Deviations in Sound Absorption Measurements in The Reverberation Room and Impedance Tube

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Abstract

This paper compares two main methods for measuring sound absorption coefficients for different materials. Chemical and physical properties of the materials studied are vastly different (Carpet, Rockwool, polyurethane foam, Gypsum, Rubber, Polyurethane sponge and wood). The impedance tube method and the reverberation room method were used to conduct the tests. To accentuate the difference between the two measurement methods, the study included weakly, median and high absorbing materials. The results shows that, the effect of source's location and the sample position angle on the sound absorption of the material in the room, also the sound absorption coefficient measured in the impedance tube is higher than that measured in the reverberation room by an amount reach 40% for both rockwool and Polyurethane sponge (porous materials). While sound absorption coefficients for hard (non-porous) materials (Gypsum and wood) are roughly identical to those for solid materials, the sound absorption coefficient measured in the impedance tube is higher than that obtained in the reverberation room. The sound absorption coefficient measured in the reverberation room for median absorbing materials as rubber and polyurethane foam (materials with internal holes and non-porous surface) is higher than that measured in the impedance tube except at minor frequencies. The relative standard deviation in the reverberation room ranged from 0.01 to 0.035.

Keywords: Sound absorption coefficient, Impedance tube, Reverberation room, Absorbing material.

1. Introduction

Gabrialo [1] extracted from the experience on another model of the tube; and there is a difference in the results. There is a variation in the results when compared to the experience with another model of tube. The experiment should be studied and repeated with the solid surface of the tube's end and holders, as well as the test sample and microphone placements, changed. The absorption qualities of porous materials are consistent with the curves' behaviour.

Also, the absorption coefficient is higher at high frequencies than at low frequencies. Many factors affect the estimation of the absorption coefficient of materials, according to Gabrialo, including how to insert the test sample, average microphone measurements, sample holder and position, as well as the hardness of the reflecting surface at the tube's end. Arunkumar and Jeyanthi [2] attempted to obtain a low-cost tube and conducted the test and comparison using a wooden sample. The initial experimental test was conducted on ammonium foil, followed by tests on the wooden sample and finally, verification tests on the reference sample. They also offered a detailed concept for measuring the material's sound absorption coefficient and dealing with mechanical and electrical components to cut costs. The tube's length, diameter, and material, as well as the sample size and microphone's placements, were all changed. Toyoda et al. [3] used a simulation program to calculate the sound absorption coefficient in the reverberation room based on the geometric of the sound. They confirmed that the sample's absorption coefficient varies depending on the room's shape, reverberation time, and dispersions. Pavel Drabek [4] in his research dealt with a comparison between the reverberation time curves for the different positions. He noted the presence of differences between them, that was attributed to the lack of homogeneous sound distribution in the room, which causes the decay of non-convergent from one place to another. This is considered important for acoustics laboratories that require high accuracy in measurements in a wide frequency range. He emphasized the importance of knowing the frequency range in which sound is adequately spread throughout the room, as well as the fact that standards do not always correspond to the reality of building materials, proportions, shape, and surfaces, making it difficult to fully match standards and reality. Oldfield [5] was concerned with the development of a novel tube for low-frequency measurements in order to investigate the influence of surface resistance. It was designed in a vertical format with a frequency range of 17 to 500 Hz. He was advised to consider the influence of tube thickness on background noise while utilizing thick materials and a sound level of 137 dB to reduce background noise. The positions of the sound source, according to Cops [6] may alter the values of the reverberation time, and thus the values of the sound absorption coefficient in the reverberation room. Cops noted that diffusers are required to get the best sound dispersal in the reverberation room, and that they followed the ISO 354 criteria in inserting Rockwool as an absorbent material in the room, with diffusers in the bottom four corners. According to Mathew [7], the absorption coefficient values are influenced by the method of installation, thickness, flow resistance, and density, and the material's absorption coefficient varies depending on the method of measurement. The tests were taken in the reverberation room and with the impedance tube, using 28 samples of polyester material with varying densities, thicknesses, and flow resistance. He devised a formula for translating sound absorption coefficients obtained in the impedance tube to those measured in the reverberation room. Hu [8] stated that reproducing the same results for the sample is challenging even when using the same criteria, such as how to cut the and how to put the sample in the tube. He also takes into account the influence of uncertainty, as the sound absorption coefficient is low at low frequencies and large at higher frequencies. It is vital to perform the test repeatability and carefully regulate the sample size in order to reduce uncertainty. According to Amadasi [9], in order to maintain measurement accuracy, it is necessary to pay attention to the composition of the test sample and measurement repeatability, as well as to humidity and temperature, as well as how to cut the sample, as irregular cutting of the same material causes a change in the value of its absorption coefficient, and also taking into account the absence of spaces on its side or behind. Niresh [10] modified the impedance tube and measured sound absorption on polyurethane materials and felt cotton in the modified and original tubes, calculating the measurement error and finding that the error rate in the modified tube is considerable at frequencies less than 200 Hz. Also, Niresh [11] proposed a measurement system based on different porosity textile materials, concluding that tube errors are caused by internal tube parts, errors in how the sample is placed or in relation to the microphones, distortion of the sound from the source, and external errors such as defects that may affect the operation of the devices attached to the circuit. The effect of the measurement devices on the tube's functioning is produced by a variety of factors, including tube weakness, vibration, ambient conditions, and operational errors.

2. Research Methodology

2.1. Reverberation room method

In a random sound incidence diffuse field, the reverberation room method is the most common method for estimating the sound absorption coefficient of a material. The sound absorption coefficient measurements in a reverberation room were performed using ISO 354: 2006 [12] and Sabine's (1922) formula. The measurements of reverberation time in the room were based on a comparison of the reverberation time of an empty room with and without sample material. The sample area ranged from 10 m² to 12 m² in the National Institute of Standards (NIS) reverberation room of total size 159 m^3 and total surface area 177.7, with unequal room dimensions and nonparallel walls.
The reverberation time T_E measured, using ISO 354: 2006, for the empty reverberation room with four sound source locations A, B, C and D. At each location of them, six microphone positions taken to measure the reverberation time. Using an omnidirectional sound source type 4296 B &K at a height 1.5 m from the room floor at room corners. The microphone heights was 1.5 m, with spacing 1.8m between each position. Using Sabine formula of reverberation times T_E and T_2 [12].

$$A_T = A_2 - A_1 = 55.3V\left[\frac{1}{C_2T_2} - \frac{1}{C_1T_E}\right] - 4V(m_2 - m_1)$$

For constant temperature t, $C_1 = C_2 = C$ so,

$$C = (331+0.6\ t)\ \text{m/s}$$

Where C : speed of sound at constant temperature t,
T_E: reverberation time of the room without sample,
T_2: reverberation time of the room with sample,
A: equivalent sound absorption area
Power attenuation coefficient m_1 and m_2, can be calculated from the attenuation coefficient

$$A = \left[\frac{55.3\ V}{C}\right]\left[\frac{1}{T_2} - \frac{1}{T_E}\right]$$

A= α * s, where α, total absorption coefficient of the room surfaces, s; surface area.

Specification of the used materials are listed in Table 1.

Table 1. Materials specification.

Material	Area m^2	Thickness m	Density kg/m^3	Air-permeability $cm^3/cm^2.s$
Carpet	14	0.005	257.63	33
Rockwool	13	0.054	120.35	85
Polyurethane foam	12	0.043	10.70	40
Gyps	13	0.016	712.95	18
Rubber	12	0.027	50.71	0.7
Polyurethane sponge	11.5	0.047	19.50	148
Wood	10.5	0.016	582.00	0.0

- *Repeatability of measured reverberation time*

The relative standard deviation [$\mathcal{E}T_{20}/T$] of the reverberation time T_{20}, can be estimated by the following formula:

$$\frac{\mathcal{E}(T20)}{T} = \sqrt{\frac{2.42 + 3,59\ /N}{f * T}}$$

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

2.2. Impedance tube method

The sound absorption measurements use the impedance tube method to determine the normal incidence absorption coefficient, as described by ISO10534-1 or ISO- 10534-2 [13]. B&K impedance tube type 4206, with accompanying devices, multichannel analyzer type 3550 and power amplifier type 2706, were used for measurements carried out. The measurement tube consists of a sound source at one end in a rigid walled tube, and the under test sample of absorbing material at the other end with two ¼" microphone.

3. Results and Discussion

Fig. 1 depicts the behavior of the Polyurethane sponge's sound absorption coefficient in both the impedance tube α_{st} and the reverberation room α_{sr}. The values of the sound absorption coefficient measured in the impedance tube at all frequencies are clearly higher than those measured in the reverberation room. The of difference between them reaches 20% at frequencies lower than 500 Hz, while for frequencies bands higher than 500Hz the difference between them reaches 40% with an increase in the absorption coefficient measured in the impedance tube than that measured in the reverberation room up to 5000Hz. The sound absorption increased in proportion to the frequency, with the highest values appearing at high frequencies, proving the principles of sound absorption in porous materials in the high-frequency region. In both the impedance tube α_{kt} and the reverberation chamber α_{kr}, the behavior of the sound absorption coefficient of rock wool is substantially identical, as shown in Fig. 1. There is a slight increase in the values of the absorption coefficient in the impedance tube α_{kt} rather than that measured in the reverberation room α_{kr}, especially for frequencies lower than 500Hz. For higher frequencies than 500Hz, the sound absorption coefficient that measured in the impedance tube has higher than that measured in reverberation room by 35%. Rock wool sound absorption appears at high frequencies as sound absorption in porous materials in high frequency range.

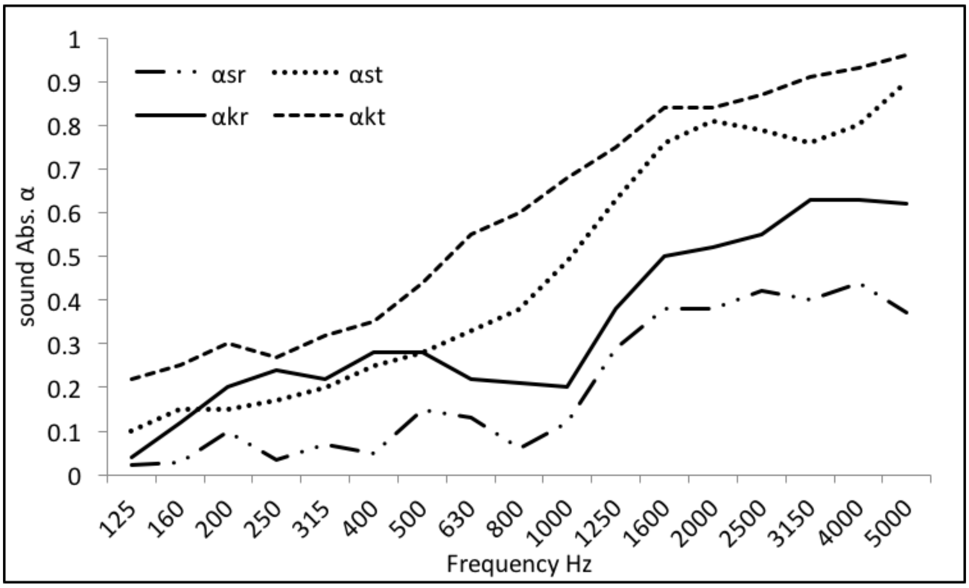

Fig.1. Polyurethane sponge and rock wool sound absorption α_{sr} , α_{kr} in a reverberation room and sound absorption α_{st} in an impedance tube.

Fig. 2 represents the sound absorption coefficient behaviour of the polyurethane foam in both the impedance tube α_{ft} as well as in the reverberation chamber α_{fr}. It is clear that there is an increase in the values of sound absorption coefficient in the reverberation chamber α_{fr} than that measured in the impedance tube nearly at all. In the low-frequency range below 800Hz, the difference exceeds 10%, and in the frequency range from 800 to 5000Hz, the difference approaches 30% with an increase in the absorption coefficient measured in the reverberation room over that measured in the impedance tube. A peak emerged at 630Hz with sound absorption in the tube due to the non-uniformity of cutting polyurethane foam, which generates air space. Rubber has the same sound absorption coefficient behaviour in both the impedance tube α_{bt} and the reverberation chamber α_{br}. It is clear that for rubber, there is an increase in the values of the sound absorption coefficient in the reverberation chamber than that measured in the impedance tube at frequencies lower than 1000Hz. The sound absorption coefficient of rubber in the impedance tube α_{bt} increases more than that in the reverberation chamber α_{br} in the frequency range 1000Hz to 2000Hz, with a difference of up to 30% between them. The absorption coefficient in the room is higher than that recorded in the tube at frequencies greater than 2000Hz to 5000Hz, by up to 25%.

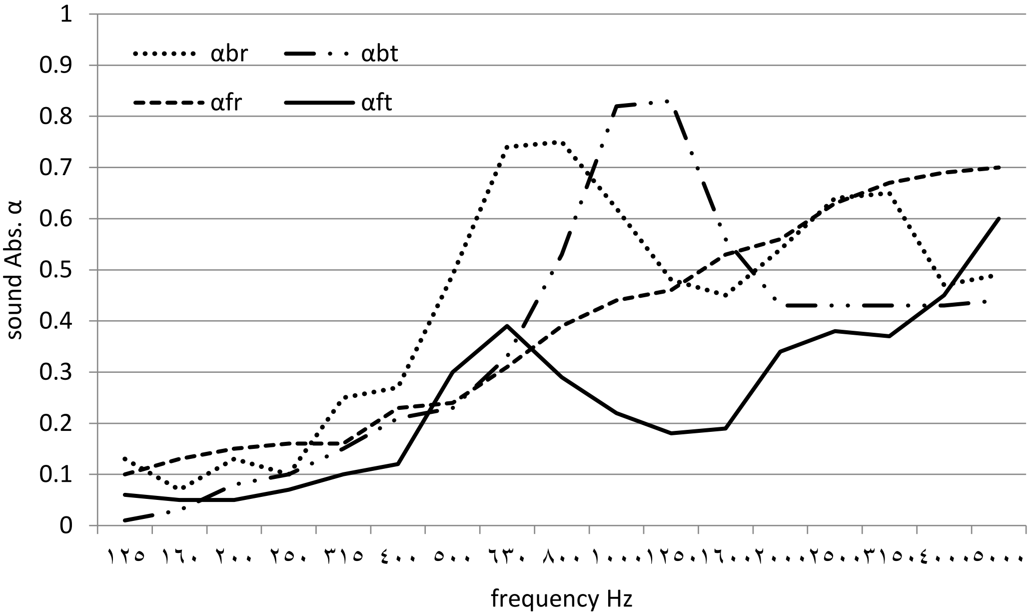

Fig. 2. Polyurethane foam and rubber sound absorption α_{fr}, α_{br} in a reverberation room and sound absorption α_{ft} in an impedance tube.

Fig. 3 shows the behavior of the sound absorption coefficient of wood in both the impedance tube α_{wt} as well as in the reverberation room α_{wr}. In general, there is an increase in the values of the sound absorption coefficient measured in the impedance tube than that measured in the reverberation room at all frequency bands. The disparity between them was enhanced by 10% for frequencies lower than 1250Hz. The difference between them gradually rose above 1250Hz, while the difference between the sound absorption coefficient measured by the tube and that measured in the room increased by up to 35% for frequencies higher than 1600Hz to 5000Hz. A peak appears at 3150Hz with considerable absorption in the tube due to non-uniformity of cutting wood, which generates air space. The behavior of the sound absorption coefficient of gypsum boards in both the impedance tube α_{Gt} as well as in the reverberation room α_{Gr}. The values of the sound absorption coefficient α_{Gt} in the impedance tube are clearly higher than those measured in the reverberation chamber α_{Gr}. The variation in sound absorption ratings between frequency bands 125 and 630Hz is less than 5%. While the sound absorption coefficient in the impedance tube was higher than that observed in the reverberation room by up to 30% at frequencies higher than 800 to 2000Hz, the sound absorption coefficient in the reverberation room gradually declined above 2000Hz. The difference decreased between them after frequency 2000Hz to reaches about 5%. Due to non-uniformity of cutting gypsum which causes air space, a peak appeared at 1250Hz with high absorption in the tube.

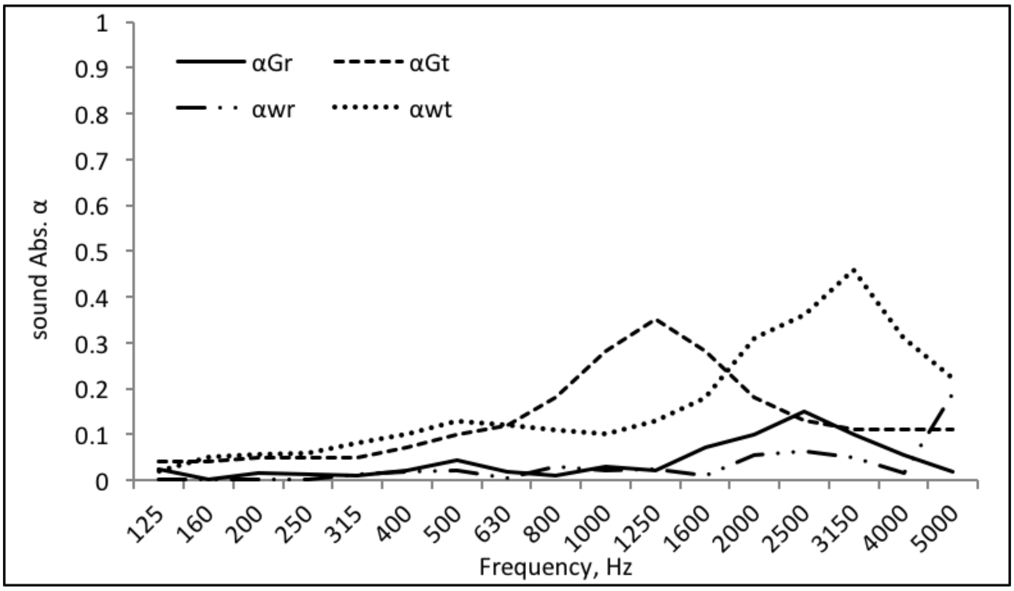

Fig. 3. Wood and gypsum sound absorption α_{Wr}, α_{Gr} in a reverberation room and sound absorption α_{Wt} in an impedance tube.

Fig. 4 shows the behavior of the sound absorption coefficient of the carpet in both the impedance tube α_{Ct} as well as in the reverberation room α_{Cr}. At frequencies ranging from 125 to 1250 Hz, it is obvious that the absorption coefficient obtained in the impedance tube differs from that measured in the reverberation chamber. The discrepancy between them reaches roughly 7% for frequencies above 1250 to 5000 Hz, while the difference between the absorption coefficient measured in the tube and the absorption coefficient measured in the room can reach up to 50% for frequencies above 1250 to 5000 Hz.

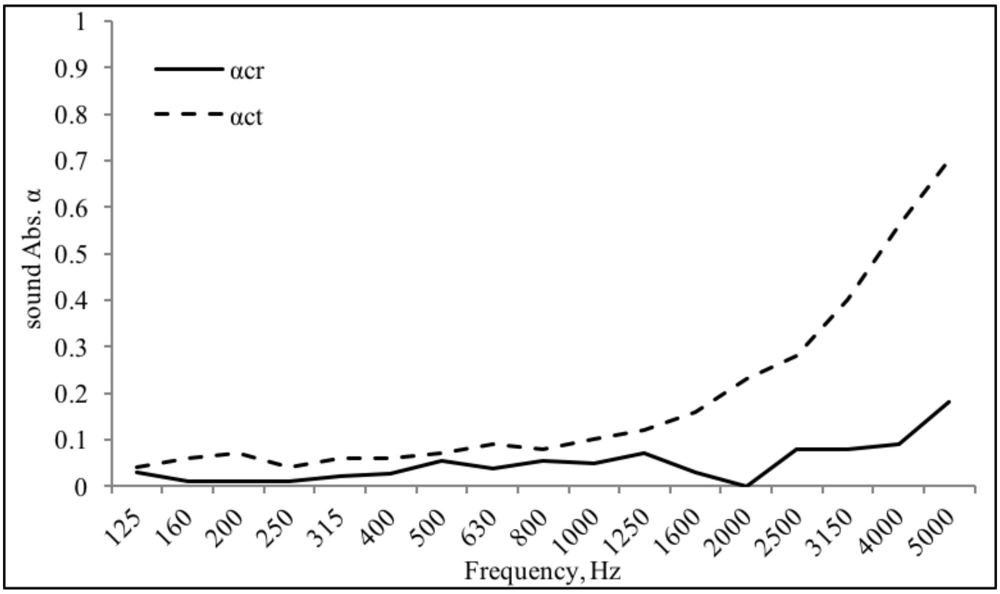

Fig. 4. Carpet sound absorption α_{Cr} in a reverberation room and sound absorption α_{Ct} in impedance tube.

Fig. 5 shows the difference between the values of the sound absorption coefficient measured in the reverberation room α_r and that measured by the impedance tube α_t of the seven different materials (αr-αt)s, (αr-αt)k, (αr-αt)f, (αr-αt)w, (αr-αt)c, (αr-αt)B and (αr-αt)G at frequencies from 125 to 5000 Hz. It is clear that the majority of the difference are conducted to the increase in the absorption coefficient measured in impedance tube than that measured in the reberberation room.

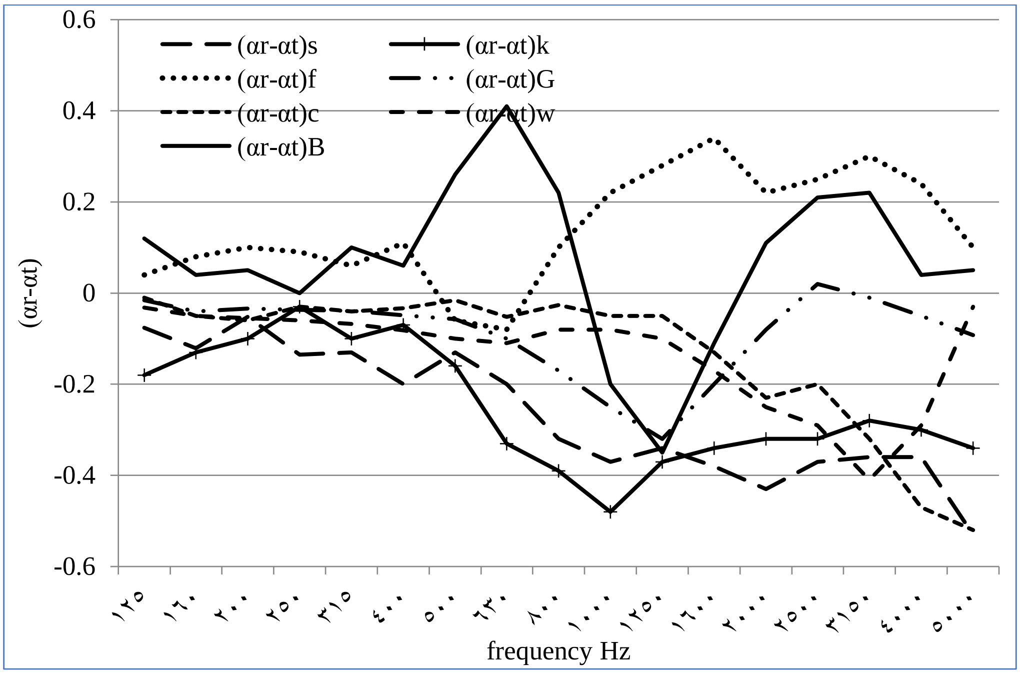

Fig. 5. Difference between sound absorption measurements in a reverberation room and sound absorption measurements in an impedance tube (αr-αt).

3.1. The reverberation time of different Materials

Fig. 6 shows the averaging reverberation time behaviour of different materials when measured in the reverberation room. The empty room reverberation time T_E represents the highest curve in Fig. 6. The poor sound absorption materials, such as gypsum reverberation time, T_G, wood reverberation time T_w, and carpet reverberation time T_b, are represented by high reverberation time values. The reverberation time of the room reduced as the sound absorption coefficient increased (Rockwool T_k, Polyurethane sponge T_S and Polyurethane foam T_f).

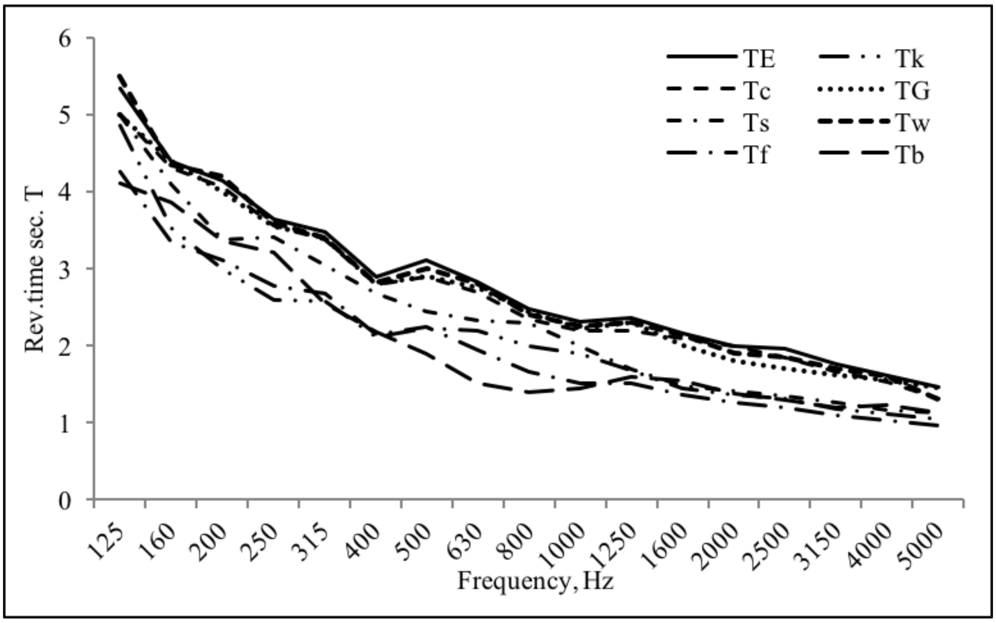

Fig. 6. Reverberation time (T) of different materials.

3.2 Influence of sample orientation angle in the reverberation room

In Fig. 7 shows the changing in the Polyurethane sponge sample orientation angle from 15^0 up to 180^0 on the reverberation room floor. Two sound source locations A and B were taken at two corners of the room. The averaging of reverberation times measurements was taken for each angle separately, with and without the absorbing material at different angles from 15^0 up to 180^0. As a result, the sound absorption coefficient of the material at specified angle $\alpha AB15^0$, $\alpha AB30^0$, $\alpha AB45^0$, $\alpha AB60^0$, $\alpha AB75^0$, $\alpha AB90^0$, $\alpha AB105^0$, $\alpha AB120^0$, $\alpha AB135^0$, $\alpha AB150^0$, $\alpha AB165^0$ and $\alpha AB180^0$, has to be evaluated and represented in Fig. 7. The maximum deviation in sound absorption coefficient of sponge due to orientation angle change are about 5% for frequencies lower than 315Hz and for higher than 2000Hz also. At frequency range from 315 to 1250Hz the maximum deviation are about 15% at 800Hz.

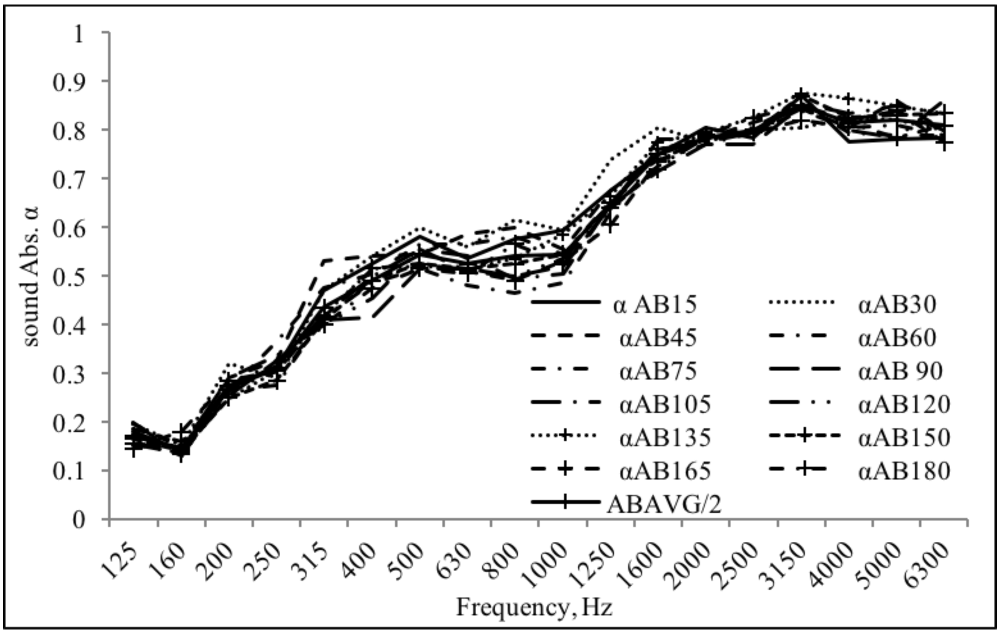

Fig. 7. The averaged sound absorption coefficient of Polyurethane sponge for all angles ranged from 15^0 up to 180^0 with sound source positioned at A and B.

3.3. Effect of sound source location on the sound absorption coefficient of the sample

Fig. 8 shows the effect of four sound source locations A, B, C, and D on Polyurethane sponge sound absorption. Reverberation time measurements were carried out with and without the absorbing material in the reverberation room. The material sound absorption coefficient at a certain angle must be determined, and the experimental results must be thoroughly studied. More measurements, including more samples of various materials, are required for the experiment. Fig. 8 depicts the values of the Polyurethane sponge's sound absorption coefficient when it is positioned at an angle of 15^0 with different sound source locations A, B, C, and D in relation to the sample's placement in the reverberation room. It is obvious that there is a difference in the values and behaviour of the sound absorption coefficient due to the effect of the sound source location relative to the sample position. During the frequency range of 125 to 6300 Hz, the difference resulting from this impact reached a value of roughly 7%.

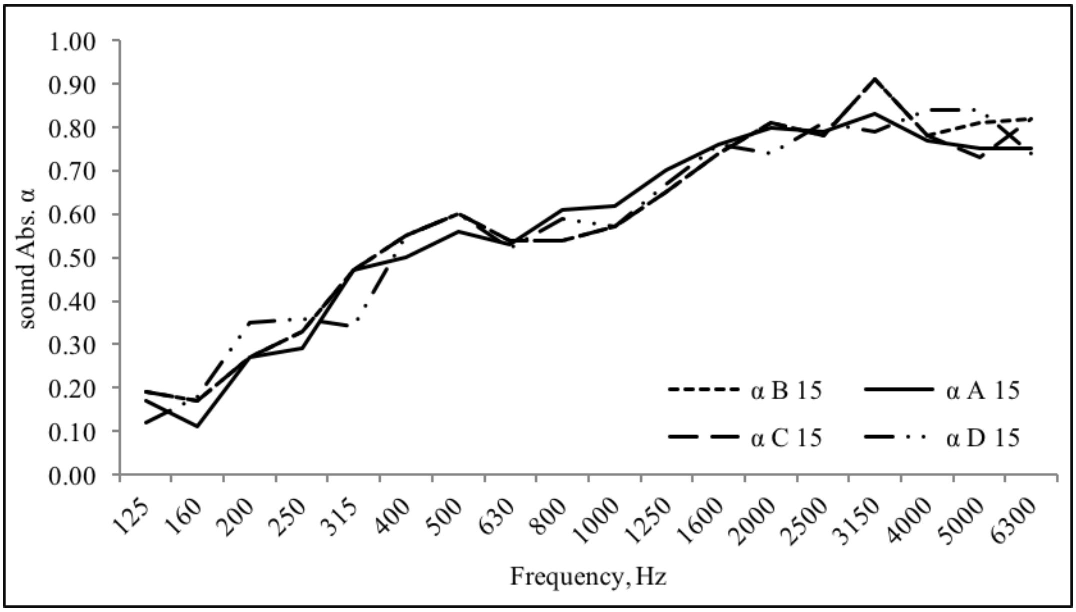

Fig. 8. Shows the effect of source locations A, B, C and D on the sound absorption coefficient of Polyurethane sponge at 15^0.

Fig. 9 shows the relative standard deviation of reverberation time measurements of different materials in the reverberation room. The highest curve in Fig. 9 is the relative standard deviation of rubber reverberation time ƐTb/Tb. The region between frequencies 630Hz and 1600 Hz, where the relative standard deviation increases, demonstrates a departure from the regular behaviour of rubber reverberation time measurements. Respectively the poor sound absorbing materials represented by a low relative standard deviation values 0.01to 0.015 of reverberation time measurements of empty, wood, carpet and Gypsum $ƐT_E/T_E$, $ƐT_w/T_w$, $ƐT_C/T_C$ and $ƐT_G/T_G$. The relative standard deviation of reverberation time measurements of polyurethane sponge, rubber, polyurethane foam and Rockwool $ƐT_s/T_s$, $ƐT_b/T_b$, $ƐT_f/T_f$ and $ƐT_k/T_k$ are in range from 0.015 to 0.025.

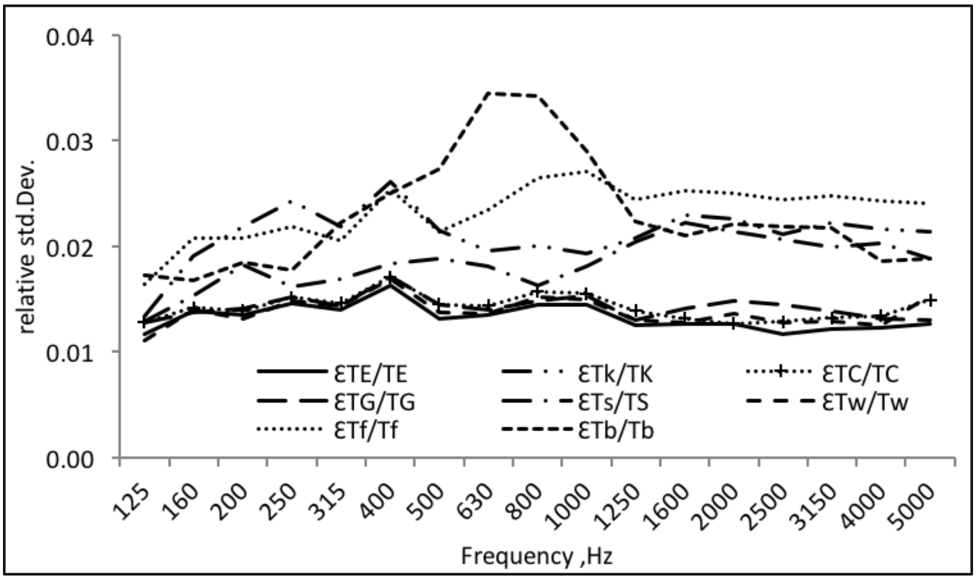

Fig. 9. Relative standard deviation of reverberation time measurements of different materials.

4. Conclusion

The installation of the test specimen, sample orientation angles (15^0:180^0), and sound source locations are both factors that can influence this estimation and should be investigated more in the future. At frequencies less than 400 Hz, the difference in measuring the sound absorption coefficient by the two approaches varied from -20% to +10%, while at frequencies higher than 400 Hz, the difference between the two methods ranged from -50% to +40%, depending on the material specifications. Also demonstrated the influence of the source's position on the material's sound absorption at various angles for placement in the room. During the frequency range of 125 to 5000Hz, the relative standard deviation of the reverberation time measurements in the room ranged from 0.01 to 0.035. The difference between the two methods was most noticeable in large thickness materials like Rockwool and sponge, where small thickness materials (0.005m:0.016m, Carpet, Gypsum, and wood high-density materials) had higher sound absorption coefficient values in impedance tube than reverberation room measurements across the entire frequency range. Due to the non-uniformity of cutting solid materials like wood, Gypsum, and polyurethane foam which causes air space, a peak appeared at 1250 Hz with high absorption in the tube. The fake absorption is caused by the cutting procedure and the occurrence of a space. On the other hand, the thickness effect of porous materials (Rockwool and sponge) with a large thickness causes an increase in the sound absorption curve in impedance tube measurements, especially at high frequencies. The sound absorption measurement in the room, on the other hand, had an extremely low result across the whole frequency range.

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References

[1] Gabriela Cristina Cândido da Silva et al, design and Construction of a Low Cost Impedance Tube for Sound Absorption Coefficients Measurements, 22nd International Congress of Mechanical Engineering (COBEM), Ribeirão Preto, SP, Brazil November 3-7, pp. 105-115 (2013).

[2] Arunkumar B. and Jeyanthi S., Design and Analysis of Impedance Tube for Sound Absorption Measurement, ARPN Journal of Engineering and Applied Sciences, Vol. 12(5),pp.1400-1405 (2017).

[3] Emi Toyoda, Shinichi Sakamoto and Hideki Tachibana, Effects of room shape and diffusing treatment on the measurement of sound absorption coefficient in a reverberation room, Journal of Acoust. Sci. & Tech., Vol. **25** (4) pp. 255-266 (2004).

[4] Pavel Drabek and Martin Zalesak, Reverberation chamber and its verification for acoustic measurements, MATEC Web of Conferences, Vol. 76, pp.1-5 (2016).

[5] Oldfield R and Bechwati F., Accurate Low Frequency Impedance Tube Measurements, Proceedings of the Institute of Acoustics, Vol. 30, Pt 4 (2008).

[6] Cops A., Vanhaecht J. and Leppens K., Sound Absorption in a Reverberation Room: Causes of Discrepancies on Measurement Results, j. Applied Acoustics Vol. 46 (21), pp. 215-232 (1995).

[7] Mathew McGrory, Daniel Castro Cirac, Olivier Gaussen and Densil Cabrera, Sound absorption coefficient measurement: Re-examining the relationship between impedance tube and reverberant room methods, Proceedings of Acoustics, Fremantle, pp.1-8 (2012).

[8] Hua X. and Herrin D. W., Reducing the Uncertainty of Sound Absorption Measurements Using the Impedance Tube Method, DOI: 10.4271/2013-01-1965, SAE International, 2013-01-1965 (2013).

[9] Amadasi G., Fulfill requirements of ISO 10534-2 and ASTM E1050 ISO 10534 Hints and Reliability, Application Note: AN9020B-02 (2015).

[10] Niresh J., Neelakrishnan S., Subha Rani and Shylendran R., An Investigation of Sound Absorbing Material in Modified Impedance Tube, IJSDR Vol.1(5), pp.249-253 (2016).

[11] Niresh J., Neelakrishnan S., Subha Rani, Investigation and correction of error in impedance tube using intelligent techniques, j.Applied Research and Technology, Vol.,14, pp. 405–414 (2016).

[12] 12-ISO 354:2006, Acoustics — Measurement of sound absorption in a reverberation room.

[13] 13-ISO 10534-2: 1998, Acoustics —Determination of sound absorption coefficient and impedance in impedance tube.