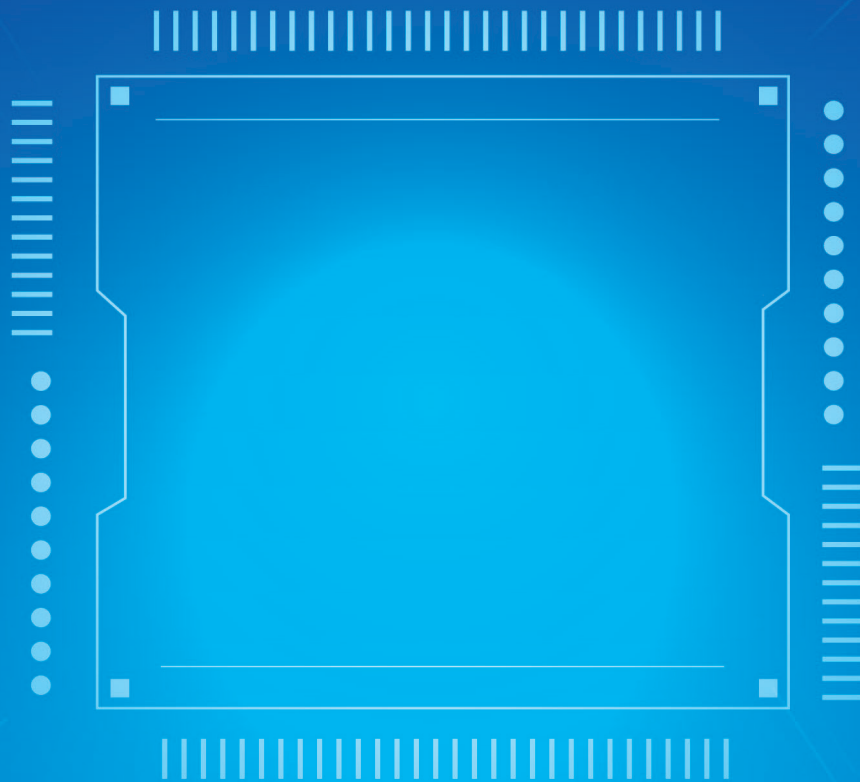




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Acoustic Characterization of Composites Made of Gypsum and Pineapple Leaf Fibres

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ABSTRACT

The research sought to characterize the acoustic properties of gypsum composite which contained 2% pineapple leaf fibre (PALF) and plain gypsum with different thicknesses. The impact of composite thickness and 2%PALF inclusion on the acoustic properties of the PALF-gypsum composite (sound absorption coefficient and sound transmission loss) were examined. A comparison of the sound transmission loss and sound absorption coefficient for frequencies between 60 and 1600 Hz was made possible by acoustic tests using an impedance tube. The sound absorption results showed that adding 2 percent PALF to gypsum significantly improves acoustic properties when compared to plain gypsum. When comparing composite samples 2% PALF (C2) to control samples (C0), the noise reduction coefficient (NRC) result revealed a 50% increase. The composite materials containing 2% PALF had the highest NRC value of 0.18. Furthermore, due to the increase in composite thickness, the sound transmission loss of 2% PALF resulted in greater acoustic insulation in the range of 30 dB. The findings of the experiments show that PALF can greatly increase the insulating qualities of gypsum composites.

INTRODUCTION

Sound absorption material design is gaining importance on a worldwide basis. Noise pollution can disturb sleep and result in a number of health problems. As a result, creating a noise control system is essential in engineering practice. The sound absorption panel is one of the most important parts of an industrial noise control system since it aids in lowering the sound energy generated by visco-thermal action. In buildings, the absorber panel is frequently used to alter the acoustic environment of a space where speech comprehension is crucial. The creation of adequate sound-absorbing materials is one of the pressing issues that has to be resolved in order to maintain an acceptable acoustic environment. Understanding the absorption and isolation capabilities of these materials requires research on their acoustic characteristics. Natural fibre composite materials have showed promise as building materials due to a variety of desirable qualities, including cheap cost, biodegradability, and renewable resources (Bledzki *et al.*, 2002; Mohammed *et al.*, 2015 and Peças *et al.*, 2018). The two forms of natural fibre research are fibre added to binders like gypsum, giopolymers and polymer matrix research. Gypsum-based composite materials have advanced significantly in recent years as a consequence of the need and demand for durable and affordable materials that are stronger, lighter, and more robust. Gypsum board is a useful material for composite manufacture due to its low energy consumption, fire resistance, light weight, acoustic and thermal insulation, and quick healing time in interior partitions, drywall, and façade panels (Li *et al.*, 2003; Rahman *et al.*, 2007 ; Zhang *et al.*, 2011; Mohandesi *et al.*, 2012 ; Garg & Pundir 2014; Aghaee *et al.*, 2015). Ismail *et al.* (2014) investigated how hybridization

affected the ability of coconut coir fibre and shredded paper-gypsum composites to absorb sound at different levels. The panel's sensitivity varies between 0.3 and 0.4 for frequencies between 250 and 8000 Hz, as seen in the data. The composites manufactured with 25% coconut coir fibre and 75% shredded waste paper had the greatest maximum sound absorption coefficient of 0.40 at 8000 Hz when compared to other samples. The exceptional thermal insulation properties of wool and the durability of coir to enhance gypsum ceiling tiles were coupled in a study by Guna *et al.* (2021). The composites' strength increases with rising coir concentrations, reaching a peak of 0.35 sound absorption coefficient at 5500 Hz. In terms of acoustics, coir fibres fared better than wool fibres. This could be because the surface morphology of coir fibre is rougher than that of wool fibre, which is smoother. Another work on using demolition wood waste as a bio-composite with gypsum was published by Pedreño-Rojas *et al.* (2017). Along with its physical and mechanical properties, the researchers also evaluated the material's acoustic properties. The sound absorption coefficient appeared of the composites was ascertained using the impedance tube technique, in accordance with UNE-EN-ISO 354 standards. 10% and 20% of the samples, respectively, were made up of wood shavings and sawdust. The reference sample was also put to the test against a perforated gypsum-wood plate by the researchers. The outcomes were contrasted with those of alternative readily accessible absorbent plates. When evaluated at a frequency of 2000 Hz, the bio-composite material improved by 20% with sound absorption coefficient of 0.53, the 20% perforated material performs better acoustically as compared to reference gypsum board. Cork-gypsum composites were the subject of yet

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another experiment by Hernández-Olivares *et al.* (1999), who discovered that although they are ineffective sound absorbers, they may also serve as sound insulators. Cork-gypsum composites have a sound absorption coefficient appeared 0.2 to 0.3 high frequency field. Recent studies have showed that the acoustic insulation qualities of gypsum-rubber sheets increase sound insulation capabilities against loud impacts. The particle size of the rubber sheet was always larger than the percentage rise of the composites (Herrero *et al.*, 2013).

In their study, Adamopoulos *et al.* (2015) examined the sound absorption of gypsum-reinforced wood and rubber residues and discovered no appreciable differences in the sound absorption between various proportions of wood and rubber. The optimal sound absorption coefficient of this solid block made of gypsum was 0.72 when the frequency was raised from 2 to 4 KHz. The best value was 0.43 when the frequency was raised from 2 to 4 KHz. Elkhessaimi *et al.* (2017) also investigated the usage of glass wool and citric acid in gypsum. The study concentrated on how the materials' microstructural effects affected the transmission loss of gypsum board. The composites' thickness and density were increased, which enhanced their acoustic insulation properties. According to the study, the 50-mm thick gypsum board with a glass wool core and citric acid has exceptional insulating properties. In a separate experiment, Ramezani *et al.* (2012) assessed the acoustic characteristics of wood fibre mortars with partial gypsum substitution (10:90, 15:85, 20:80, 25:75, and 30:70 by ratio). With a transmission loss of 18 dB compared to 15 dB for plain gypsum samples, the results showed that substituting gypsum with wood fibre in a 30:70 ratio enhanced transmission loss characteristics over plain cement. Additionally, it was determined from the data that increasing the thickness from 1.0 cm to 1.5 cm reduced transmission loss across the whole frequency range under study. Oliveira *et al.* (2019) looked at the effects of gypsum composites made of expanded polystyrene and leftover cellulosic pulp. The researchers observed that there was no appreciable fluctuation in the quantities of any substance and that the greatest outcomes were achieved at a low frequency (250 Hz). The proposed composite materials' acoustic insulating properties, however, were verified. For the measured frequencies of 250 Hz and 500 Hz, the recipe with the highest cellulose pulp content had the highest sound absorption coefficient appeared of 0.33 and 0.16, respectively, while the second sound absorption coefficient appeared is 0.12 for the frequency of 1000 Hz. Arroyo *et al.* (2020) also found that 5% micro silica added to gypsum foam considerably enhanced the strength of gypsum composites, particularly at low frequencies. The sound absorption coefficient appeared is 0.64 at a frequency of 200 Hz.

On the other hand, a number of Malaysian researchers have mentioned employing extracted PALF for sound absorption. (Putra *et al.*, 2018; Yahya *et al.*, 2019) Initiatives to incorporate PALF in craft goods have just lately started, despite Malaysia being one among Southeast Asia's top producers of pineapple (Mohamed *et al.*, 2009).

Satyanarayana *et al.* 1990 found that the mechanical properties of PALF make it suitable for a wide range of applications. Because they are frequently discarded, pineapple leaves can also serve to reduce environmental consequences. As a result, the focus of this study is on the acoustic performance of the PALF-gypsum composite. The aim of the study has lately been impacted by the quest for ecologically friendly building materials. The study's conclusions will be beneficial to the building sector, which calls for the adoption of more lightweight and sound-insulating materials. As a consequence, composites comprised of PALF and gypsum were created, and their acoustic characteristics were studied.

MATERIALS AND METHODS

Materials

Pineapple Fibre

The PALF utilized in this study was obtained from the Faculty of Chemical Engineering at Universiti Teknologi Malaysia and was crushed to a size of 15 mm. This PALF's surface treatment was also completed. Sodium hydroxide (NaOH) at a concentration of 6 percent was used as an alkali therapy for PALF. At a constant temperature of 25°C, the fibre was soaked in an alkali solution for 24 hours. A PALF sample utilized in the investigation is shown in Figure 1.



Figure 1: Pineapple leaf fibre with 15 mm size.

Gypsum

For this study, gypsum powder was obtained from a Malaysian supplier. The gypsum powder was created with the intention of being used in the production of gypsum plasterboard, which is commonly used in ceiling plastering. A gypsum sample utilized in the investigation is shown in Figure 2



Figure 2: Gypsum powder.

Sample Preparation

With thicknesses of 9 mm, 12 mm, and 15 mm depending on market thickness, the gypsum base PALF composites were created utilizing a 2-weight percent fibre composition (C2) and reference gypsum (C0). A viscous combination of gypsum and water was created. Prior to volume measurement, the fibre and gypsum were weighed on a precision weighing scale with a resolution of 0.01 kg. The mold was taken from its location and relocated for two minutes to a vibrating device for quick compaction of the composite components, ensuring that the mixture was properly compressed to generate composites with fewer air spaces. A 24-hour period of room temperature solidification was given to the composite compositions in the mold. In order to make sure the samples were completely dry, they were then put in an oven set at 105°C for 24 hours.

Testing Specimen

Figure 3 depicts the results of measuring sound absorption using an ASTM C384-04 Bruel and Kjaer impedance tube on large samples (100 mm) at frequencies ranging from 50 Hz to 1600 Hz. The samples were positioned at the impedance tube's end and protected by a flat surface. To keep the sample stable, a sample holder with a 100 mm diameter was placed at the impedance tube's end. In order to pick up sound waves from the speaker, the sample surface was placed at the other end of the impedance tube. Two microphones that can pick up sound waves were employed with a loudspeaker generator, and a value between 0 and 1 was established as the sac indication value. The output was processed after the technique was converted into digital signals using user-friendly software. Scalar numbers, which reflect the amount of sound energy absorbed when it impacts a surface, were used to determine the NRC. Values around 0 show strong surface reflection, while values close to 1 suggest high surface absorption, hence values can be used to identify the existence of a surface. The arithmetic mean was widely used to specify the NRC at four distinct frequencies: 250, 500, 1000, and 2000 Hz. The formula is as follows, where α is the sound absorption coefficient at the selected frequency:

$$NRC = (\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}) / 4 \quad (1)$$

The 100 mm samples were put through three tests using a 100 mm inner diameter tube and microphones spaced at the usual intervals. It took 30 seconds to finish each exam. Throughout the studies, each sample in each tube arrangement had to be rotated three times within the sample holder, 90 degrees each time. The average of three measurements for each tube configuration was noted and preserved for subsequent data processing. The measurement data were stored in Microsoft Excel workbook format for reporting and post-processing. In the range of 63 to 1600 Hz, this produced a thorough collection of sac frequencies. The mold and samples utilized for the test of the acoustic characteristics are shown in Figures 4 and 5.

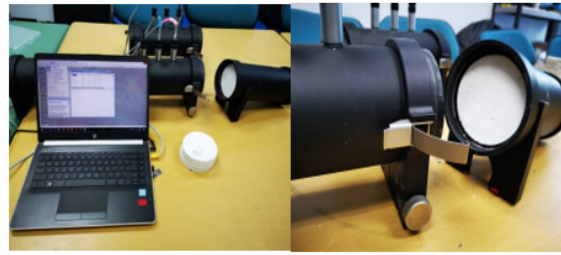


Figure 3: Impedance Test according to ASTM C384-04.



Figure 4: Mold for acoustic properties.



Figure 5: Samples for acoustic properties test.

Sound transmission loss measurements (STL) at frequencies ranging from 63 Hz to 1600 Hz were carried out on large samples using the transfer function technique according to ASTM C384-04 Bruel & Kjaer impedance tube (100 mm). The microphones were uniformly spaced apart, and each 100 mm sample was measured once within a tube that was 100 mm in diameter. Additionally, the 100 mm inner diameter tube and the wide spacing microphones were used to examine each 100 mm sample once. Each circular sample was put through two testing cycles. The test began with the specimen being tested being placed into a very absorbent foam cone at the other end of the testing chamber. For the second part of the test, the end of the test chamber had to be left open and the foam cone removed. Each test took around 30 seconds. After being examined in each of the three impedance tube configurations, the three sets of data for each sample were combined. This produced a whole set of transmission loss statistics covering the frequency range of 63 to 1600 Hz. The whole frequency data set was averaged for each of the three experiments.

RESULTS AND DISCUSSIONS

Acoustic Properties of PALF- Gypsum Composites
Plain gypsum and PALF-gypsum composite materials underwent acoustic testing to evaluate their acoustic

properties. As a result of the experiment, the sound absorption coefficient and Sound transmission loss values of ordinary gypsum and gypsum with PALF were determined.

Sound Absorption Coefficient

This section discusses the plain and PALF-gypsum composite sound absorption coefficient. This is seen in Figure 6. The frequency band between 1500 and 1600 Hz saw a little 0.23 rise in specimen C2. In the middle, between 200 and 500 Hz, there is no discernible uptick. Samples of ordinary gypsum had a lower degree of resonance at frequencies under 1000 Hz. In prior tests, ordinary gypsum had a comparable effect. A simple sample peak absorption of 0.1 at a lower frequency of 600 Hz was determined by Bouzit *et al.* (2019). When

compared to standard gypsum, Figure 6 demonstrates a slight rise in C2 in the 1000–1600 Hz frequency range (C0). This was made possible because of the profile's downward frequency decrease at that time. Incorporating PALF dramatically improved Gypsum's frequency response between 500 and 1600 Hz. A description of their results provided by Oliveira *et al.* (2019) lends weight to this view. A clear relationship exists between the amount of residual cellulose pulp and expanded polystyrene and how they affect gypsum composite boards. According to Elkhessaimi *et al.* (2017) research, adding aggregate to gypsum composite board improved its ability to absorb sound. Pedreño-Rojas *et al.* (2017) study on the acoustic properties of ceiling plate composites manufactured from reclaimed wood and gypsum found that gypsum plate composites outperformed pure gypsum materials

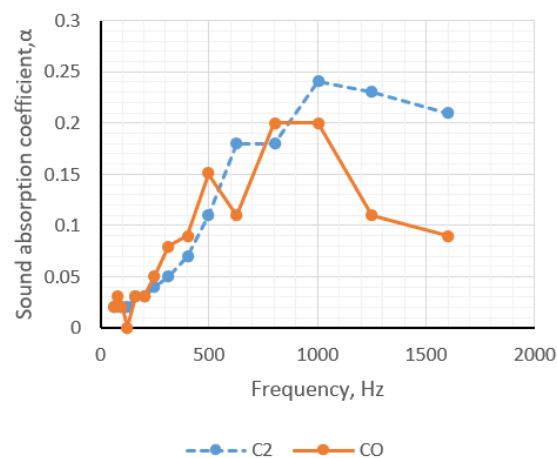


Figure 6: Comparison of sound absorption coefficient of 15 mm plain gypsum with 2% PALF-gypsum composite.

In comparison to conventional gypsum, adding 2 percent PALF to it had very little of an impact on the sound absorption coefficient (Figure 6). The inclusion of PALF produced a 0.23 advantage for frequencies between 1200 and 1400 Hz. The frequency of C2 rose from about 500 to 1250 Hz. Overall, C2's traits looked to have significantly improved. The test only examined frequencies up to 1600 Hz, hence the research opted for this number rather than 2000. The NRC value is calculated using the same frequency of 1600 Hz by Flores Medina *et al.* (2016). The averages for the three samples at each frequency

were calculated by the NRC, as shown in Table 1. The highest NRC was found in sample C2, showing that sample C2 had more absorption than the control sample C0. Therefore, compared to the C0 gypsum control mix, these mixtures are able to absorb more sound waves. It was found that the NRC had increased by 50% when the percentage change in NRC from C0 to C2 (Table 1) was compared. Gypsum forms sound absorption coefficient to a greater extent when PALF is added at a 2 percent concentration.

Table 1: C2 NRC values and NRC percent reduction as compared with the control.

Sample	NRC	%Increase
15mm (C0)	0.12	-
15mm (C2)	0.18	50

STL value of 44 dB at 400 Hz. Ramezani et al. (2012) found equivalent outcomes when contrasting wood fibre with ordinary gypsum board. Comparative to the current study, a comparable investigation showed lesser increases in STL. According to Table 2, specimen sample C2 had the greatest STL, surpassing control sample C0. There is an 18% increase in STL at 500 Hz when comparing

Sound Transmission Loss Performance

Figure 7 displays the Sound transmission loss (STL) for C0 and C2. Over the majority of the frequencies examined, the control sample (C0), which was free of PALF, had the lowest STL. Furthermore, it appears that PALF reduces the frequency of sound waves that travel through gypsum above 850 Hz. The control specimen's STL, which is close to 450 Hz, is below the 850 Hz threshold. The STL of the C2 was greater in this range than that of regular gypsum (C0). Sample C2 exhibits a greater STL across the whole studied frequency range, with values of 55 dB at 400 Hz and 44 dB at 125 Hz. The suggested PALF-gypsum composite material fared well when compared to ordinary gypsum, which had an

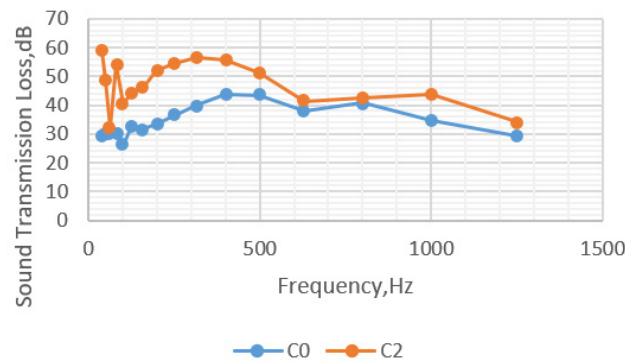


Figure 7: Comparison of STL of 15 mm plain gypsum with 2% PALF-gypsum composite.

the percentage change in STL from C0 to C2 (Table 2). A greater degree of STL is often produced by adding 2 percent PALF to gypsum.

Table 2: Comparison of STL between C0 and C2 Specimen.

Frequency (Hz)	STL(C0)	STL(C2)	%Increase
500	43.49	51.2	18
1000	34.74	43.72	26

Thickness Effects on Acoustic Properties

Depending on their intended function and the necessity to absorb sound, acoustic materials come in a variety of thicknesses.

Sound Absorption

The effect of a 2 percent weight PALF composite material thickness on the sound absorption coefficient from 63 to 1600 Hz for each octave band is shown in Figure 8, it illustrates how the material's growing thickness caused the volume to expand. In the observed frequency range, it was found that the frequency rose with increasing material thickness (from 63 Hz to 1600 Hz).

This is because materials that are thicker absorb more acoustic energy than those that are thinner. A 9 mm thick PALF-gypsum composite material's sound absorption coefficient stabilized in the 0.10 to 0.15 range after 500 Hz. Within the frequency range of 500 Hz-100 Hz, the sound absorption coefficient increased in thickness by 12 mm, going from 0.09 to 0.21. The sound absorption coefficient is 0.25 for a 15 mm thickness at 1200 Hz. In conclusion, thicker materials get a greater sound absorption coefficient delivered at a lower frequency than thinner materials. The results of Lim *et al.* (2018) and Putra *et al.* (2018) lend credence to this hypothesis. They observed that as the thickness of the enlarged sound absorption coefficient expanded, so did its low frequency. Figure 9 displays the thickness of C0 at various thicknesses. The highest peak, which was about 0.21 at about 600 Hz, was seen in the 9 mm sample. As can be observed, a 12 mm sample's density for the 800-1000 Hz range was 0.19. All of the examined sample thicknesses shown a considerable reduction in absorption in the frequency range over 1200 Hz. At a frequency of 1000 Hz, the sac for the 15 mm sample was 0.2. All of the data included peaks between 600 and 1000 Hz.

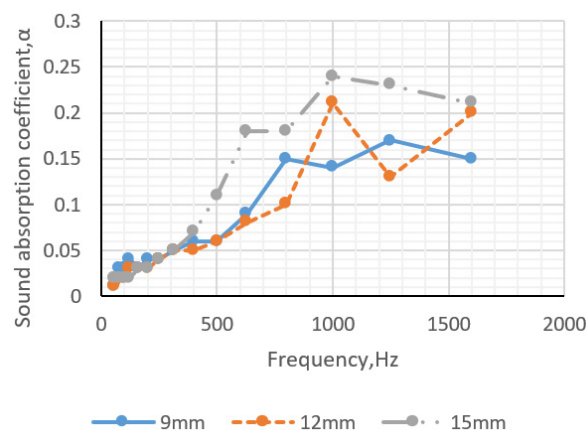


Figure 8: Sound Absorption Performance of C2 in different thicknesses.

Figure 10 shows the NRC results, which showed a nearly 50% increase above the control using the averages of each frequency for the three samples analyzed. The PALF (C2) sample displayed the highest NRC over a range of

thicknesses, suggesting a greater level of absorption than the control sample thicknesses (C0). Gypsum board produces more scarification when PALF is combined with ordinary gypsum.

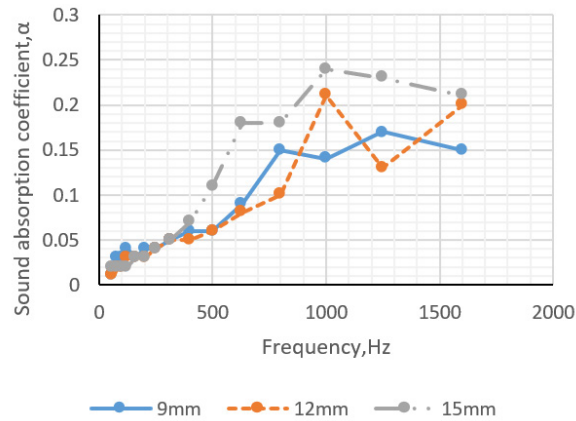


Figure 9: Sound Absorption Performance of C0 in different thicknesses.

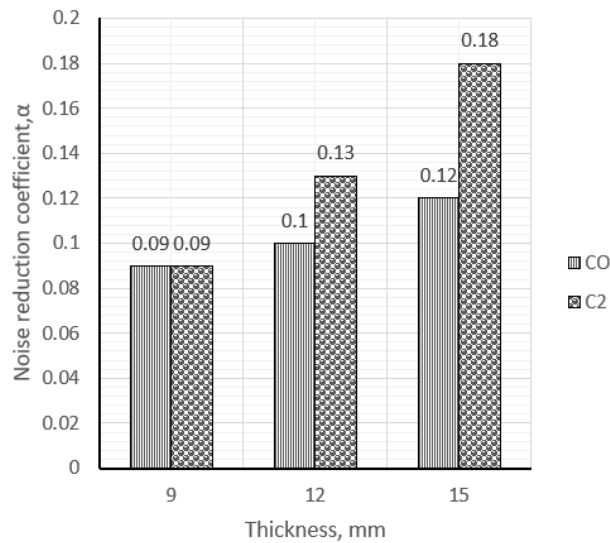


Figure 10: NRC comparison for each sample thickness C0 and (C2)

Sound Transmission Loss (STL)

The STL of the C2 at samples with thicknesses of 9 mm, 12 mm, and 15 mm is shown in Figure 11 and was measured by utilizing an impedance tube. STL seems to increase with sample thickness. The STL for a sample that was 9 mm thick at a frequency of 500 Hz was 46 dB, 49 dB for a sample that was 12 mm thick, and 51 dB for a sample that was 15 mm thick. All three of the thicknesses had STLs of 40 dB or less at 1000 Hz, with the 9 mm sample having an STL of 29 dB. At 1000 Hz,

the 12 mm sample showed a 39 dB STL. At 1000 Hz, the 15 mm sample showed a 40 dB STL. All thicknesses had a drop in STL at 1250 Hz. As a result, thickness should be taken into account more when constructing a composite material for acoustic sound quality. The capacity of a material to block the transmission of sound is dependent on its thickness, density, and stiffness of the specimen (Elkhessaimi *et al.*, 2017). The researchers found that composite materials perform better when they are thicker and denser. Similar findings were made in this inquiry's

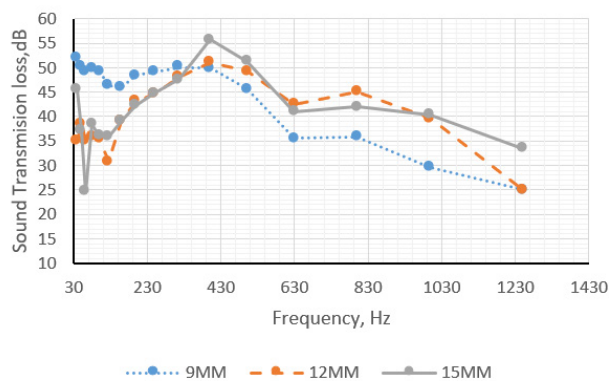


Figure 11: STL of C2 in different thicknesses

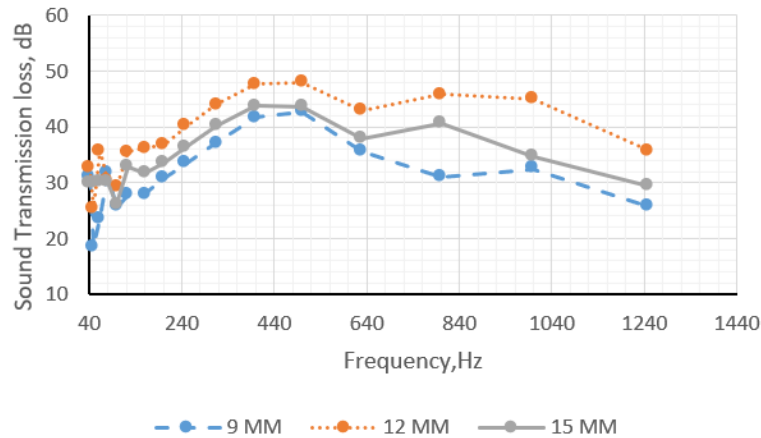


Figure 12: STL of C0 in different thicknesses.

assessment of the thicknesses of various PALF-gypsum specimens. The material with the thinnest thickness had the lowest STL in the majority of the frequencies examined. The STL for various C0 thicknesses is shown in Figure 12. For frequencies up to 500 Hz, the STL of the 9 mm panel was 45 dB, while for frequencies up to 1000 Hz, it was 31 dB. The 12 mm panel generates 49 dB STL at 500 Hz and 1000 Hz frequencies (35 dB). At 500 Hz, the STL of the 15 mm panel was 48 dB, and at 1000 Hz, it was 45 dB. As a result, as C0's thickness rose, its STL changed to the higher number

Relationship between Acoustic Properties and Thickness

The acoustic performance of a material is affected by its thickness, density, and porosity. It was looked at how acoustic characteristics affected non-acoustic factors as density, porosity, and thickness. The porosity and density values were 48 percent and 1280 kg/m³, respectively,

for each thickness of 9 mm, 12 mm, and 15 mm. When the specimen thickness was compared to the NRC, it was found that the NRC values rose as the specimen thickness did.

Relationship between NRC and PALF-Gypsum Composite Materials Thickness

Figure 13 demonstrates how a PALF-gypsum composite material's NRC value rises with thickness, reaching a maximum at 15 mm for both samples C0 and C2. The graph shows that when specimen thickness rose, the NRC increased as well. With correlation coefficients of 0.99 for C2 and 0.96 for C0, it is found that the link between NRC and growth in thickness has very little dispersion and that it climbs evidently almost linearly as a function of NRC. The sound absorption coefficient appeared to benefit from increases in thickness, as seen in Figure 14. However, there didn't seem to be any obvious advantage to adding PALF to the gypsum mix proportions because the NRC

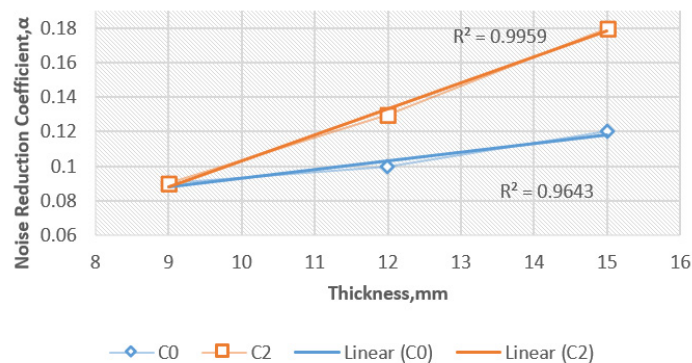


Figure 13: Relationship between NRC and thickness of PALF-gypsum composites.

values for all thicknesses were less than 0.35. According to past research, materials with a sound absorption coefficient appeared of 0.35 or less are regarded reflective for acoustic applications while materials with a sound absorption coefficient appeared of 0.35 or higher are considered effective absorbers (Cuthbertson *et al.*, 2019). The composite substance is therefore inefficient as an absorber. Applications that need for improved sound energy reflection, particularly in sound frequency bands

below 2,000 Hz, may benefit from the usage of PALF composite gypsum board.

DISCUSSION

The goal is to determine whether this material can be utilized as a component of an acoustic material to help reduce noise in buildings. The addition of PALF to gypsum reduces sound waves passing through the composite material at most frequencies, according to a

detailed examination of STL data. Advanced acoustic applications that demand greater STL properties may benefit from PALF-gypsum composite materials. The increase in thickness within the lower and higher thirds of the 63 to 1600 Hz observed frequency test range resulted in a rise in the sound absorption coefficient, a measurement of the amount of sound waves absorbed by a substance at a certain frequency. When compared to C2, the frequency spectrum's centre in plain gypsum (C0) displayed some modifications. The NRC increased by more than 50% on average when C2 data was compared to control samples (C0), showing that it did so at 1000 Hz (C2). The outcomes demonstrated that adding PALF to gypsum greatly enhanced sound absorption when compared to the control. The majority of the examined frequency ranges showed the impact. The gypsum composite material, however, cannot be claimed to have robust characteristics because the NRC values are less than 0.35. When enhanced sound energy reflection is desired, especially below 1000 Hz, this PALF-gypsum composite material may be employed. The composite's acoustic and thermal insulation qualities are significantly influenced by the thickness of the material at the conclusion of the experimental studies. The sound absorption coefficient appeared and STL get better as sample thickness increases. The strongest measure of how well a material can increase STL, as this essay has shown, is the composite thickness. The acoustic tests revealed that while the STL was enhanced, there was only a little gain in sound absorption when PALF was added to the composite materials. As a result of meeting both structural and acoustic criteria, the composite material has the ability to act as a sound insulator. Advanced acoustic applications that demand greater STL properties may benefit from PALF-gypsum composite materials. The suggested acoustic material will be used in artificial ceilings or walls. In particular for insulating gypsum board, which can take the role of plaster boards as acoustic insulators in constructions.

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Conflict of Interest

On behalf of all authors, the corresponding author affirms that there are no conflicts of interest.

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