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Research Paper

Comparative Study on the Effect of Air Gap on Aglomex Material Measurement of the Acoustic Absorption Coefficient and Acoustic Impedance

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ABSTRACT: *This research focuses on the need to develop and enhance a procedure for the design of material with high acoustic properties, sound absorption materials as the main component of acoustic materials. Noise is a threat that humans are expose to each day without any contemplation. The effect of air gaps on the Aglomex material was investigated with impedance tube using standing wave method to measure the acoustic properties (absorption coefficient and acoustic impedance) of the sound absorbing material. Sine wave generator using one-third of octave frequencies and white noise generator based on the equation of simple harmonic motion, but utilizes distance as a variable, instead of time as the analysers used for the measurement. The results comparing both analysers reveal most details describing the enhanced absorption coefficient chart of the sample with air gap.*
KEYWORDS: *Absorption coefficient, Acoustic Impedance, Sound, white noise, air gap, Sine wave.*

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I. INTRODUCTION

Noise is a threat that humans are exposed to on daily bases without any consideration, and noise is an unwanted sound. Reactions to noise is dependent on the characteristics of the sound which comprise frequency, complexity of sound, intensity, and duration. Acoustic absorption refers to the process by which a material, object, or structure absorbs in sound energy when it come across sound waves, portion of the absorbed energy is transformed into heat, while, the remaining portion is transmitted through the absorbing body. The energy that changed into heat is believed to have been 'lost [1]. The dissipation of sound energy within a porous structure is known as sound absorption, and is produced because sound is transformed into small amounts of heat when it is forced to move from pore to pore. Sound absorption is especially a critical factor when a designer is positioning noise measurements on systems that incorporate porous or multi-layered acoustic treatments. The sound absorption coefficient, is assessed between 0 and 1 and a function of frequency, is characteristically used for sound absorption quantification.

Acoustic impedance and specific acoustic impedance are degrees of the opposition that a system displays to the acoustic flow rising from an acoustic pressure applied to the system [2]. It is apparent that a lot more investigation will be required before the relation between acoustic impedance and the absorption coefficient applied in general practice can be comprehended. Unfortunately, this interconnection is not simple, and to simplify it, there must be a critical study of the methods of measurement of the usual absorption coefficient [3]. [4] examined the thermal and acoustic properties of innovative basalt natural fibre insulating panels by methods of a Heat Flow meter apparatus: The range of 0.030 - 0.034 W/mK was concluded. The acoustic absorption coefficient was evaluated by means of Kundt's Tube. The outcomes were compared with traditional solutions with associated chemical composition, but confronted with worse mechanical resistance.

The use of 2 and 4 microphones was evaluated to estimate the normal incidence absorption coefficient of some fibrous porous materials [5]. Also, [6] studied the generation of three different layers of industrial tea leaves waste with or without a major backing layer of textile woven material to examine the properties of sound absorption. The outcome indicates that the sound absorption properties increased with an increase in the thickness layer of the major single backing cotton material. Thus, this reveals that natural materials and renewable materials exhibit positive sound attenuation properties.

The present study focuses on the comparison of the effect of air gaps on the Aglomex material with the two analyzers, instead of backing with other materials. The analyzers are the sine wave generator and white noise generator which uses impedance tubes. Thus, this will efficiently make the measurement of the acoustic impedance and absorption coefficient of the material in the tube more simplified.

II. MATERIALS AND METHODS

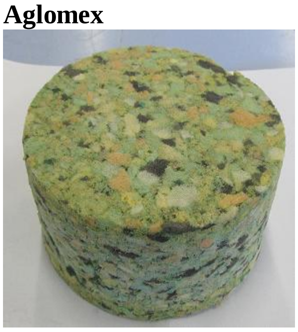
Aglomex sample, National Instrument (NI) LabVIEW and National Instrument equipment such as NI 9263, NI 9234, NI CDAQ 9174 for data acquisition and processing, one microphone, loudspeaker, Impedance tube, Power Amplifier, computer, meter rule, Sine wave generator, developed NI LabVIEW application for white noise generation. The one microphone method was used and not the standardized procedures for the measurement of the normal incident absorption coefficients of acoustical material. These methods comprise of the Kundt's tube, also known as standing wave or impedance tube: standing wave ratio [7] and the transfer-function methods [8].

The one microphone method was employed because it has a distinct advantage in that it prevents the somewhat complicated calibration procedure that is essential for transfer function measurements. Using the transfer function method, the microphone does not hamper with the sound field inside the tube due to its side wall mounting. Nonetheless, challenges can spring up as a result of the limited number of microphones locations and the insufficiency of spacing distance between the microphones (according to [7] that from one microphone to another, the distance in between should be more than five times the diameter of the microphone). So, the one microphone method, when compared with 2 - 3 microphones method and reverberation chamber offer a quick broadband alternative.

2.1 Samples description

Material used in this research were sourced by Pronorma, a Portuguese company working in the field of Acoustic sampling of structures “Table 1”.

Table 1. *Showing the material sample and their application.*

Aglomex	
	**Material:** Flexible Polyurethane foam with different densities. **Process:** Re-use of polyurethane foams of various uses, from mops up mattresses of various types. **Applications:** Isolation to Aerial sounds Isolation to Percussion sounds

2.2 Experimental setup

Application of the standing wave method, a white noise sound source is positioned at one end of the tube, and terminate at the other end containing the Aglomex sample. At the instance, the sound is initiated a standing wave pattern develops in the tube, and a microphone travel through the length of the tube starting at the loudspeaker’s end and travelling a 1cm distance for each measurement and terminating at the sample end. A picture describing the experimental setup is shown in Figure 1. The developed NI LabVIEW application for white noise generation take details of the location and level of the first extrema together with the minima and maxima that accompany with it. From this information the sound absorption coefficient and specific acoustic impedance of samples can be evaluated. This is accomplished with multiple frequency of 5 Hz resolution from 0 Hz to 6500 Hz at 1cm distance at a time, with an extensive scan through the entire tube distance.

White noise is said be a statistically random signal with its power spread equally across the signal frequency domain. Specifically, it is described with a flat power spectral density in which signal at every frequency has the same power within a static bandwidth which is the difference between frequencies of lower and upper limits in an uninterrupted set of frequencies measured in Hertz.

Aliasing emerges when a signal is evaluated at an insufficient sampling rate to capture the changes of that signal. This suggests that there is the existence of some undesirable components in the reconstructed signal that were not existing in the original signal that was sampled. Aliasing appears because signal frequencies overlap some times when the sampling frequency is very small or too low compared to the signal being measured [9].

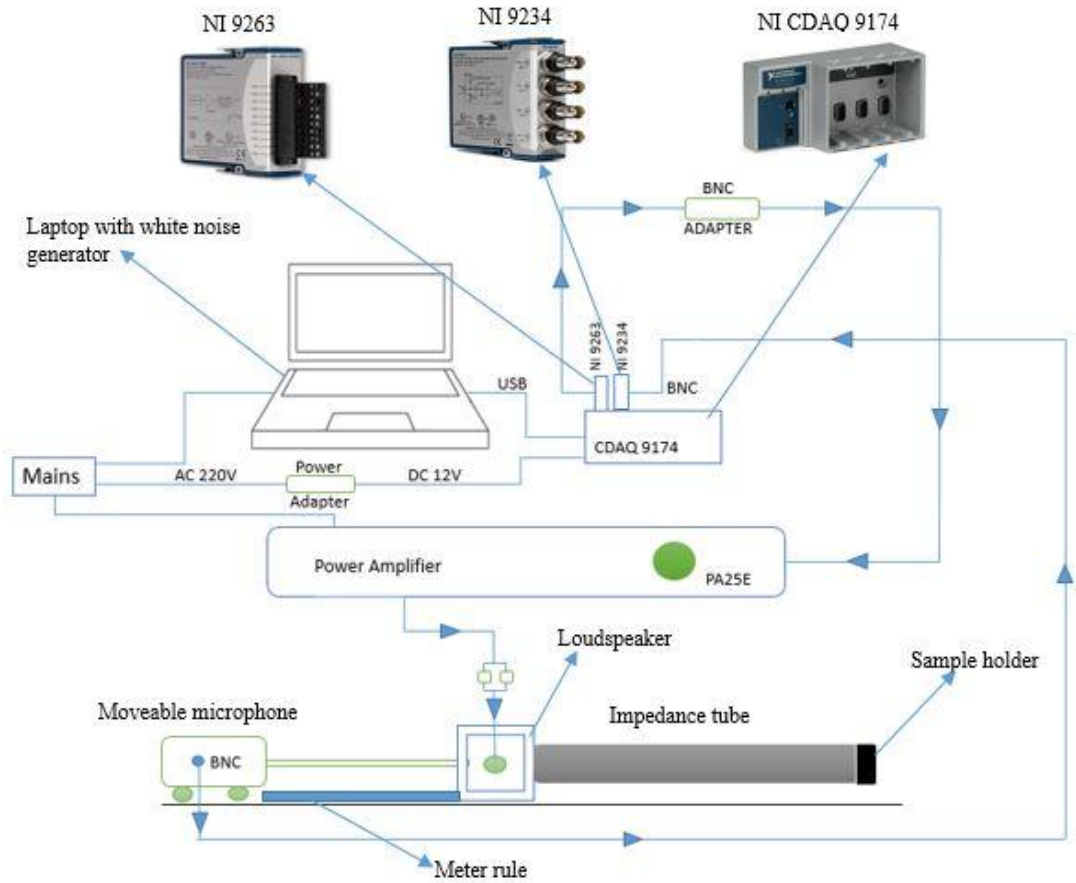


Figure 1. Schematic block representation of the Experimental Setup

The measurement of the Acoustic Impedance in an Impedance tube, starts by defining the Standing Wave Pressure ratio SWR as:

$$SWR = \frac{P_{max}}{P_{min}} = \frac{A+B}{A-B} \tag{1}$$

where P_{max} is the pressure maximum of the standing wave in the tube, P_{min} is the pressure minimum and?

$$R = \frac{B}{A} = \frac{SWR+1}{SWR-1} \tag{2}$$

defines the ratio coefficient between the reflected and incident wave amplitude.
A new approach to model a standing wave in a tube was utilized in this paper. “Figure. 2” below reveals a real illustration of experimental data recorded along the length of an impedance tube for a harmonic signal.

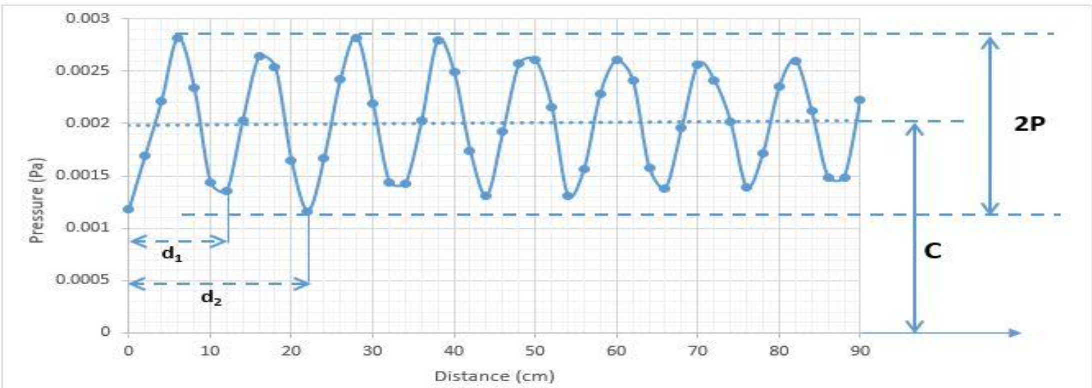


Figure 2. Plot showing the Amplitude vs distance for a standing wave with a frequency of 1700 Hz

The harmonic waveform that correspond mathematically with the sine function in the time domain is:

$$P(t) = P \cdot \sin(\omega t + \alpha) + C \quad (3)$$

where ω is the angular frequency of the wave, C is the offset mean pressure and α is the phase angle, where the latter two quantities cab be obtained from:

$$C = \frac{P_{max} + P_{min}}{2} \quad (4)$$

$$\alpha = 1 - \left(\frac{SWR - 1}{SWR + 1}\right)^2 = 1 - R^2 \quad (5)$$

Since each spectral component of the white noise is similar in pattern to that of the harmonic waveform (after application of the FFT), and following the earlier line of thought that harmonic spectral components can be represented as a sinusoidal function of the distance d instead of time t, the waveform shown in “Figure.2” is suggested to be written as:

$$P(d) = P \cdot sin(\widehat{\omega} d + \widehat{\alpha}) \quad (6)$$

Making the analogy between equations (3) and (6), we have:
$t(s) \rightarrow d(m)$
$\omega(rad \cdot s^{-1}) \rightarrow \widehat{\omega}(rad \cdot m^{-1})$
$\alpha(rad) \rightarrow \widehat{\alpha}(rad)$
The values for $P, C, \widehat{\omega}$ and $\widehat{\alpha}$ are extracted with the help of the software developed in LabVIEW, where:

$$P = \frac{P_{max} - P_{min}}{2} \quad (7)$$

$$P_{max} = C + P \quad (8)$$

$$P_{min} = C - P \quad (9)$$

Taking into account the phase angle, the distance $d_1$of the first minimum from the sample being measured was determined from:

$$d_1 = -\frac{\widehat{\alpha}}{\widehat{\omega}} + \frac{3\pi}{2\widehat{\omega}} \quad (10)$$

If $d_1 < 0$, then the value from equation (10) must be amended to:

$$d_1' = d_1 + \frac{2\pi}{\widehat{\omega}} \quad (11)$$

since it does not make sense to have a negative distance. The distance d_2 from the sample to the second minimum can be determined from the wavelength $\lambda = 2(d_2 - d_1)$; hence:

$$d_2 = \begin{cases} d_1 + \frac{2\pi}{\widehat{\omega}}, & d_1 > 0 \\ d_1' + \frac{2\pi}{\widehat{\omega}}, & d_1 < 0 \end{cases} \quad (12)$$

Therefore, with the above equation producing d_1 and d_2, the real and imaginary components of the acoustic impedance $Z_n$can be calculated from:

$$\mathrm{Re}\left(\frac{Z}{\rho c}\right) = \frac{1 - R^2}{1 + R^2 - 2R\cos(\Delta)} \quad (13)$$

$$\mathrm{Im}\left(\frac{Z}{\rho c}\right) = \frac{2R\sin(\Delta)}{1 + R^2 - 2R\cos(\Delta)} \quad (14)$$

where ρ is the density of air, c is the speed of sound in the tube and Δ is the phase angle between the incident and reflected sound pressure?

$$\Delta = \left(\frac{4d_1}{\lambda} - 1\right)\pi = \left(\frac{2d_1}{d_2 - d_1} - 1\right)\pi \quad (15)$$

With the Real and Imaginary components of the Acoustic Impedance (equations 13 and 14), the Acoustic Impedance in rayls can finally be determined from:

$$Z = \rho c \sqrt{\mathrm{Re}^2\left(\frac{Z}{\rho c}\right) + \mathrm{Im}^2\left(\frac{Z}{\rho c}\right)} \quad (16)$$

2.3 Sample averaging

Averaging means that sampling of the frequency for a given duration by the software is added after a subtraction is made due to buffer problems associated with the program, then the average is generated and stored for both of the pressure minima and maxima.

III. RESULTS AND DISCUSSION

The acoustic measurements were carried out by the impedance tube with the setup that contains a single microphone that transforms sound pressure into electrical signals which is encapsulated and displayed on the developed NI LABVIEW software and is analysed to view the effect and relationship of the material tested and its acoustic impedance and absorption coefficient recorded.

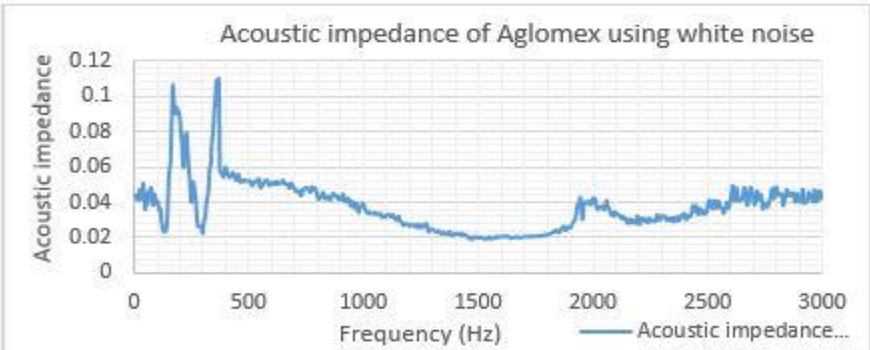


Figure 3. Chart showing the Acoustic impedance of Aglomex sample using white noise with 5 Hz resolution

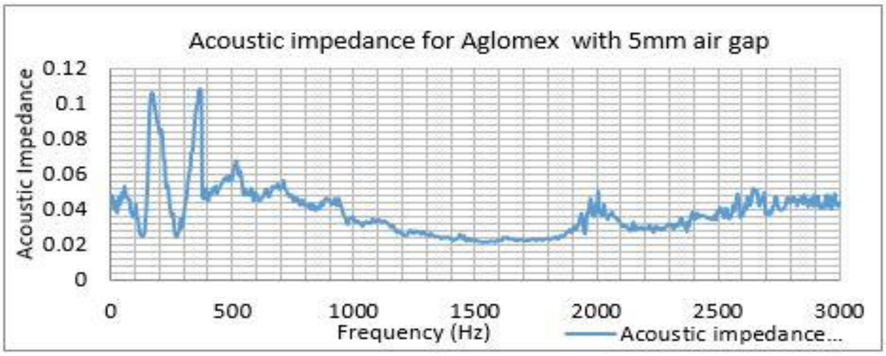


Figure 4. Chart showing the Acoustic impedance of Aglomex sample with 5mm air gap using white noise with 5 Hz resolution

The acoustic impedance at a distinct frequency implies that certain amount of sound pressure is generated at a given air vibration at that frequency. In other words, a material with a low acoustic impedance will hinder the movement of sound energy less than when a high acoustic impedance is allowed to passed through a medium, this means that the higher the acoustic impedance the lower the absorption coefficient of that sample. Thus, Figure 3. Shows that the Aglomex sample has a moderately low acoustic impedance [10] and [2]. The acoustic impedance shown in Figure 3 and 4 respectively shows that there is more to understand than just looking at the chart pattern. This is because the response of the plot of the acoustic impedance result at some point shows characteristic of impedance and at other points tends to dispute the characteristics of impedance around the 0 -370 Hz frequency, then from 360 Hz which also correspond with the plot of the absorption coefficient it start to yield the characteristics of acoustic impedance till about 2800 Hz for both chart of without air gap and with air gap.

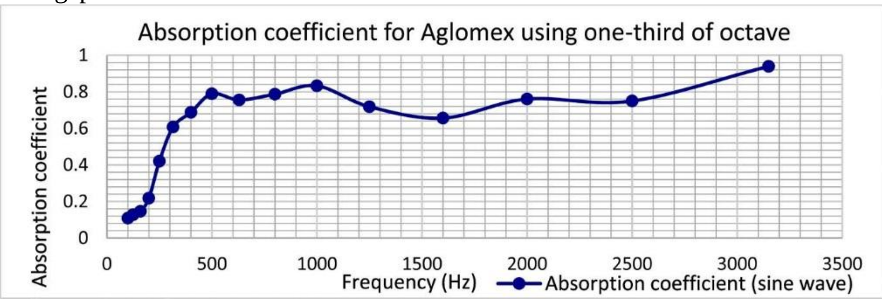


Figure 5. Chart showing the Absorption coefficient of Aglomex sample using sine wave with one-third of octave

The result in Figure 5, reveals a steady rise from 100 Hz to 500 Hz then starts to fluctuate around the absorption coefficient range of 0.62 - 0.82 till a frequency of 2500 Hz. After 2500 Hz no proper averaging of the frequencies was obtained because at this point the analyser is measuring noise. Using the sine wave and one third of octave and the impedance tube shows that the frequency range of 0 Hz to 89 Hz is not measurable and this is shown in Figure 6 below

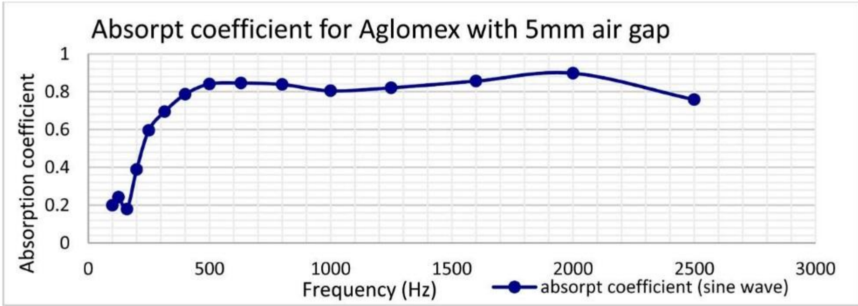


Figure 6. Chart showing the Absorption coefficient of Aglomex sample with 5mm air gap using sine wave with one-third of octave

The same Aglomex sample was investigate again with the introduction of air gap of 5mm, the result obtained is shown in Figure 6. It reveals an improvement from the previous without air gap in Figure 5. This also increase steadily from 100 Hz to 500 Hz then tries to maintain a steady absorption coefficient of 0.82 from the 500 Hz to about 2000 Hz which corresponds with the investigation executed by [11] and [12]. It was also observed in this measurement also that from above 2500 Hz the analyser could no longer average the frequencies due to noise measurement. But, according to [9] Porous or fibrous absorbing materials exhibit good sound absorbing characteristics at high frequency > 1000 Hz but for low frequencies < 250 Hz there is a rapid decrease in the sound absorption coefficient which corresponds with the results displayed the chart in Figure 7 below. It also added that increasing the thickness of the material helps to improves the low frequency sound absorption coefficient.

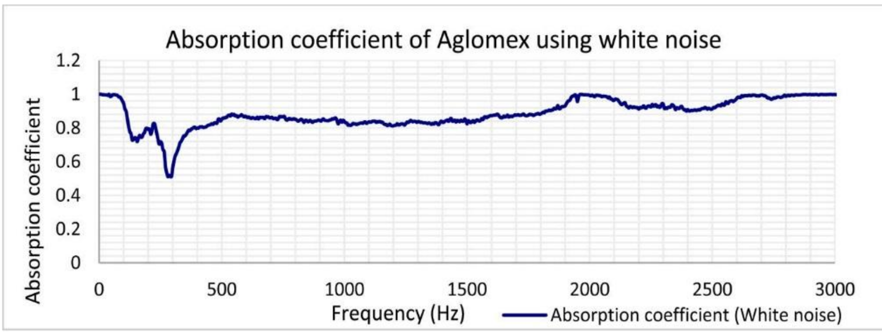


Figure 7. Chart showing the Absorption coefficient of Aglomex sample using white noise with 5 Hz resolution

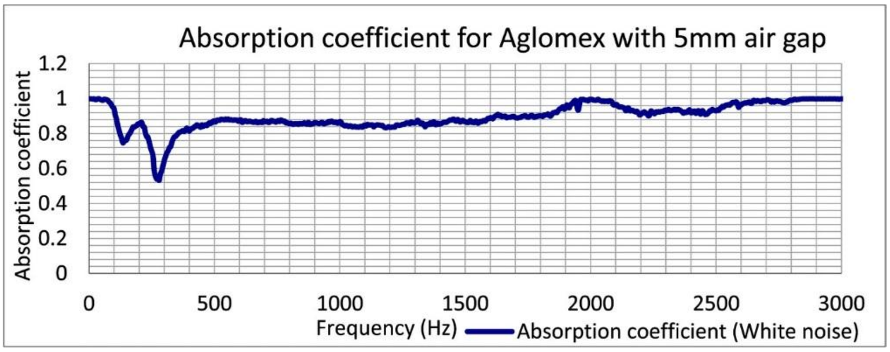


Figure 8. Chart showing the Absorption coefficient of Aglomex sample with 5mm air gap using white noise with 5 Hz resolution

The results obtained is showing a reverse action for the absorption coefficient from the maximum range of 1 at 0 Hz to average range of 0.5 at 295 Hz in Figure 7 and Figure 8 corresponding to [9] before starting to increase gradually showing the absorption characteristics of the sample measured. The adding of 5mm air gap to the Aglomex sample produced an improved plot shown in Figure 8 and the flow of the sound is absorbed in a steadier manner showing a steady and gradual increasing absorption coefficient with reduced fluctuations.

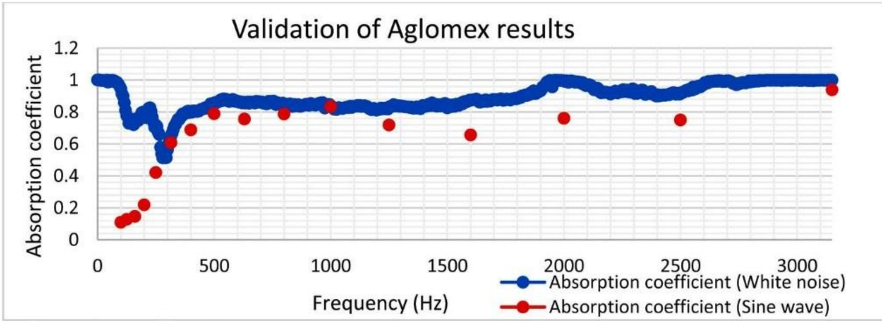


Figure 9. Chart showing plots of results of both the sine wave with one-third of octave and white noise with 5 Hz resolution for Aglomex combined together

For the validation of the Aglomex sample for both sine wave and white noise analysers shown in Figure 9, it produced better result presentation the sample used for measurement with the white noise in comparison with the sine wave analyser. It can be seen that the red dots are sparse (not dense) so information of many areas of the plot is hidden or not known as compared to the blue dots that are dense due to the method employed that is, 5 Hz frequency resolution for every 1 cm distance moved by the microphone.

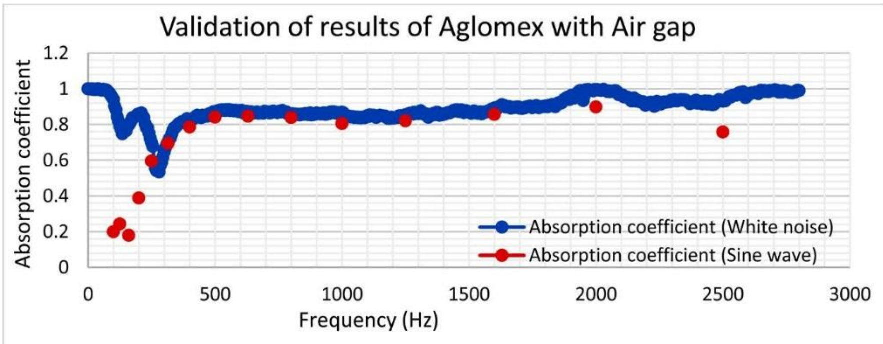


Figure 10. Chart showing plots of results of both the sine wave one-third of octave and white noise with 5 Hz resolution for Aglomex with air gap combined together

The sample of Aglomex was further validated with overlapping the results in which air gap was introduced shown in Figure 10. It reveals a matching result of over 70% between the sine wave generator and the white noise generator. This implies that the new method is also reliable and can give validated results. The final outcome shows an almost matching plot from 315 Hz to 2500 Hz. Using the sine wave generator, it was observed that information of many areas of the chart is hidden or not known as compared to the white noise generator. The white noise generator employs 5 Hz frequency resolution for every 1 cm distance moved by the microphone. Thus, producing most of the details produced in the plot.

IV. CONCLUSION

The Comparative Study on the Measurement of the Acoustic Absorption Coefficient and Acoustic Impedance with the effect of Air Gap on Aglomex Material in a Standing Wave Impedance tube was presented. It was observed when comparing the acoustic absorption coefficient and impedance of the Aglomex material that;

The higher the absorption coefficient the lower the acoustic impedance of the Aglomex material, the air gap also enhanced the performance of the Aglomex material in terms of its absorption coefficient. Thus, making the Aglomex material to act like a less dense material. Also, the moderately dense material with air gap makes the material absorption coefficient appears to stabilize the absorption rate. For the absorption coefficient to be high and effective the material would be one with a less dense structure [10]. And the Aglomex in which the air gap was introduced produced a more stable absorption coefficient as observed in the PN70 and Ekla materials investigated by [13]. On the other hand, a very dense material would produce a low and unstable fluctuations in the absorption coefficient as shown in the Black rubber and Pladur materials studied by [13].

It can be concluded that the introduction of the air gap in the measured sample produced an efficient result from the comparison with both analysers, thus, indicating an improved method of measurement of the acoustic impedance and absorption coefficients of the material.

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