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Estimation of Sound absorption Coefficient from the Sound Power

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ABSTRACT

Sound absorption measurements were carried out in the reverberant room in accordance with ISO354. The present paper gives an experimental technique to estimate the sound absorption coefficient of a material based on the sound power in the reverberation room according to ISO 3741. This is in order to be able to calculate the sound absorption coefficient of the material needed to reduce the sound pressure levels in the room. Depending on Newton’s (iteration) method inferred equivalent sound absorption area and sound absorption coefficient will be obtained from the sound power equation Measurements were taken on four different materials to test the method's validity (wood, rubber, Gypsum, and polyurethane sponge). For boor sound-absorbing materials, acceptable results were obtained for the corresponding sound absorption area. Due to the mutual dependency on both the properties of the material and the parameters of the reverberant environment, there was an unstable discrepancy in the results of the sound absorption coefficient for high sound-absorbing materials. The relative standard deviation for sound absorption was 0.00 while the uncertainties for sound power was 0.7dB

Key words : Sound Absorption Estimation, Sound Power, Reference Sound Source, Newton (iteration) Method, and Measurement Uncertainty.

1. INTRODUCTION

The sound absorption coefficient is one of the most commonly used parameters in acoustics and the most important factor of acoustic material. the measurement of different quantities indicates the importance of room patterns from the average number of measurements to decay and that the difference is not significant [1]. Evaluating methods for reverberation time with different rooms, as well as calculating the absorption coefficient and standard deviation of the measurements presented[2]. Multi-factors affect the selection of the sound-absorbing materials with their properties in order to obtain a high sound absorption coefficient in order to preserve the environment from noise pollution [3]. Different models Demonstrate estimating and measuring the reverberation time of reverberant rooms. It is not possible to decide which one is the best, some of them create formulas and others verify them [4]. An approximation of the acoustic energy decay in room impulse responses generated using the image-source technique. A closed-form expression describing the energy decay curve is proposed. The proposed approach was tested with uniform and nonuniform sound absorption coefficients in various room sizes and reverberation levels. The suggested method allows designers to perform a preliminary examination of a simulated reverberant environment without having to run time-consuming image-method simulations [5]. A comparison of the reverberation time values of seven models (Sabine, Eyring, Millington-Sette, Fitzroy, Arau, Kuttruff, and Neubauer) with Lab measurements of different configurations of the absorbed panel in the reverberation room and discusses their**.** applications. The results show that all the formulas produce inaccurate T60 predictions, with the difference between measured and modeled values above 16% in every configuration. The large difference between those prediction models and measured RT values may be due to the fact that the formulas require a thoroughly diffuse sound field, which is not satisfied [6]. A proposed experimental method to calculate the sound absorption coefficient of absorbing materials of small samples than those required by standards under a synthesized diffuse acoustic field in free-field conditions. The obtained results compared to numerical simulations using the transfer matrix method, it provides absorption coefficients in good agreement with those obtained by simulations for a laterally infinite material [7]. A new technique based on active intensity and sound energy density measurements was introduced to measure the sound absorption of materials [8]. The Sabine absorption coefficient is investigated theoretically based on Miki's model for porous absorbers backed by a rigid wall or an air cavity [9], in which the Sabine absorption coefficient is investigated theoretically based on Miki's model for porous absorbers backed by a rigid wall or an air cavity. A fixed or impulsive reference sound source can be used to effectively estimate the equivalent sound absorption area. Using stationary and impulsive reference sound sources, two approaches for measuring similar sound absorption areas (sound pressure level or sound exposure level measurements) are used. In the four rooms, two reverberation rooms, and two normal rooms, the reverberation times were measured [10]. According to ISO 354 [11], the reverberation room method allows us to quickly estimate the sound absorption of material in the reverberant field by using reverberation time.

2. OBJECTIVE OF STUDY AND EXPERIMENTAL METHODS

2.1 Objective of Study

The main objective is an estimation of the sound absorption coefficient of a material using the sound power (L_w) of the reference sound source (RSS) in the reverberation room. The following procedures were carried out in the reverberation room to determine the sound absorption coefficient of a material:

(1) Qualification test of the reverberation room

(2) Calibration of reference sound source (RSS) in the reverberation room

(3) Reverberation time measurements of the reverberant room in two cases, with and without the absorbing material in the room, using omnidirectional sound source 4296 B&K.

(4) Sound absorption coefficient (α_m) calculation of material from Sabine formula,

(5) Using the Newton (iteration) method to obtain inferred equivalent absorption area (Ac), from the sound power (LW) of the reference sound source (RSS) 4204 B&K,

(6) calculating the sound absorption coefficient (αc) from an inferred area (A_c),

(7) Comparison between calculated (α_m) and estimated sound absorption coefficient (α_c) of the material.

2.2 Experimental Methods

The reverberation room verified the requirements of surfaces absorption as in ISO 3741[12]. It has a total surface area of 178 m^2 and a volume of 160m^3. All measurements were carried out in the reverberation room with the following characteristics:

Non-diffusers are present in the room, Non-parallel surfaces, and non-equalized dimensions, with a height ranging from 4.18m to 4.27m, length dimensions ranging from 6.10 to 6.3m, and width ranging from 5.8 to 6m.

3. CALIBRATION and QUALIFICATION

3.1 Calibration of Reference Sound Source (RSS) in the Reverberation Room

Calibration of the reference sound source (RSS) was carried out in the reverberation room according to ISO 6926 [13], and ISO 3741 at more than one location (x_1, y_1, x_2, y_2, and x_3, y_3). As a result of the sound power (L_w) determination of the reference sound source, at multi-locations, the best two locations were obtained at x_3& y_3 as well as the accompanying uncertainty. The values of averaging L_w for the reference sound source at multi locations were represented in figure 2.

3.2 Qualification of the reverberation room was carried out according to ISO 6926 and 3741

Measurements of the reverberation time (T) in the reverberation room were carried out according to ISO 3382-2 [14]. The sound source and microphone spacing were more than 1.8m, and the spacing between microphone positions and any wall was more than 1m. The omnidirectional sound source type 4296 B&K with a pink noise was located at the RSS locations (x_1, y_1, x_2, y_2, and x_3, y_3) and at a height of 1.50m from the room floor. The reverberation time (T) was measured at the accompanying six microphone positions for each source location.

Measurements of the sound pressure level (L_{spl}) were carried out according to ISO 3741 standard. As the room qualified, the reference sound source type 4204 B&K was located on the room floor at two locations. And the distance between the two source locations was 2m.

4. CALCULATIONS AND UNCERTAINTY

4.1 Sound power Calculations and Related Uncertainty

Using ISO 3741 standard to calculate the sound power L_w of RSS from the following formula;

$$L_w = \overline{L_{P(ST)}} + \{10\log \frac{A}{A_0} \text{ dB} + 4.34 \frac{A}{S} \text{dB} + 10\log\left(1 + \frac{SC}{8vf} \text{dB}\right) + C_1 + C_2 - 6\} \quad (1)$$

Using sabine formula

$$A = \left[\frac{55.26 * V}{c}\right]\left[\frac{1}{T}\right] \quad (2)$$

Where;

$\overline{L_{p(ST)}}$, is the SPL in a given center frequency band, averaged over all source and microphone positions.

A, is the equivalent sound absorption area of the test room.

T, the reverberation time of the room & A_0, the ref. value, $1m^2$. And c; speed of sound
V, is the volume of the room, f, is the mid-band frequency and S, is the test room surface area.
C_1, is the correction of the reference quantity, and C_2, is the correction of the radiation impedance, in decibels
The environmental conditions in the reverberation room during measurements are represented in Table 1.

Table 1: Environmental conditions

Measurements	Temperature t^0c	Pressure kpa	Humidity H %
L_w	21±0	101.0±0	55±0
A	20±0	101.2±0	55±0

* Uncertainty Determination

According to ISO 3741 standards, uncertainties of the sound power levels, $u(L_W)$, in decibels, have been calculated by the total standard deviation, σ_{tot}, in decibels as;

$$u(Lw) = \sigma_{tot} \quad (3)$$

The total standard deviation σ_{tot} in decibels can be determined as;

$$\sigma_{tot} = \sqrt{{\sigma_{Ro}}^2 + {\sigma_{omc}}^2} \quad (4)$$

$$\sigma_{omc} = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}\left(L_{p,j} - L_{av}\right)^2} \quad (5)$$

Where; $L_{p,j}$; is the sound pressure level measured at a position
L_{av}; is its arithmetic mean level calculated for all these repetitions.

$$\sigma_{Ro} = \sqrt{(c_1u_1)^2 + (c_2u_2)^2 + \cdots + (c_nu_n)^2} \quad (6)$$

The total standard deviation (σ_{tot}) were represented in figure 3, for different RSS locations (x_1, y_1, x_2, y_2 and x_3, y_3) by σ_{tx1y1}, $\sigma_{tx2,y2}$ and $\sigma_{tx3,y3}$ of the sound power of RSS.

- **Calculations of Sound absorption (α) and Repeatability**

Four materials were measured in the reverberation room with the following characteristics:

Table 2: Specification of measured materials

material	Density (kg/m^3)	Thickness (cm)	Air-permeability cm^3/cm^2/s
Wood W	582	0.016	0.0
Rubber R	50.71	0.027	0.7
Sponge S	195	0.047	148
Gypsum G	712.95	0.016	40

4.2 Sound absorption coefficient Calculation using Sabine formula

The reverberation time (T) values obtained by the various procedures described above, and the variation in the reverberation time (T) of the materials in the reverberation room when containing rubber (T_R), wood (T_w), Polyurethane sponge (T_s), Gypsum (T_G) and for empty room without any sample inside it (T_E), also represented in Figure 5.

Using reverberation times T_1 and T_2

$$A_T = A_2 - A_1 = 55.3V\left[\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right] - 4V(m_2 - m_1) \quad (7)$$

for constant temperature t, $c_1=c_2=c$ so,

$$C = (331+0.6\ t)\ m/s \quad (8)$$

Where c; speed of sound at constant temperature t
T_1:reverberation time of the room without sample
T_2:reverberation time of the room with sample

Power attenuation coefficient m_1 and m_2, can be calculated from the attenuation coefficient

$$A = \left[\frac{55.3\ V}{c}\right]\left[\frac{1}{T_2} - \frac{1}{T_1}\right] \quad (9)$$

$$A = \alpha s = \alpha_1 s_1 + \alpha_2 s_2 \quad (10)$$

$$\alpha_2 = \frac{\alpha s - \alpha_1 s_1 \alpha_1}{S_T}$$

Where: α, the total absorption coefficient of the room surfaces and material inside the rooms, A, total surface area of the room surfaces and material inside the room, S_1, is the surface area of the room, α_1, the absorption coefficient of the room surfaces, and S_2, the area of the absorbent material and α_2, the absorption coefficient of the material.

- **Repeatability of reverberation time**

The relative standard deviation of the reverberation time T_{20}, can be estimated by the following formula:

$$\frac{\varepsilon(T_{20})}{T} = \sqrt{\frac{2.42+3.59\ /N}{f \cdot T}} \quad (11)$$

$\varepsilon(T_{20})$, is the standard deviation of the reverberation time, T: is the reverberation time measured, f; is the centre frequency of the one-third-octave band, N; is the number of decay curves evaluated and $\varepsilon(T_{20})/T$; is the relative standard deviation.

- **Sound absorption coefficient estimated from inferred equivalent absorption area (A)**

The absorbent material was placed inside the reverberation chamber, whose absorption coefficient is unknown, using the RSS type 4042 at x_3, y_3 locations and the sound pressure level (L_{spL}) measurements have been carried out in 1/3 octave band ranging from 125Hz to 10kHz according to ISO 3741at the six microphone positions associated with each location of the reference source. Using the sound power (L_w) of the reference sound source (RSS) and (L_{spL}) with equation 12, inferred equivalent sound absorption area (A_c) can be obtained and sound absorption coefficient α_c was estimated. Using the reverberation time of the room (T), the measured absorption coefficient α_m was calculated using Sabine formula. This is to be able to obtain the sound absorption coefficient of the material using the inferred formula (12), as will be appear in figures 8, 9 and 10.

By converting equation (1) into

$$10\log\frac{A}{A_0} = L_w - \overline{L_{P(ST)}} - 4.34\frac{A}{S}\,dB - \{10\log\left(1 + \frac{SC}{8vf}dB\right) + C_1 + C_2 - 6\} \qquad (12)$$

5. RESULTS AND DISCUSSION

5.1 Calculations of RSS Sound Power and Accompanied Uncertainty (σ)

The sound power of the reference source was calculated from multi measurements of the reverberation time (T) and sound pressure level (L_P) which carried out in the reverberation room.

Figure 1, represents the average reverberation time T_E for empty room at different locations (x_1, y_1 & x_2, y_2 and x_3, y_3) of the sound source in the reverberation room represented as T_{EX1}, T_{EY1}, T_{EX2}, T_{EY2} and T_{EX1}, T_{EY1}. The difference in the reverberation time results is very small for different locations of the sound source, starting from the frequency of 500Hz up to 10000Hz. There is also a difference between the reverberation time values in the frequency range lower than 500Hz, and the largest difference is about 0.5 seconds.

When the RSS was placed at x1 location, its measured sound power level value (Lwx1) was 89.55dBA, and when it was placed at y1 source location, the value of (Lwy1) was 89.36dBA, according to the measurements taken in the reverberation room at many locations. When the RSS was sited at x2 and y2 locations, the sound power level (Lwx2 & Lwy2) values were 90.18dBA and 89.82dBA respectively. The RSS was moved to new two locations, x3 and y3, with measured sound power (Lwx3 and Lwy3) values of 89.72dBA at x3 and 89.62dBA at y3.

Figure 2, appears the average sound power level L_{wx1y1} as a result of RSS measurements which carried out at x_1, y_1 locations and combined together to calculate the average sound power. The average sound power levels L_{wx2y2} and L_{wx3y3} represents the average sound power emitted from the RSS which were carried out at x_2, y_2 and at x_3, y_3 locations respectively. The curves of the average power appear with the same behavior, and the difference between each other nearly less than 0.5dB.

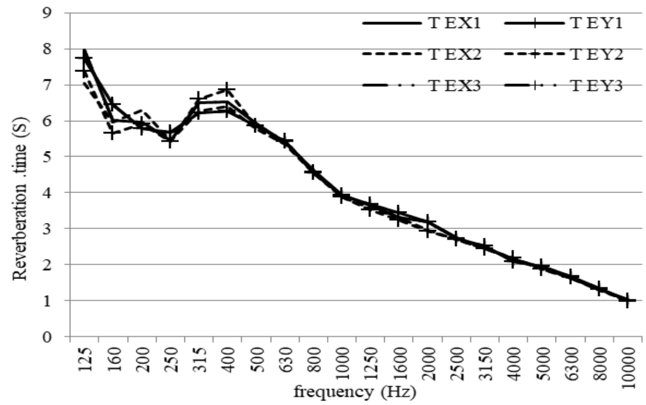

Figure 1: Reverberation time T_E at different RSS Locations x_1, y_1 & x_2, y_2 and x_3, y_3

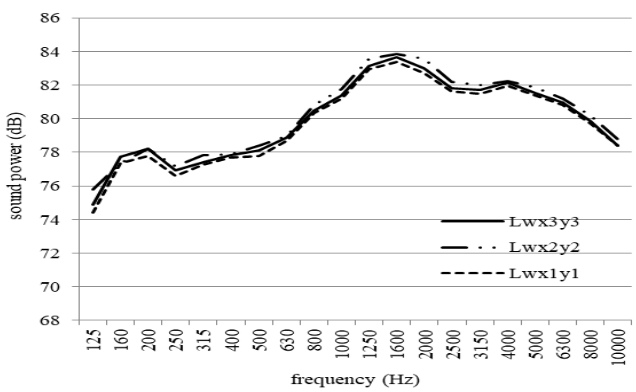

Figure 2: Averaged sound power L_{wx1y1}, L_{wx2y2} and L_{wx3y3} of RSS at x_1, y_1 & x_2, y_2 and x_3, y_3 locations

Figure 3, describe the total standard deviation (uncertainties) σ_{wx1y1}, σ_{wx2y2} and σ_{wx3y3} accompanied with the average sound power level L_{wx1y1}, L_{wx2y2} and L_{wx3y3} of RSS at x_1, y_1 & x_2, y_2 and x_3, y_3 locations. Generally, the total standard deviation for the three cases is lower than 0.6dB, except at frequencies lower than 400Hz the total standard deviation increased up to 1dB. But in high frequency range upper than 8000Hz it is increased up to 0.7dB.

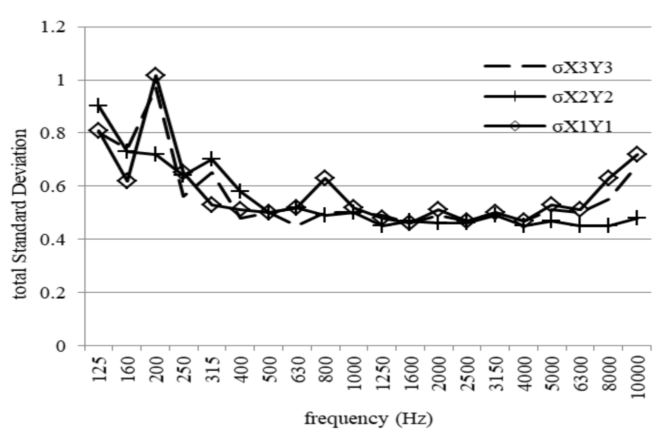

Figure 3: Accompanied uncertainty σ_{wx1y1}, σ_{wx2y2} and σ_{wx3y3} with average sound power

5.2 Sound absorption (α) and standard deviation of reverberation time ($\mathcal{E}_T$ - Repeatability)

The reverberation time of different materials in the reverberation room are represented in figure 4. Firstly the reverberation time of empty room TE was measured. When the reverberation room included the individual materials separately, the measurements were repeated. There is nearly a visible difference between the (TE) of an empty room and the (TE) of a room containing rubber (TR), wood (Tw), Gypsum (TG), and polyurethane sponge (Ts) separately, as shown in figure 4. The empty room's reverberation time (TE) is the longest of all, and it gradually decreases until it reaches 1.65sec at 6300Hz.

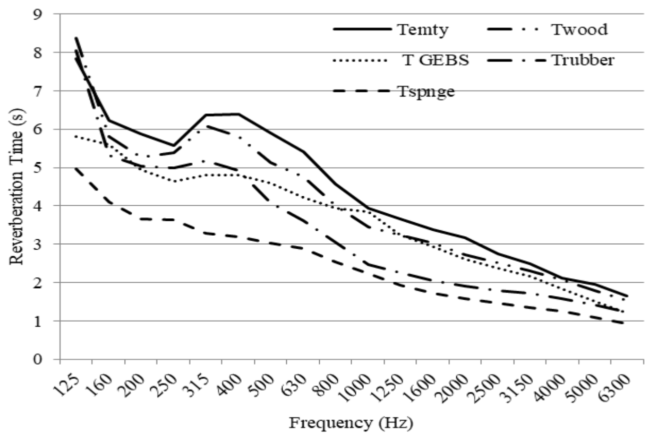

Figure 4: Reverberation time of: empty room (T_E), rubber (T_R), wood (T_w), Gypsum (T_G) and sponge (T_s)

In Figure 5, appears the equivalent sound absorption area of the empty reverberation room calculated from sabine (A_{mE}) and the inferred total absorption area (A_{cE}) from (equation 12). From comparing between the two curves we noticed that, there is almost no noticeable difference between the absorption area of empty room calculated from sabine (AmE) and the inferred total absorption area (AcE) from (equation 12), meaning that the inferred equation are valid between them. So that, they almost have the same values for the sound absorption coefficient of them (αmE and αcE) as in figure 8. Figure 6 illustrates this. At frequencies lower than 315Hz, the equivalent absorption area A_{ms} of sponge measured in the room using sabine and the inferred absorption area A_{cs} obtained from the inferred (Equ.12) for sponge are quite near to each other. In the frequency range less than 315 Hz, the difference in sponge absorption area measured by the two methods A_{mS} and A_{cS} is minor, but for frequencies above 2500 Hz, the difference surpasses 1 m^2. The difference in sponge absorption area between 315Hz and 2500Hz reaches a maximum value of 5m^2 for frequency bands between 315Hz to 2500Hz. While the difference in absorption area calculated by the two methods A_{mG} and A_{cG} reaches a maximum value of 2m^2 in the absorption area of gypsum.

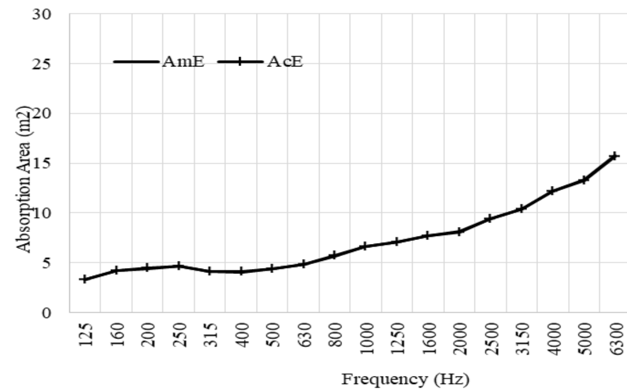

Figure 5: Eequivalent sound absorption area of empty room A_{mE} and A_{cE}

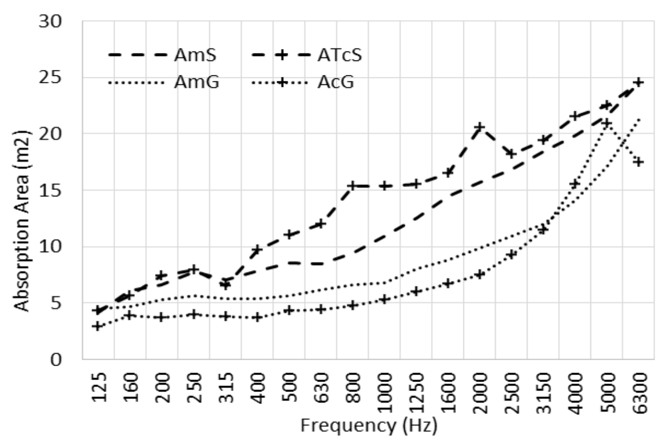

Figure 6: Eequivalent sound absorption area of Sponge A_{mS} , A_{cS}, and for Gypsum, A_{cG}, A_{mG}. .

The equivalent absorption area of wood A_{mw} represented in figure 7, was measured in the room using sabine, and the sound absorption area A_{cw} inferred from (equation 12) for wood were identical, meaning that, Equation 12 was valid for A. Looking at, we find that there is a small difference for absorption area of wood between A_{mw} and A_{cw} during all the frequency range between 125 to 6300 Hz, meaning that the equations are almost true during all the frequency range. While in absorption area of rubber there is no difference between A_{mR} and A_{cR} at frequencies less than 500 Hz while Above that, there is a difference of approximately 2m^2 between them. That is, the equation is almost correct in the frequency range less than 500Hz for rubber.

Looking at Figure 8, it is almost that there is no difference between the values of the measured sound absorption coefficient α_{mE} from sabine and the estimated sound absorption coefficient α_{cE} (from equation 12). And the difference in the sound absorption coefficient of the wall material ($\alpha_{mE} - \alpha_{cE}$) when it was empty differs by amount 10% at a frequency of 6300 Hz only, but in general the difference during all the frequency range did not exceed 5% for the absorption of the walls. α_{mE} and α_{cE} values in the range of

0.018–0.1, indicating a very low sound absorption for room surfaces. So it is possible to estimate the sound absorption coefficient (α) for all surfaces of the empty room α_{cE}. It was discovered that the values of the sound absorption coefficient for Gypsum computed α_{mG} from sabine and estimated α_{cG} (from equation 12) are more similar. The difference of ($\alpha_{mS} - \alpha_{cS}$) in highly absorbent materials (sponge) did not surpass 10% in all frequency ranges, with the exception of the frequency range between 500 and 1650Hz, when the difference grew to 50%. Through all frequencies from 125-6300Hz, the inferred sound absorption coefficient α_{cS} for sponge is larger than the sound absorption coefficient α_{ms} for sponge from sabine.

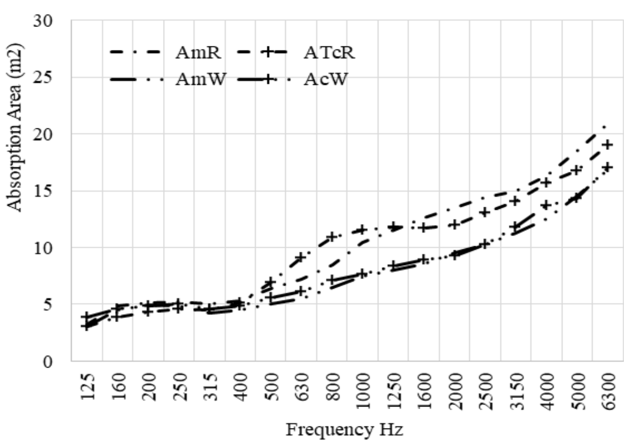

Figure 7: Equivalent sound absorption area of wood, A_{cw}, A_{mw}, and rubber A_{cR}, A_{mR}..

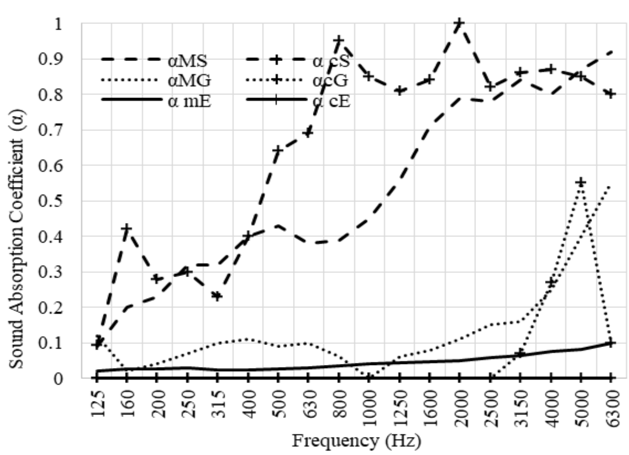

Figure 8: Sound absorption coefficient for empty room α_{mE}, α_{cE}, sponge α_{mS}, α_{cS} and for Gypsum α_{mG}, α_{cG}

When calculating the sound absorption of the wood α_{mw} by sabine method as shown in Figure 9, and compared with estimated α_{cw} that which was inferred from equation 12. The difference in the sound absorption coefficient of wood α_{mw} from sabine formula ranged from 0 up to 0.1 at 6300Hz and the estimated sound absorption coefficient α_{cw} ranged from 0 up to 0.28 at 6300Hz. Also for sound absorption calculation of the wood α_{mR}, as shown in Figure 9, and the values of the sound absorption coefficient estimated α_{cw} that which was inferred from equation 12. Appears the sound absorption coefficient of wood α_{mR} from sabine formula ranged from 0 up to 0.1 at frequency bands from 125 - 6300Hz and the estimated sound absorption coefficient α_{cR} ranged from 0 up to 0.28 at frequency bands from 125 - 6300Hz..

When comparing between the differences of the sound absorption coefficients in Figure's 8 and 9. As appear In Figure 10, the difference ($\alpha_m - \alpha_c$), between α_m (sabine) and α_c (estimated form equ.12), that for different sound absorbing materials wood (D_w), rubber (D_R), Gypsum (D_G), and sponge (D_S). The difference ($\alpha_m - \alpha_c$) for four materials nearly comparable with each other especially for frequencies lower than 1250Hz. But The difference ($\alpha_m - \alpha_c$) deviates at one or two frequencies through the frequency range up to 5000Hz which applied generally for sound absorption determination. So we can conclude that, the difference between α_c and α_m didn't depend on the material characteristics alone but also on some of the room factors (shape, diffusivity, etc..). For frequencies less than 500Hz the difference less than 0.05, for upper frequencies than 500Hz the difference increased up to 0.1, and at specified frequencies the difference deviates up to -0.2 and at other materials the difference increased up to -0.58.

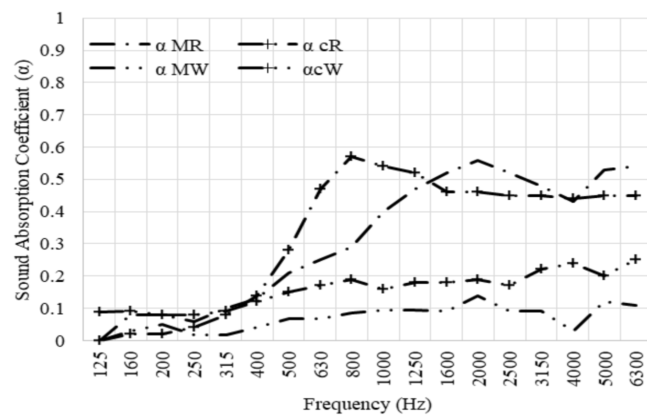

Figure 9: sound absorption coefficient for wood α_{mw}, α_{cw} and rubber α_{mR}, α_{cR}

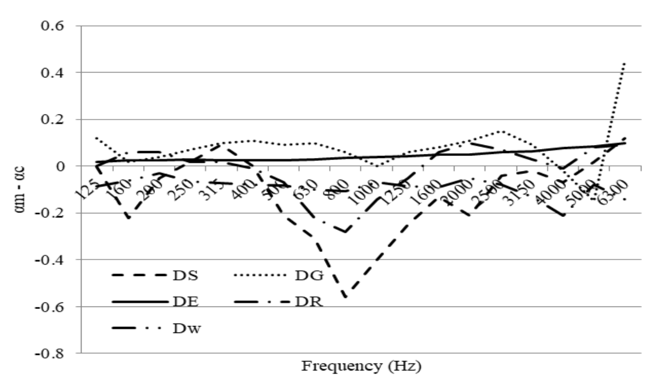

Figure 10: Difference between ($\alpha_m - \alpha_c$ =D), for S,W,R,G and E

Figure 11 appears the relative standard deviations of reverberation time measurements of different Materials (empty room, rubber, wood, Gypsum and sponge) in the reverberation room. The relative standard deviation of reverberation time of all study cases ($\mathcal{E}/T_E$, $\mathcal{E}/T_w$, $\mathcal{E}/T_R$, $\mathcal{E}/T_S$ and $\mathcal{E}/T_G$) is equal to 0.00 to 0.03.

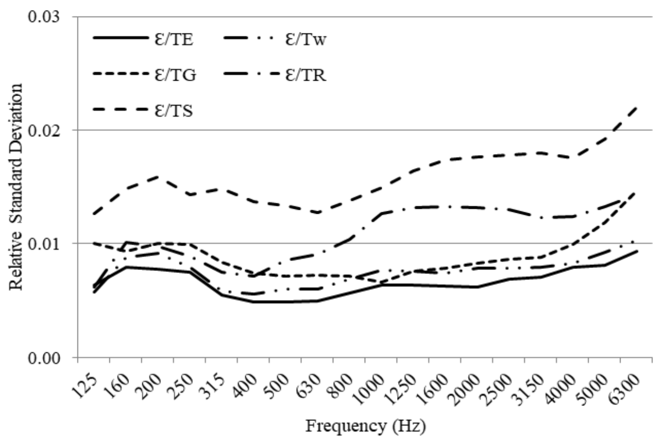

Figure 11: Relative standard deviation of (T) for empty room and different materials ($\mathcal{E}/T_E$, $\mathcal{E}/T_w$, $\mathcal{E}/T_G$, $\mathcal{E}/T_R$ and $\mathcal{E}/T_S$).

6. CONCLUSION

There is no noticeable difference obtained between equivalent sound absorption area from sabine and equivalent sound absorption area from inferred formula (A_m and A_c) for wood and room walls material, and the method is valid. But for other materials like sponge, Gypsum, and rubber there is a difference between them.

The graph shows the equation validity is clear in poorly absorbent materials such as wood, rubber, and gypsum, as if the difference in the absorption coefficients ($\alpha_m - \alpha_c$) reached a maximum of 10%, except in rubber for frequency bands between 500 Hz to 1000 Hz, the difference increased up to about 25%.

But when calculating α_m & α_c for each material that was measured in this research (Figures 7 and 8) from sponge, rubber, and wood, there is a difference between α_m & α_c at different frequencies in the frequency range from 125 Hz to 6300 Hz depends on the measured and inferred absorption area. This difference varies at different frequencies, i.e. it is not constant with all frequency bands.

In general, the difference between ($\alpha_m - \alpha_c$) for sound absorption coefficients is less than 10% for room walls materials such as Gypsum and wood. For sponge and rubber as well. At some frequencies, the difference between ($\alpha_m - \alpha_c$) is small, while at others, it fluctuates. As a result, the difference is determined by the material's qualities. However, there is a relationship between some room parameters (shape, diffusivity, etc.) and the stability of this difference when the materials change. Closer examination finds the greatest similarity between the two systems for equivalent sound absorption area in all frequency bands from 125 to 6300Hz (A).

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