RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 7 No. 1 (2026) 127-139
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Sustainable Acoustic Insulation: Sound Transmission Loss in Fish Scale-Epoxy Composite Materials

Woon Li Ying[1], Shahmir Hayyan Sanusi[1]*

[1] *Faculty of Mechanical and Manufacturing Engineering*
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor

*Corresponding Author: shahmir@uthm.edu.my
DOI: https://doi.org/10.30880/rpmme.2026.07.01.014

Article Info

Received: 10 December 2025
Accepted: 9 March 2026
Available online: 28 February 2026

Keywords

Fish scale composite, Epoxy resin, Acoustic Properties, Sound Transmission Loss (STL), Acoustic Insulation,Sustainable Material

Abstract

The rapid development in urbanization and industrial activities has led to a significant increased in noise pollution, raising serious concern for both public health and environmental. While conventional acoustic material such as synthetic fibres are effective in reducing noise level, but their non-biodegradable and potentially hazardous nature has prompted interest in more sustainable alternatives. This study investigated the sound transmission loss (STL) characteristics of fish scale-reinforced epoxy composites as an eco-friendly solution for noise control applications. Fish scales were chemically treated and processed into granule and powdered fish scale, then incorporated into epoxy resin at different fish scale ratios, thickness, and structural arrangements. The STL performance of the resulting composite samples was evaluated using an impedance tube across a frequency range of 70 Hz to 6000 Hz. Scanning Electron Microscopy (SEM) was also employed to examine internal morphology and correlate structural features with sound insulation behavior. The results demonstrated that the incorporation of fish scales, especially in powdered form at optimized ratios, significantly enhanced the STL of composite panels compared to conventional PVC and pure epoxy panels. The study emphasized the importance of optimizing both filler loading and sample thickness, as excessive filler content was found to increase rigidity and negatively impact sound insulation. These findings highlighted the potential of fish scale-reinforced composites as sustainable, high-performance materials for sound insulation, contributing to waste reduction and supporting the advancement of green material development in architectural and industrial acoustic applications.

1. Introduction

The rapid pace development of urbanization and industrialization in this modern era had significantly increased the noise pollution levels, creating unwanted sound a persistent environmental stressor that affected on both human health and ecological well-being [1,2]. In general, noise pollution was formed by transportation, industrial activities and expanding urban environments, which resulted in effects such as hearing loss, sleep disturbances, stress and reduced productivity. According to World Health Organization (WHO), noise had recognised as a major environmental risk, ranked after air and water pollution, which brought negative impact on life quality [1]. The negative impact associated with long term exposure to noise, especially exceeding recommended safety level had highlighted the necessity of application of effective noise control measures in both public and industrial settings. In past, the conventional absorptive materials such as synthetic fibre and polyurethane foams applied in industrial had shown its excellent sound absorption capabilities. However, these synthetic fibre materials were hazardous and non-biodegradable which led to public health concern. With that, this prompted the search for suitable alternative sustainable materials to mitigate unwanted sound [3].

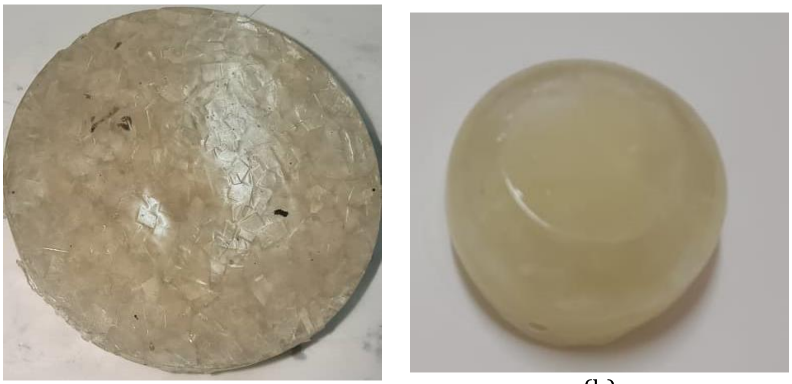
The exploration of alternative sustainable materials had stimulated extensive research into acoustic applications particularly about bio-based and recycled materials. Among various acoustic properties, sound transmission loss (STL) is an essential measurement for material's capabilities to act as a sound barrier. Unlike sound absorption material, sound insulating material generally prevent sound from passing through, where the noise transferring between spaces had been reduced. This term has specifically measured on how much sound energy was blocked by materials, where it had become one of the important parts in noise control applications such as automotive parts and industrial activities [3,4]. In addition, it is important in achieving high STL in order to improve indoor comfort and privacy in both homes and commercial buildings. There were several factors that influenced the STL in a composite material such as density, internal structures and impedance mismatch. According to acoustic mass law, STL able to improve when the material's mass increased, highlighted the importance of selecting suitable material and panel design [4,5]. There were several previous studies on bio-based composites had shown the significant improvement in STL through optimizing the type of filler, ratio content, thickness of the sample and internal structures [3,6,7]. However, all this research were well-documented for plant-based fibre which showing a clear research gap. With that a study about acoustical performance of fish scales waste had evaluated to examine the potential of alternative sustainable materials in noise reduction field [8,9]. Fish scales waste was generally generated by fish industry, and it was commonly discarded in improper way, causing environmental problems such as water pollution and ecological imbalance [8]. Fish scale has its own unique collagen-hydroxyapatite microstructure, but the potential as sustainable acoustic materials was still underexplored [8,9]. Many researchers have focused studied on plant or synthetic fibre composite, leaving a huge knowledge gap regarding the possibility of optimal composition of fish scale-reinforced panels in noise reduction. Therefore, this study would like to evaluate the potential of fish scale in enhancing its sound insulation properties to provide alternative sustainable acoustical materials to industry.

This study aimed to address the potential of acoustic properties of fish scale reinforced with epoxy resin. This research was specifically investigated on how variation forms of fish scale in no matter granule or powdered fish scale, fish scale ratio, panel thickness and structural arrangement such as random and sandwich structure, the parameters that influenced sound transmission loss (STL) over the frequency spectrum. This project was to demonstrate the feasibility of repurposing fish scale waste as effective and sustainable solutions for noise control, contributing to waste minimisation and advancement of green engineering in industrial [10,11]. The findings of this project were expected to provide a valuable insight into development of green engineering acoustic insulation materials and support the broaden transition towards sustainable materials design in noise management.

2. Methodology

2.1 Sample preparation

In this project, fish scales were chemically treated to remove organic residues and impurities before being incorporated into epoxy resin composites. The treated fish scales were processed into two forms, granule and powdered fish scale, and subsequently mixed with epoxy resin and hardener at a 3:1 ratio to prepare composite panels according to the specified experimental parameters. For granule fish scale samples, filler ratios of 10%, 15%, and 20% were utilized, while powdered fish scale samples were prepared with ratios of 10%, 25%, and 50%. Panels were fabricated with thicknesses of either 5 mm or 15 mm, and structural configurations included both random and sandwich arrangements. All mixtures were cast into molds and allowed to cure at room temperature for one day. Figure 1 showed examples of samples in 100mm and 28mm.



(a) (b)

Figure 1: Example sample in different diameters (a)100mm (b) 28mm

Table 1 summarized the various sample compositions and parameters evaluated in this study using impedance tube testing. This systematic approach was designed to assess the influence of fish scale geometry, panel thickness, filler ratio, and structural arrangement on the sound insulation properties of the composites, with the goal of determining the optimal design for industrial noise reduction applications.

Table 1: **Sound absorption parameters**

Geometry size	Diameter (mm)	Thickness	Ratio (%)	Fish scale Arrangement
Granule fish scale	28	5	10	Sandwich
				Random
			15	Sandwich
				Random
			20	Sandwich
				Random
		15	10	Sandwich
				Random
			15	Sandwich
				Random
			20	Sandwich
				Random
	100	5	10	Sandwich
				Random
			15	Sandwich
				Random
			20	Sandwich
				Random
		15	10	Sandwich
				Random
			15	Sandwich
				Random
			20	Sandwich
				Random
Powdered fish scale	28	5	10	Sandwich
				Random
			25	Sandwich
				Random
			50	Sandwich
				Random
		15	10	Sandwich
				Random
			25	Sandwich
				Random
			50	Sandwich
				Random

Table 1(Continued): Sound absorption parameters

Geometry size	Diameter (mm)	Thickness	Ratio (%)	Fish scale Arrangement
Powdered fish scale	100	5	10	Sandwich
				Random
			25	Sandwich
				Random
			50	Sandwich
				Random
		15	10	Sandwich
				Random
			25	Sandwich
				Random
			50	Sandwich
				Random

Table 2 presented the weight distribution of epoxy resin and fish scale incorporated into each composite sample according to the designated ratios. Samples were categorized by structural arrangement (random or sandwich), fish scale form (granule or powdered), filler weight percentage, and panel thickness. In the sample notation, 'R' designates a random structural arrangement, 'S' denotes a sandwich structure, and 'P' indicated powdered fish scale as the filler. For instance, "S10% 15mm" refered to a sample comprising 10% granule fish scale in a 15 mm thick sandwich structure, while "SP25% 5mm" represents a 5 mm thick sandwich-structured composite containing 25% powdered fish scale reinforced in epoxy resin. This systematic preparation enabled a comprehensive evaluation of the effects of composition, structural configuration, and filler form on the sound insulation performance of the composites.

Table 2: Weight Distribution among Samples

No.	Sample	Diameter	Weight of Epoxy Resin (g)	Weight of Fish Scale (g)
1	Pure epoxy (15mm)	28	12	0
		100	148	0
2	Pure Epoxy (5mm)	28	5.3	0
		100	55.8	0
3	Pure Epoxy (2mm)	28	2.2	0
		100	22	0
4	R20% 5mm	28	4.2	1.1
		100	44.6	11.2
5	R15% 5mm	28	4.5	0.8
		100	47.4	8.4
6	R10% 5mm	28	4.8	0.5
		100	50.2	5.6
7	P50% 5mm	28	2.65	2.65
		100	27.9	27.9
8	P25% 5mm	28	4.0	1.3
		100	41.9	14.0
9	P10% 5mm	28	4.5	0.5
		100	50.2	5.6
10	S20% 5mm	28	4.2	1.1
		100	44.6	11.2
11	S15% 5mm	28	4.5	0.8
		100	47.4	8.4
12	S10% 5mm	28	4.8	0.5
		100	50.2	5.6
13	S P50% 5mm	28	2.65	2.65
		100	27.9	27.9
14	S P25% 5mm	28	4.0	1.3
		100	41.9	14.0
15	S P10% 5mm	28	4.8	0.5

Table 2 (Continued) : Weight Distribution among Samples

No.	Sample	Diameter	Weight of Epoxy Resin (g)	Weight of Fish Scale (g)
15	S P10% 5mm	100	50.2	5.6
16	R20% 15mm	28	9.6	2.4
		100	118.4	29.6
17	R15% 15mm	28	10.2	1.8
		100	125.8	22.2
18	R10% 15mm	28	10.8	1.2
		100	133.2	14.8
19	P50% 15mm	28	6.0	6.0
		100	74.0	74.0
20	P25% 15mm	28	9.0	3.0
		100	111.0	37.0
21	P10% 15mm	28	10.8	1.2
		100	133.2	14.8
22	S20% 15mm	28	9.6	2.4
		100	118.4	29.6
23	S15% 15mm	28	10.2	1.8
		100	125.8	22.2
24	S10% 15mm	28	10.8	1.2
		100	133.2	14.8
25	S P50% 15mm	28	6.0	6.0
		100	74.0	74.0
26	S P25% 15mm	28	9.0	3.0
		100	111.0	37.0
27	S P10% 15mm	28	10.8	1.2
		100	133.2	14.8
28	PVC 2mm	28	1.1	0
		100	15.1	0
29	PVC 5mm	28	3.2	0
		100	45.3	0

2.2 Experiment Method

The sound transmission loss (STL) of all the composite panels were measured though an impedance tube that is equipped with four microphones, as shown in Figure 3. The sample was placed in the center of the tube, along with all microphones arranged at specific positions in order to capture the sound pressure levels before and after the sound passed through the material. Then, a loudspeaker will generate sound waves, and the STL results will be recorded and analyzed by VA-LAB IMP software. Figure 4 showed the schematic setup of four microphone impedance tubes, where this method allowed to measure STL accurately over a wide frequency range from 70 Hz to 6000 Hz. To ensure in obtaining complete data, both small and large diameter impedance tubes were used in this study.

Due to the limitation in the experimental sound transmission loss (STL) results, the mass law equation (Equation 1) was applied to estimate the STL performance of the best performance sample when compared to a 2mm thick pure epoxy panel and PVC panel. Specifically, the formula was used to predict how the STL of the sample would change if its thickness were reduced. According to the mass law, STL is logarithmically related to the thickness of the material. The expected change in STL when the thickness is altered can be calculated using the following equation:

$$\Delta STL = 20log_{10}(\frac{t_2}{t_1}) \quad (1)$$

In addition, a Scanning Electron Microscopy (SEM) was also used in this study to observe the surface and internal features of both raw granule and powdered fish scales, which as shown in Figure 5. By using SEM, clearer and detailed images of fish scale at high magnification have been provided, which allowed us to analyze their morphology, surface texture and presence of pores. This morphology analysis allowed us to explain how different forms of fish scale might influence the sound insulation performance of the composite panel.

By combining both STL and SEM analysis and theoretical mass law predictions, these experimental approaches allowed a comprehensive assessment of how different parameters of fish scale reinforced with epoxy resins composites affect the sound insulation performance.

Figure 3: Impedance tube equipment

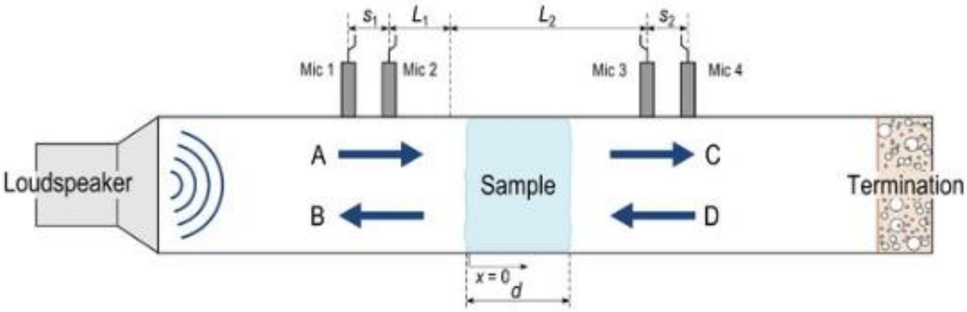


Figure 4 : Schematic diagram of four microphone impedance tube[12]

Figure 5: Scanning Electron Microscope (SEM) [13]

3. Results and Discussion

3.1 Sound Transmission Loss

3.1.1 Sound Transmission Loss between different panels' thickness

Figure 6 showed the sound transmission loss (STL) characteristics of pure epoxy panels with varying thicknesses (2 mm, 5 mm, and 15 mm) across the frequency spectrum. As expected, increasing panel thickness generally led to higher STL values. The 2 mm panel exhibited the lowest STL, peaking at 35.05 dB at 4500 Hz, while the 5 mm panel showed a sharp increase near 2000 Hz and achieved a peak STL of 57.49 dB at 4000 Hz. Although the 15 mm panel peaked at 47.77 dB at 2500 Hz, it maintained higher STL values at lower frequencies compared to thinner panels. Overall, the 5 mm pure epoxy outperformed the 2 mm panel by 64% and the 15 mm panel by 20.34% in terms of peak STL.

This trend can be explained by the interplay between panel mass, stiffness, and acoustic impedance mismatch. According to the mass law of sound insulation, increasing panel mass generally enhanced STL, particularly at low frequencies, due to greater mass provided higher resistance to sound wave transmission [3,14]. The greater mass of the 15 mm panel favored low-frequency attenuation, but the additional thickness may introduce internal damping that smoothed resonant peaks and limited high-frequency performance [14]. In contrast, the 5 mm panel achieved stronger STL at higher frequencies, likely due to more pronounced resonance and mass-spring effects, which improved sound insulation efficiency in these ranges. These findings provided a useful benchmark for assessing the impact of filler content on epoxy-based composites.

Figure 7 further compared the effect of thickness on the sound transmission loss (STL) of two epoxy resin composite panels with 50% powdered fish scale at 5 mm and 15 mm thicknesses. Unexpectedly, the thinner 5 mm panel outperformed the thicker 15 mm panel across nearly the entire frequency range, peaking at 57.96 dB at 4000 Hz, while the 15 mm panel reached a maximum of 45.34 dB at 630 Hz before declining. The 5 mm panel exhibited 27.8% better performance than its thicker counterpart, demonstrating superior sound isolation at high frequencies.

This outcome suggested that high filler loading in thicker panels may lead to excessive density, restricting internal vibration and increasing acoustic transparency at higher frequencies. In contrast, the lighter and more flexible 5 mm panel benefited from pronounced mass-spring resonance and sharper impedance mismatch, enabling more effective sound blocking in the high-frequency range [6,14,15]. Thicker, denser panels may allow more acoustic energy to transmit rather than dissipate, particularly at higher frequencies, resulting in reduced overall sound isolation.

In summary, the STL results emphasized the importance of balancing filler ratio and panel thickness when designing composite acoustic materials. Excessive fish scale content in thick panels can lead to diminishing returns, highlighting that optimal sound insulation achieved through careful tuning of both material composition and structural arrangement. These results aligned with previous studies on natural fiber composites, where thin, well-optimized panels achieved excellent sound insulation due to favorable resonance and impedance properties [15].

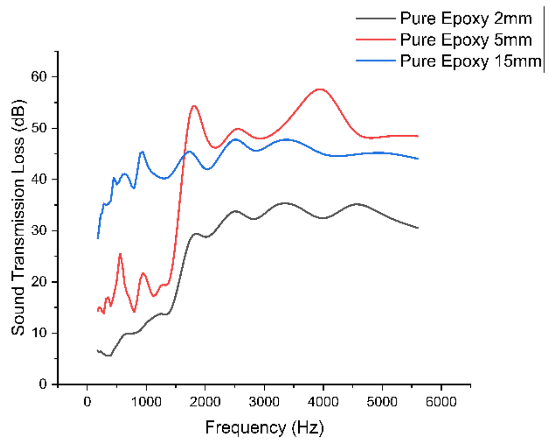


Figure 6: Sound Transmission Loss of pure epoxy without any filler in different thickness: 2mm. 5mm and 15mm.

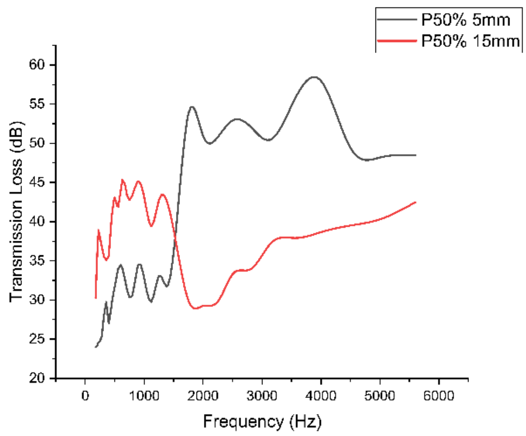


Figure 7: Sound Transmission Loss of Powdered Fish Scale in Two different panel thickness's: 5mm and 15mm.

3.1.2 Sound Transmission Loss between varies ratio of fish scale.

Figure 8 showed the comparative analysis of sound transmission loss (STL) for 5 mm thick epoxy resin panels reinforced with randomly distributed granule fish scales at varying weight ratios of 10%, 15%, and 20%, with a pure epoxy panel as the control. All composite panels displayed similar STL trends, characterized by multiple peaks and troughs from 100 Hz to 1400 Hz. Among the samples, the R10% panel exhibited the best overall sound insulation, reaching a peak STL of 38.39 dB at 1250 Hz with a 50.5% improvement over the pure epoxy panel, which peaked at 25.51 dB at 560 Hz. The R15% panel followed closely, achieving a peak STL of 36.43 dB, while the R20% panel had the lowest performance, with a maximum STL of 28.82 dB, both samples showed its improvement of 42.9% and 13% respectively over pure epoxy control.

These results clearly showed that increasing the fish scale content beyond 10% reduced STL performance, likely due to increased density and stiffness in the composite matrix. Such characteristics diminished the material's ability to dissipate sound energy effectively, as internal friction and micro-vibrational damping were constrained in overly dense structures. This trend aligned with findings from other bio-composite systems, where optimal filler ratios balance mass loading and internal damping, improving acoustic insulation, while excessive filler increases rigidity and inhibited energy dissipation pathways [3,7,16]. Previous studies also report that too much mass reduced the effectiveness of viscoelastic damping, as seen in recycled coal ash composites and natural fibre-based absorbers, underscoring the need for optimized compositions [7,16].Comparatively, the R10% panel outperformed the R15% and R20% panels by 5.4% and 33.2%, respectively, in peak STL, suggesting that 10% granule fish scale provided an optimal balance between impedance mismatch and internal flexibility.

In conclusion, in terms of peak STL, it had suggested that a 10% granule fish scale ratio achieved an optimal balance between impedance mismatch and internal flexibility. These findings highlighted the importance of filler optimization and structural design in developing effective and sustainable sound-insulating composites. Selecting the right amount of fish scale filler was essential to maximize STL performance while maintaining composite flexibility.

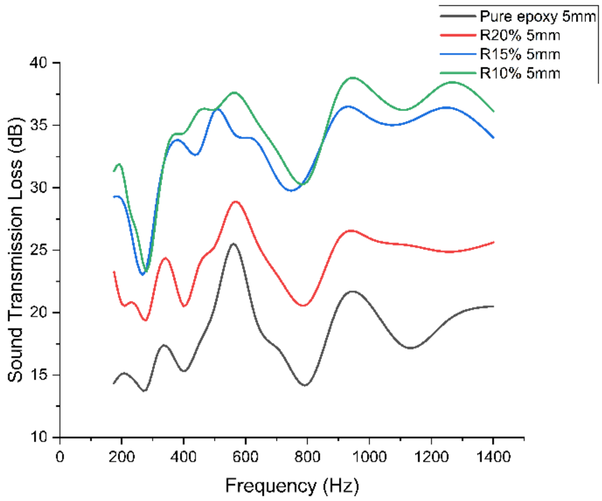


Figure 8: Sound Transmission Loss of 5mm Pure Epoxy Panel and 5mm Epoxy Panels Reinforced with Randomly Distributed Granule Fish Scales in Varies Ratio of 10%,15% and 20%.

3.1.3 Sound Transmission Loss between different structural arrangements of fish scales

Figure 9 showed the comparative analysis of sound transmission loss (STL) characteristics of 5 mm thick panels, including a pure epoxy control and two composite panels reinforced with 10% granule fish scale in either random (R10%) or sandwich (S10%) configurations. All panels showed similar STL patterns, with multiple peaks and troughs from 100 Hz to 1400 Hz. Overall, the R10% panel demonstrated the best sound insulation, reaching a peak STL of 38.39 dB at 1250 Hz, with an improvement of 50.5% over the pure epoxy panel, which peaked at 25.51 dB at 560 Hz. The S10% panel also outperformed the control, with a lower peak STL of 32.28 dB at 500 Hz, reflecting a 26.5% improvement. Notably, the R10% panel exceeded the S10% panel by 18.9%, indicating that the random distribution of granule fillers facilitated more efficient sound energy dissipation.

The enhanced STL in the randomly distributed composite contributed by the increased internal friction and the presence of more scattering surfaces created by the dispersed particles, which more effectively trap and convert sound energy into heat than the more ordered sandwich structure. In the sandwich panel, the relatively undisturbed epoxy core allowed sound waves to propagate more freely between face sheets, thereby limiting overall STL improvement. These findings highlighted the importance of internal particle distribution and microstructural complexity in maximizing sound insulation performance. This observation was consistent with previous studies highlighting the benefits of heterogeneous filler dispersion for energy dissipation and sound attenuation in bio composite and multilayer systems [7,16,17].

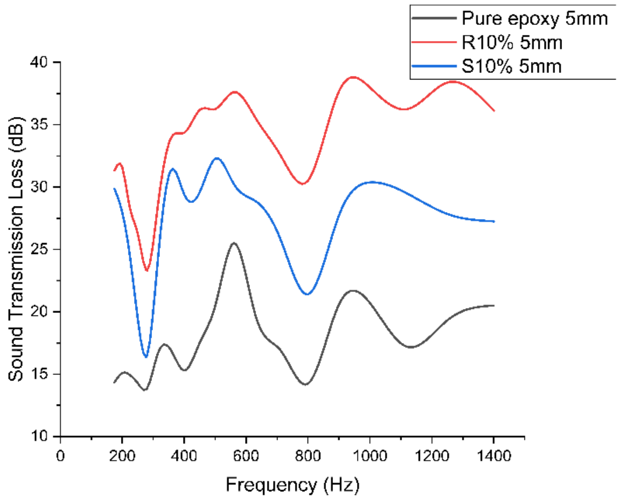


Figure 9: Sound Transmission Loss Of 5mm Pure Epoxy Panel And 5mm Epoxy Panels Reinforced With 10% Granule Fish Scales in Random and Sandwich Structural Arrangement.

3.1.4 Comparison of Sound Transmission Loss between PVC panel, Pure Epoxy panel and best performance samples

Figure 10 presented a comparative analysis of Sound Transmission Loss (STL) for 2 mm thick panels: pure epoxy, PVC, and a predicted P50% composite panel. This prediction was conducted due to impedance tube malfunction. The STL values for the P50% sample were calculated using Equation 1, with results summarized in Table 3. Across the frequency range of 100 Hz to 6000 Hz, the pure epoxy panel consistently outperformed the PVC panel, indicating superior sound insulation properties. The epoxy panel reached a peak STL of 35.05 dB at 4500 Hz, while the PVC panel peaked at only 20.03 dB at 5600 Hz, representing a 75% improvement in STL for epoxy over PVC. This performance contributed by the higher stiffness and lower viscoelastic damping of epoxy resin, which better resists sound wave penetration and provided greater impedance mismatch. In contrast, the viscoelastic nature of PVC increased its susceptibility to resonance, diminishing its sound reflection capabilities at higher frequencies.

The predicted P50% 2 mm composite outperformed both the epoxy and PVC panels across nearly the entire frequency spectrum, with a peak STL of 49.96 dB at 4000 Hz. This represents a 42.5% improvement over pure epoxy and a remarkable 149.4% improvement over PVC. While this aligned with the acoustic mass law, which relates STL to increasing surface mass density [5], the exceptional performance of the P50% panel, despite its thinness, is explained by enhanced internal damping mechanisms provided by the powdered fish scale filler [7]. The inclusion of fine powder created an additional energy dissipation pathways, internal friction, micro-vibrational damping, and wave scattering, while its random dispersion increased microstructural impedance mismatches which had further promoting reflection and absorption of sound energy. In summary, the analysis demonstrated that while pure epoxy already surpasses PVC in thin panel sound insulation, the P50% epoxy composite offered even greater advantages, especially in frequency ranges where PVC is ineffective. These results confirmed the potential of natural filler reinforcement for optimizing sound insulation in lightweight, sustainable acoustic panels.

Table 3: Predicted Result for P50% 2mm s

Frequency (Hz)	**Sound Transmission Loss (dB)**	
	P50% 5mm	**P50% 2mm (predicted)**
175	23.98	15.98
200	24.17	16.17
224	24.6	16.6
250	24.78	16.78
280	25.37	17.37
315	27.95	19.95
355	29.76	21.76
400	27.03	19.03
450	29.62	21.62
500	31.7	23.7
560	34	26
630	34.06	26.06
710	31.29	23.29
800	30.64	22.64
900	34.5	26.5
1000	32.76	24.76
1120	29.75	21.75
1250	33.08	25.08
1400	31.82	23.82
1750	53.79	45.79
2000	50.96	42.98
2240	50.72	42.72
2500	52.91	44.91
2800	52.15	44.15
3150	50.49	42.49
3550	55.56	47.59
4000	57.96	49.96
4500	49.41	41.41
5000	48.19	40.19
5600	48.49	40.49

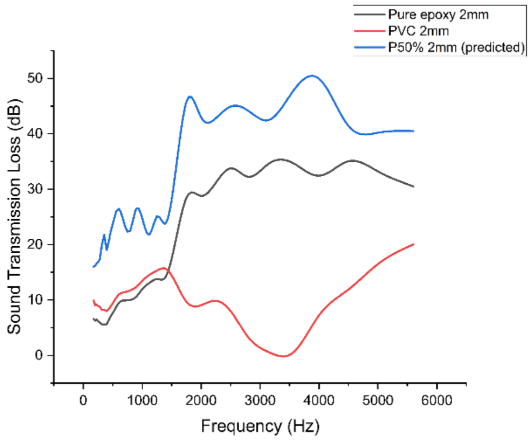


Figure 10: Comparison of Sound Transmission Loss Among 2mm Thick Pure Epoxy, 2mm Thick PVC Panel and Panel P50% 5mm

3.2 Acoustic Performance

Parameters such as geometry form of fish scale, panel's thickness, porosity, weight percentage fish scale and structural arrangement played important roles in determining the sound insulation performance. In terms of geometry form, the fish scale form had a significant impact on STL results, where composites with powdered fish scales had generally provided higher STL values as compared to granule fish scale, especially when at optimal ratios of powdered fish scale. The denser structure and finer particle size of powdered fish scale increased internal friction and scattering of sound waves, which helped block the transmission of airborne noise. However, excessive addition of either filler types reduced STL, likely due to increased stiffness and loss of internal energy dissipation pathways. Therefore, selecting the right filler form and optimizing its ratio is essential for maximizing sound insulation performance.

For panel's thickness, the thicker panels generally improved STL especially at low frequencies due to the additional mass that enhanced the resistance to sound wave transmission. However, beyond an optimal thickness, it could result in reduced performance which is likely caused by excessive rigidity or compromised internal structure. The results showed that carefully balancing thickness with internal microstructure is important for achieving high STL without making the panel unnecessarily rigid.

Porosity was a key factor in the acoustic performance of the composites, as the open and interconnected pores were able to trap and dissipate sound energy. This means that if a material lacks these characteristics, it has higher chances to isolate sound instead of absorption. In the context of sound transmission loss (STL), a lower level of open-cell porosity can actually be advantageous, since dense and less porous structures offer greater resistance to the passage of sound. In this study, the SEM analysis revealed that both granule and powdered fish scale filler had limited open pores, which resulted that a composite panel having more solid internal structures. This outcome showed that the fish scale had a strong isolation properties due to its own structures. Figure 11 and Figure 12 showed the SEM image of both granule and powdered fish scale.

The weight percentage of fish scale fillers showed the significant effect on the sound transmission loss (STL) of the composite panels. The optimal STL performance was achieved at moderate fish scale ratio such as 10% to 15% for granule fish scales and 25% for powdered fish scales. These optimal ratios of fish scale regardless of form provided the right balance of mass and internal structures to maximize sound blocking, while allowing composite to effectively scatter and resist sound transmission. However, excessive fish scale loading tended to decrease STL due to increased panel rigidity and reduced internal energy dissipation. These findings demonstrated that simply increasing filler content does not guarantee better sound insulation. Instead, careful optimization of filler ratio, panel structure, and thickness is essential for maximizing STL in fish scale-reinforced composites.

By comparing both random and sandwich structural arrangements in fish scale-reinforced epoxy panels, random arrangements with uniformly dispersed fillers generally resulted in better sound transmission loss (STL) than sandwich structures. For example, the R10% panel achieved a peak STL of 38.39 dB at 1250 Hz, outperforming the S10% panel which reached only 32.28 dB at 500 Hz. This was because random arrangement structural provided more internal scattering and friction which blocked sound effectively. In contrast, sandwich structures will trap the sound wave longer, which had better absorption properties rather than insulation properties. In overall, to achieve the best sound insulation result, it required the suitable optimization for both structural arrangements and filler characteristics to suit the specific application.

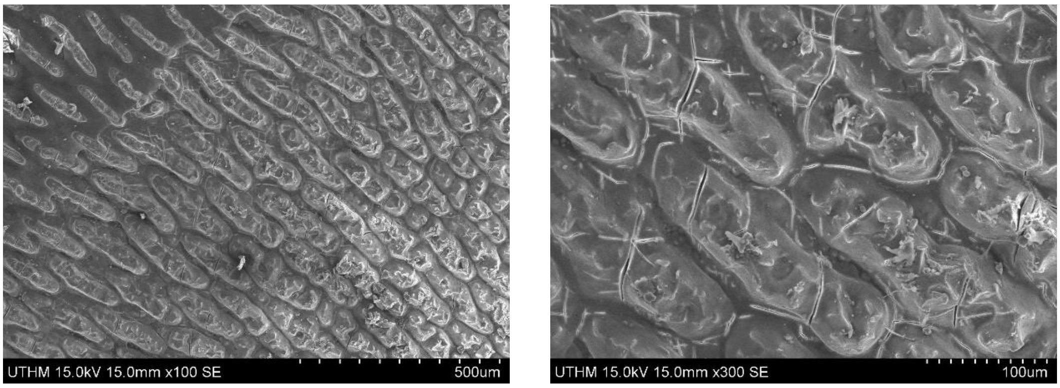


Figure 11: SEM image for granule fish scale (a) 100 µm (b) 300 µm

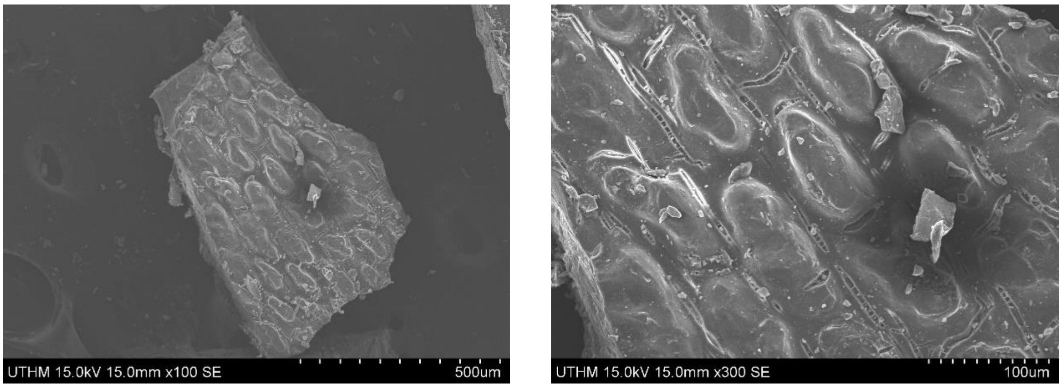


Figure 12: SEM image for powdered fish scale (a) 100 µm (b) 300 µm

4. Conclusion

This project evaluated the sound transmission loss (STL) performance of fish scale-reinforced epoxy composites as sustainable alternatives for acoustic insulation. The experimental results demonstrated that key parameters such as fish scale form (granule or powder), filler ratio, panel thickness, and structural arrangements significantly influenced STL values. Optimal STL performance was achieved with moderate filler ratios, particularly 10% granule or 50% powder fish scale, and with random structural arrangements. Excessive filler content or overly thick panels led to increased rigidity and decreased sound insulation efficiency. Overall, the findings confirm that fish scale waste can be effectively repurposed into high-performing, eco-friendly acoustic panels, providing both technical benefits and environmental value.

4.1 Recommendation

Future research should explore different species of fish scales, as variations in composition and structure could further enhance STL performance. It is also recommended to assess mechanical durability, moisture and biological resistance, and long-term performance under real-world conditions. Comprehensive life cycle assessments (LCA) will provide deeper insights into the environmental benefits of these composites. Finally, exploring multifunctional applications could broaden their commercial potential. Continued collaboration between researchers, engineers, and industry will be essential for advancing fish scale composites as scalable, sustainable solutions in acoustic engineering.

Acknowledgement

The author thanks the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), for providing exceptional assistance and experimental facilities.

Conflict of Interest

There is no conflict of interest regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

References

[1] "Noise," World Health Organization. Accessed: Jan. 17, 2025. [Online]. Available: https://www.who.int/Europe/news-room/fact-sheets/item/noise
[2] B. Basu et al., "Investigating changes in noise pollution due to the COVID-19 lockdown: The case of Dublin, Ireland," Sustain Cities Soc, vol. 65, Feb. 2021, doi: 10.1016/j.scs.2020.102597.
[3] X. Zhu, B.-J. Kim, Q. Wang, and Q. Wu, "Recent Advances in the Sound Insulation Properties of Bio-based Materials," Bioresources, vol. 9, no. 1, Dec. 2013, doi: 10.15376/biores.9.1.1764-1786.
[4] D. A. Bies And C. H. Hansen, Engineering Noise Control, Crc Press, 2017. Doi: 10.1201/9781315273464.
[5] J.-Y. Jang, C.-S. Park, & K. Song. (2022). Lightweight soundproofing membrane acoustic metamaterial for broadband sound insulation. Mechanical Systems and Signal Processing, 178, 109270. https://doi.org/10.1016/j.ymssp.2022.109270
[6] L. Xu et al., "Improved sound absorption by size gradient granular materials due to Brazil-nut effect," Applied Acoustics, vol. 229, Feb. 2025, doi: 10.1016/j.apacoust.2024.110416.
[7] Umberto Berardi And Gino Iannace, "Acoustic Characterization Of Natural Fibers For Sound Absorption Application ," May 2015, Doi: 10.1016/J.Buildenv.2015.05.029.
[8] M. Manjudevi, M. Kamaraj, J. Aravind, and L. S. Wong, "Application of the Circular Economy to Fish Scale Waste," Dec. 01, 2024, Elsevier B.V. doi: 10.1016/j.scenv.2024.100170.
[9] D. Qin et al., "Development and Application of Fish Scale Wastes as Versatile Natural Biomaterials," Chemical Engineering Journal, vol. 428, Jan. 2022, doi: 10.1016/j.cej.2021.131102.
[10] A. K. Mohanty, S. Vivekanandhan, J.-M. Pin, and M. Misra, "Composites from Renewable and Sustainable Resources: Challenges and Innovations." [Online]. Available: http://science.sciencemag.org/
[11] S. Yildizhan, A. Çalik, M. Özcanli, and H. Serin, "Bio-Composite Materials: A Short Review of Recent Trends, Mechanical and Chemical Properties, And Applications," European Mechanical Science, vol. 2, no. 3, pp. 83–91, Sep. 2018, doi: 10.26701/ems.369005.Faith Mokobi,
[12] E. Levi, M. Neri, M. Pilotelli, E. Alessio Piana, And A. Maria Lezzi, "Numerical And Experimental Study On Metamaterials Featuring Acoustical And Thermal Properties," J Phys Conf Ser, Vol. 1599, No. 1, P. 012032, Aug. 2020, Doi: 10.1088/1742-6596/1599/1/012032.
[13] "Scanning Electron Microscope (SEM): Principle, Parts, Uses." Accessed: Jan. 17, 2025. [Online]. Available: https://microbenotes.com/scanning-electron-microscope-sem/
[14] S. Gokulkumar, P. R. Thyla, L. Prabhu, and S. Sathish, "Measuring Methods of Acoustic Properties and Influence of Physical Parameters on Natural Fibers: A Review," Dec. 01, 2020, Bellwether Publishing, Ltd. doi: 10.1080/15440478.2019.1598913.
[15] Khai Hee Or, Azma Putra, & Mohd Zulkefli Selamat. (2016). Oil palm empty fruit bunch fibres as sustainable acoustic absorber. Applied Acoustics, 119, 9–16. https://doi.org/10.1016/j.apacoust.2016.12.002
[16] C. Arenas, C. Leiva, L.F. Vilches, & J.A. Gonzalez Ganso. (2016). Approaching a methodology for the development of a multilayer sound absorbing device recycling coal bottom ash. Applied Acoustics, 114, 154–162. https://doi.org/10.1016/j.apacoust.2016.08.021
[17] J. Wang et al., "Sound Absorption Performance of Porous Metal Fiber Materials with Different Structures," Applied Acoustics, vol. 145, pp. 431–438, Feb. 2019, doi: 10.1016/j.apacoust.2018.10.014.