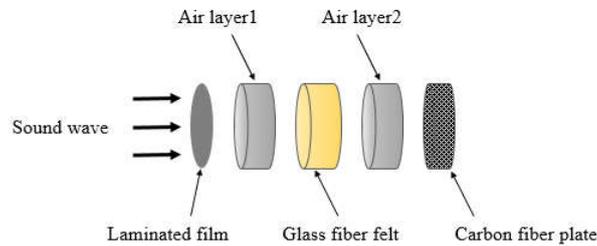


Figure 5. Composite structure of laminated membranes, glass fiber felt and carbon fiber board

Table 2. Sequence parameter of composite structure

Sample	Laminated film	Air layer1	Glass fiber felt	Air layer2	Carbon fiber board	Thickness / (mm)
P1	+	-	+	-	+	17
P2	+	-	+	+	+	32
P3	+	+	+	+	+	47

+used, -not used.

Figure 6 shows the sound insulation performance of three kinds of composite structures (P1, P2 and P3). It reveals that, for the composite structure, the addition of air layer improves the sound insulation property. The P3 structure with two air layers had the best average STL, which can reach 17.1 dB. Besides, the P1 structure without air layer decreased by 6 dB compared to P3 structure. It was also found that the P2 structure reached the highest STL of 17.5dB in the 500~1 000Hz frequency range among the three structures.

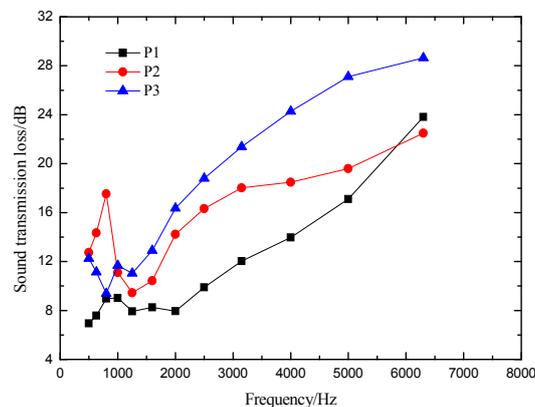


Figure 6. Sound insulation property of 3 kinds of composite structure

According to table 2 and Figure 8, it was noted that the air layer increased the overall thickness of composite structure. At the same time, due to the great difference of impedance between air and glass fiber felt as well as air and carbon fiber board, each additional air layer increased two acoustic reflection surfaces, which lead to the propagation path extension of sound waves in the composite structure. For this reason, the effect of acoustic energy consumption of fiber structure was enhanced indirectly, and the sound insulation of composite structure was improved.

Comparing the P1, P2, and P3 structure from Figures 7 and 8, it was found that the sound transmission loss of the composite structure was improved as adding the number of the air layer in the

1.0-6.3 kHz range. When the number of air layer increases from 0 to 1 and 2, the sound insulation performance increased obviously, but the increasing extent of sound transmission loss reduced. At the same time, it could also be found that a crest occurred at 800Hz in the acoustic characteristic curve of P2 structure, but there was a trough at the same position in the acoustic characteristic curve of P3 structure. The phenomenon was due to that the laminated membrane was tightly close to glass fiber, and glass fiber inhibited the vibration of laminated film caused by sound wave.

4. Conclusion

Acoustic properties of nylon 66 scrim reinforced PVF laminated films and their corresponding sandwich structures with glass fiber felt and carbon fiber board were investigated. The decrease of gridlines spacing could effectively improve the sound transmission loss. For sandwich structure, the best sound insulation property could be obtained by adding the number of air layer. However, the effect was diminishing with the increase of the air layers.

Acknowledgments

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References

- [1] Y M Li, Z F Chen, Y Yang, et al. Sound insulation property study on superfine glass fiber paper composite material [J]. *Cotton Textile Technology*, 2017, 45 (03): 5-8.
- [2] C Ye, J L Su. Influence of micro structural parameters on sound insulation performance of membrane-type acoustic metamaterials [J]. *Noise and Vibration Control*, 2017, 37 (1): 163-166.
- [3] G Y Zhang. Research on the sound insulation properties of membrane-type acoustic metamaterials [D]. National University of Defense Technology, 2014.
- [4] R Cao. The study of sound insulation performance of membrane acoustic metamaterial [D]. Harbin Institute of Technology, 2015.
- [5] C J Naify, C M Chang, G Mcknight, et al. Transmission loss and dynamic response of membrane-type locally resonant acoustic metamaterials [J]. *Journal of Applied Physics*, 2010, 108 (11): 114905-114905-7.
- [6] Y Yang, Z Chen, C Wu, et al. Effect of the number and stacking sequence of membranes in glass fiber felt composite structure on acoustic properties [J]. *Fibers & Polymers*, 2017, 18 (1): 182-189.
- [7] J Mei, G C Ma, M Yang, et al. Dark acoustic metamaterials [J]. *Physics*, 2012, 41 (7): 425-433.
- [8] X Z Zhong, P S Zhu. Application of PVF membrane in fiber absorbing material [J]. *Audio Engineering*, 2002 (1): 11-12.
- [9] X Z Zhong, X H Luo, L Dong. Effects of covering layers on the sound absorptive property of a fiber glass board [J]. *Applied Acoustics*, 1998 (04): 41-43.
- [10] L Li. Research on surface treatment and thermal decomposition of polyvinyl fluoride film [D]. Beijing University of Chemical Technology, 2011.
- [11] S L Liu, C G Zhao, W Zhang. Influence of backplane materials on the combustion characteristic of solar panels [J]. *Fire Science and Technology*, 2016 (9): 1218-1220.
- [12] M J Lu. Study on thermal decomposition characteristics and service lifetime prediction of PVF [J]. Beijing University of Chemical Technology, 2014.
- [13] J Wang. Research on preparation and properties of poly (vinyl fluoride) films [J]. Beijing University of Chemical Technology, 2014.
- [14] Y Yang, Z Chen, Z Chen, et al. Sound insulation properties of sandwich structures on glass fiber felts [J]. *Fibers and Polymers*, 2015, 16 (7): 1568-1577.