Estimation and Determination Correction for the Area Effect of the Sound Absorber Material

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Abstract: A method of predicting the area effect of absorbent surface with finite dimensions is introduced using least square fitting method. The measured value of sound absorption coefficient for any area of the absorbing material can be corrected to be like that of the absorption of standardized area. This is obtained from the estimated equations at each frequency. In order to obtain these corrections, some experiments are carried out in a reverberation room using different absorber materials with different areas such as carpet, sponge, foam and polyisoprene.

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1. Introduction:

The sound absorption properties of materials is an essential tool of noise control specialists, whether choosing materials for the insulation of buildings and ductwork, designing theatres and concert halls, planning roadway noise barriers or controlling source noise(1).

There are currently two main methods of performing absorption type measurements - impedance tube testing using the standing wave ratio or two-microphone method and reverberation room testing. The sound absorption of material depends on frequency and the angle of sound incidence. In application relating to building acoustics and industrial noise control sound may arrive at any angle i.e. random incidence; in most cases reflections and reverberation will result in sound incidence in all angles simultaneously. So that determination the sound absorption coefficient in reverberation room gives the actual and reliable value.

In random incidence, sound absorption coefficient increases when the dimensions of an absorbent surface become as small as the dimension of wavelength. This phenomenon is usually referred to as area effect, and it becomes evident when the absorption coefficient is large. This phenomenon occurs due to edge effect, which includes diffraction or scattering at the edge of the absorbent surface (2). Kimihiro Sakagami and others (3) explained that the edge effect is considered if the absorber is rather small.

The reflection coefficient decreases when the angle of incidence on the material surface increases, consequently the absorption coefficient increases (4). As the surface area of material is larger, it has more probability to be exposed to sound waves of larger angle. So that when the material is larger in surface area, it must have higher sound absorption, but the opposite behavior is done i.e. the larger the surface area the smaller the absorption coefficient. This contrast is due to the edge effect of the material (5), which indicates that this effect is more effective than the incidence angle effect.

ISO 354(6) is used to determine the absorption coefficient of material in reverberation room makes a condition to the standardized area of material to be measured between $10m^2$ and $12m^2$ for room of volume less than $200m^3$, and if the volume is greater than $200m^3$ the standardized area will be increased by factor of $(V/200m^3)^{2/3}$, This condition causes a restricted application in practice. In this paper estimated equations of the area effect and corrections between the non scandalized areas and the standardized area by using a least squares fit method are introduced.

In the present study, different materials with different areas were measured in reverberation room. We measured absorption coefficient of foam, rubber, carpet and sponge. The purpose is to make the measured value of sound absorption coefficient for any area of the absorbing material corrected to be like that of the absorption of standardized area. This is obtained from the estimated equations at each frequency.

2. Experimental Work:

In order to verify the effectiveness of an introduced method, four materials of different areas are used to determine the sound absorption coefficient (%), the following table gives their properties:

material	Density (kg/m^3)	Thickness (m)	Area (m^2)
carpet	154	0.004	2,4,6,8,10,12 and 14
foam	16	0.050	2,4,6,8,10,12 and 14
sponge	14	0.011	2,4,6,8,10,12 and 14
polyisoprene	100	0.005	2,4,6,8,10,12 and 14

Using loud speaker, which is omni-power sound source type 4296 B&K, power amplifier type 2716 B&K and sound analyzer type 2260 B&K, these materials are measured in the reverberation room in the national institute for standards (NIS). The reverberation room used for the measurements has a volume of $160m^3$. Set up, instrumentation and method of measurements are carried out according to ISO 354(6). All the measurements are carried over the interested frequency range from 125 Hz to 5000 Hz. In this method, the effect of the sample on time rate of the sound decay in the room at each frequency is observed and compared with that of time rate of sound decay of room without the sample at the same frequency. From these comparative tests, the absorption coefficient is calculated for the sample at a specified frequency, according to the following equation, the random incidence sound absorption coefficient was determined (6):

$$\alpha = \left(\frac{A_2 - A_1}{S}\right), \qquad (1)$$

Where: S is the area of specimen, m^2; A_2 is the equivalent absorption area of specimen, m^2; A_1 is the equivalent absorption area of the reverberation room without the specimen, m^2;

$$A_2 = \frac{55.3V}{cT_2} - 4Vm_2, \qquad (2)$$

$$A_1 = \frac{55.3V}{cT_1} - 4Vm_1, \qquad (3)$$

Where: V is the volume of reverberation room, m^3; T_2 and T_1 are the accordingly reverberation time in the reverberation room with specimen and without specimen; m_1 and m_2 are the power attenuation coefficient in m^{-1} calculated according to ISO 9613-1 (7), using the climatic condition that have been present in the reverberation room with and without the test specimen; c_2 and c_1 are the sound speed in air in the reverberation room with and without the test specimen.

$$m = \frac{\alpha_c}{10 \lg(e)},$$

Where: α_c is the attenuation coefficient in decibels per meter for atmospheric condition.

3. 3- Results and Discussion:

3.1) Absorption coefficient vs area and the estimated equation

Figures 1a, 1b, 1c and 1d show the results of the measured absorption coefficient in reverberation room with different areas. These figures show approximately that at all frequencies of the sound absorption coefficient decrease as the sample areas increase, and stated that at the smallest sample area of $2m^2$, most of the results for the absorption coefficient at higher frequencies exceed unity, which is theoretically not correct. This is due to the so-called edge effect (3, 8-10); tables 1a, 1b, 1c and 1d show the estimated absorption coefficient equations which are extracted from the measured absorption coefficient data of the different areas at each frequency. Where the R–squared (R^2) value is an indicator from 0 to1 that reveals how closely the estimated values for the trend line correspond to your actual data.

3.2) Absorption area corrections

- Since our room volume is less than 200 m^3, according to ISO 354**(6)** the standardized area of material to be measured must be between $10m^2$ and $12m^2$. We considered the area of $11m^2$ is the standardized area. The correction which is given to the measured sound absorption coefficient for materials of non standardized area is the deviation between absorption coefficient value calculated from the estimated equations of standardized area and that obtained from the measured absorption coefficient value of non standardized area.

- Fig.2a shows that at low frequencies from 125Hz to 630Hz, the absorption coefficients of carpet material for all areas approximately, do not need corrections to be added to their measured values, except the absorption of area $2m^2$ which needs correction for absorption over all the frequency range.

At higher frequencies, and with larger area $14m^2$, 12 m^2 and 10 m^2, this figure indicates that these areas rather do not need corrections for absorption. While the absorption of smaller areas needs this. And for smaller areas, the measured absorption needs corrections over all frequencies.

- Fig.2b shows that, like the carpet the absorption of area $2m^2$ needs correction for absorption over all the frequency range. While larger areas $14m^2$, 12 m^2 and $10m^2$ approximately, do not need corrections approximately.

- Fig. 2c gives the same behavior of Fig.2b for foam. But the correction curve of $8m^2$ does not need corrections at lower frequencies.

- Fig. 2d gives the same behavior of Fig.2c for sponge material.

1. a) carpet material

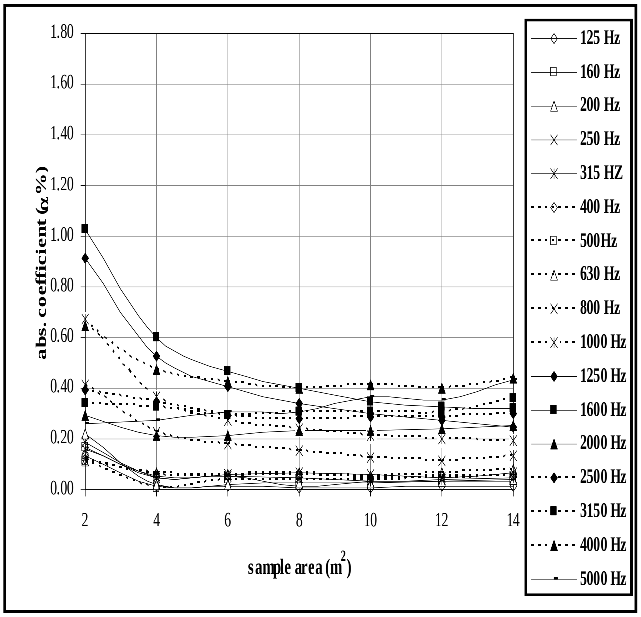

Fig.1a: variation of the measured absorption coefficients of carpet material with the area

f (Hz)	R^2	Estimated equation
125	0.7469	$\alpha = 0.0019S^2 - 0.0367S + 0.17$
160	0.8146	$\alpha = 0.002S^2 - 0.0391S + 0.2106$
200	0.6979	$\alpha = 0.0032S^2 - 0.0599S + 0.2816$
250	0.6726	$\alpha = 0.002 S^2 - 0.0387S + 0.226$
315	0.8257	$\alpha = 0.0017S^2 - 0.0349S + 0.2018$
400	0.7859	$\alpha = 0.0009S^2 - 0.0185S + 0.1405$
500	0.4275	$\alpha = 0.0013S^2 - 0.0226S + 0.1259$
630	0.8034	$\alpha = 0.0011S^2 - 0.02S + 0.1424$
800	00.952	$\alpha = 0.3827S^{-0.6499}$
1000	0.9701	$\alpha = 0.9494S^{-0.6409}$
1250	0.9938	$\alpha = 1.3771S^{-0.6617}$
1600	0.9803	$\alpha = 1.4624S^{-0.6093}$
2000	0.5764	$\alpha = 0.0014S^2 - 0.0223S + 0.3107$
2500	0.9654	$\alpha = 0.0018S^2 - 0.0353S + 0.4526$
3150	0.8420	$\alpha = 0.0014S^2 - 0.0229S + 0.3877$
4000	0.9284	$\alpha = 0.0039S^2 - 0.0764S + 0.7567$
5000	0.9368	$\alpha = 0.2335S^{0.0408S}$

Table(1a): R-squared and estimated equations of carpet material; where α is estimated absorption coefficient and S is the area

1. b) foam material

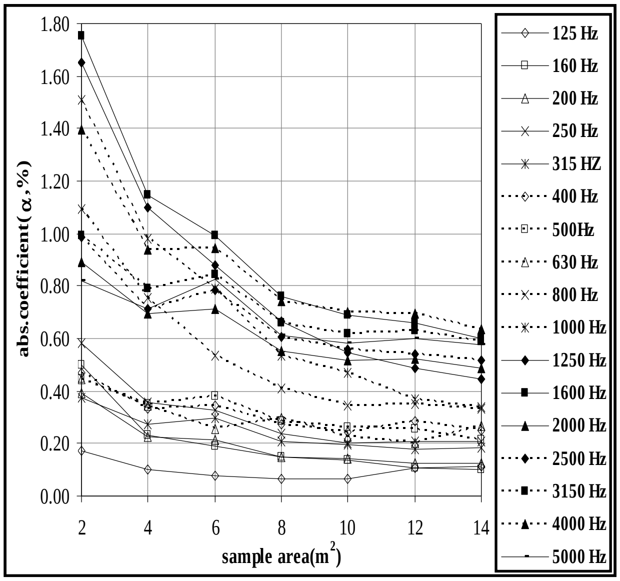

Fig.1b variation of the measured absorption coefficients of foam material with the area

f Hz)	R^2	Estimated equation
125	0.9065	$\alpha = 0.0021S^2 - 0.0374S + 0.2278$
160	0.9843	$\alpha = 0.8033S^{-0.802}$
200	0.9706	$\alpha = 0.5675S^{-0.6009}$
250	0.9551	$\alpha = 0.0042S^2 - 0.0949S + 0.7236$
315	0.9087	$\alpha = -0.0998Ln(S) + 0.4354$
400	0.8771	$\alpha = 0.0022S^2 - 0.0503S + 0.5419$
500	0.9252	$\alpha = 0.4791e^{-0.0567S}$
630	0.8895	$\alpha = 0.0028S^2 - 0.0595S + 0.5468$
800	0.9905	$\alpha = 0.0085S^2 - 0.1953S + 1.4253$
1000	0.9848	$\alpha = -0.61Ln(S) + 1.8784$
1250	0.9914	$\alpha = 2.8039S^{-0.6948}$
1600	000.99	$\alpha = 2.5371S^{-0.5535}$
2000	0.9391	$\alpha = -0.2078Ln(S) + 1.0224$
2500	0.9111	$\alpha = 1.2259S^{-0.3268}$
3150	0.8972	$\alpha = 0.0026S^2 - 0.0725S + 1.1058$
4000	00.919	$\alpha = 0.0067S^2 - 0.1605S + 1.6145$
5000	0.7193	$\alpha = 0.8558e^{-0.0311S}.$

Table (1b): R-squared and estimated equations of foam material; where α is estimated absorption coefficient and S is the area

1. c) sponge material

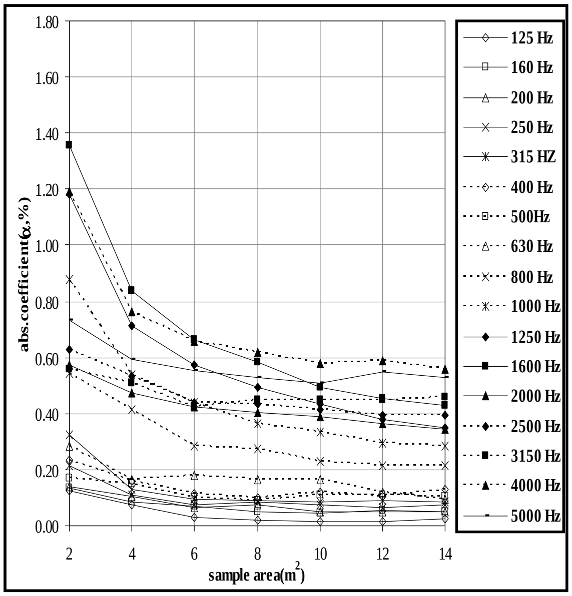

Fig.1c: variation of the measured absorption coefficients of sponge material with the area

f (Hz)	R^2	Estimated equation
125	00.982	$\alpha = 0.0016S^2 - 0.0336S + 0.1825$
160	0.9503	$\alpha = 0.0011S^2 - 0.024S + 0.1735$
200	0.9257	$\alpha = 0.0009S^2 - 0.0211S + 0.174$
250	00.869	$\alpha = 0.002S^2 - 0.0403S + 0.2656$
315	0.8442	$\alpha = 0.0034S^2 - 0.0685S + 0.4048$
400	0.9334	$\alpha = 0.0021Sx^2 - 0.0419S + 0.3006$
500	0.8464	$\alpha = 0.0011S^2 - 0.0225S + 0.2089$
630	0.8429	$\alpha = -0.0783Ln(S) + 0.3167$
800	0.9768	$\alpha = 0.0034S^2 - 0.0809S + 0.683$
1000	0.9925	$\alpha = 1.2609S^{-0.5819}$
1250	0.9965	$\alpha = 1.7548S^{-0.6154}$
1600	00.995	$\alpha = 1.9751S^{-0.5933}$
2000	0.9913	$\alpha = 0.6749S^{-0.25}$
2500	0.9706	$\alpha = 0.0025S^2 - 0.0578S + 0.7261$
3150	00.831	$\alpha = 0.002S^2 - 0.038S + 0.6196$
4000	0.9187	$\alpha = 1.3915S^{-0.3717}$
5000	0.9193	$\alpha = 0.003S^2 - 0.0611S + 0.8227$

Table (1c): R-squared and estimated equations of sponge material; where α is estimated absorption coefficient and S is the area

1. d) polyisoprene material

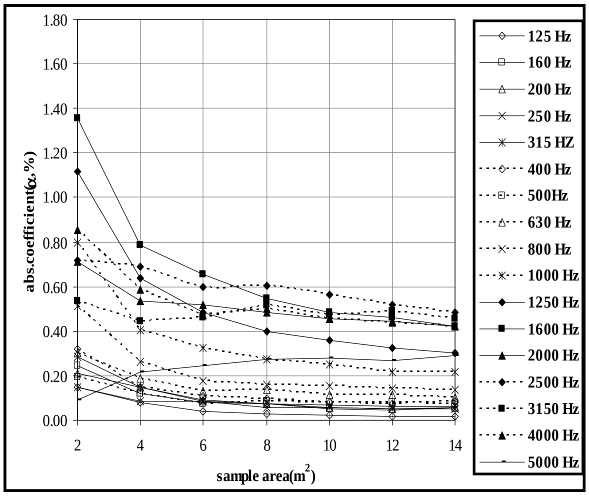

Fig.1d: variation of the measured absorption coefficients of polyisoprene material with the area

f (Hz)	R^2	Estimated equation
125	0.988	$\alpha = 0.3334S^{-1.1421}$
160	0.9472	$\alpha = 0.3958S^{-0.8264}$
200	0.9904	$\alpha = 0.0019S2 - 0.0424S + 0.2878$
250	0.9571	$\alpha = 0.1982S^{-0.5344}$
315	00.946	$\alpha = 0.4382S^{-0.7942}$
400	0.9345	$\alpha = 0.4526S^{-0.7209}$
500	0.9464	$\alpha = 0.0016S^2 - 0.033S + 0.2379$
630	0.9401	$\alpha = 0.4003S-0.5319$
800	0.9646	$\alpha = 0.7085S^{-0.6726}$
1000	0.9902	$\alpha = 1.123S^{-0.6588}$
1250	0.9855	$\alpha = 1.6713S-^{0.6672}$
1600	0.964	$\alpha = 1.9067S-^{0.585}$
2000	0.9668	$\alpha = 0.8164S^{-0.2535}$
2500	0.165	$\alpha = 0.7646e^{-0.0325S}$
3150	0.9126	$\alpha = -0.0204Ln(S) + 0.5212$
4000	0.9076	$\alpha = 1.0011S^{-0.3454}$
5000	00.988	$\alpha = -0.0022S^2 + 0.049S + 0.0244$

Table (1d): R-squared and estimated equations of polyisoprene material; where α is estimated absorption coefficient and S is the area

Hz)	Estimated absorption. of standardized area ($11m^2$)	Absorption correction of $14m^2$	Absorption correction of $12m^2$	Absorption correction of $10m^2$	Absorption correction of $8m^2$	Absorption correction of $6m^2$	Absorption correction of $4m^2$	Absorption correction of $2m^2$
125	-0.004	0.017	0.014	0.014	0.009	0.017	0.015	0.136
160	0.023	0.010	0.008	0.014	-0.006	0.028	0.025	0.141
200	0.010	0.032	0.027	0.017	0.020	0.008	0.012	0.213
250	0.042	0.026	0.004	0.015	0.022	0.020	0.005	0.148
315	0.024	0.024	0.015	0.011	0.022	0.033	0.030	0.137
400	0.046	0.006	0.010	0.002	0.016	0.008	0.017	0.074
500	0.035	0.017	0.011	0.004	0.006	0.005	-0.027	0.079
630	0.056	0.022	0.009	-0.005	0.011	0.004	0.009	0.061
800	0.050	0.030	0.043	0.072	0.102	0.149	0.332	0.050
1000	0.204	-0.013	-0.003	0.009	0.036	0.068	0.162	0.467
1250	0.282	-0.037	-0.008	0.021	0.058	0.123	0.245	0.632
1600	0.339	-0.017	-0.016	0.006	0.060	0.128	0.261	0.686
2000	0.235	0.018	0.006	-0.001	-0.001	-0.023	-0.020	0.057
2500	0.282	0.018	0.005	0.004	0.000	0.008	0.063	0.108
3150	0.305	0.053	0.002	-0.001	0.000	-0.012	0.024	0.037
4000	0.388	0.050	0.012	0.024	0.011	0.039	0.088	0.258
5000	0.366	0.067	-0.010	-0.001	-0.058	-0.057	-0.095	-0.109

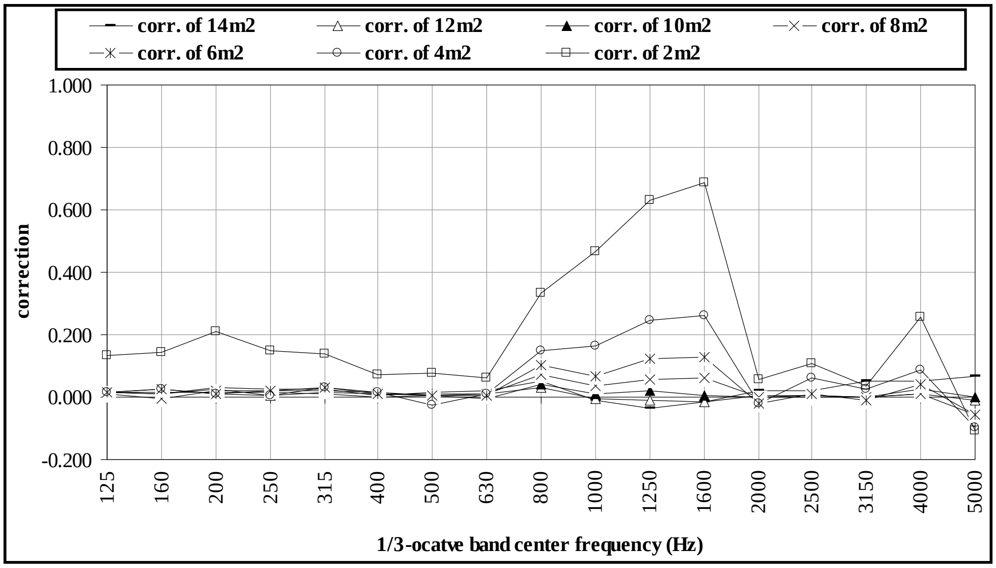

Fig.2a: absorption correction surface area for carpet material

4- Conclusion

Estimated equation at each frequency for the area effect is introduced and the deviation of the measured absorption coefficient from the estimated absorption coefficient of standardized absorber area is corrected.

As it was expected, the variation of absorption coefficient with the area directed to be increased at smaller areas (2), see figures 1a, 1b, 1c and 1d.

All materials need corrections for the measured absorption coefficient at area of 2m^2, over all the range of interested frequency, due to its edge effect

Rather All materials do not need corrections for the measured absorption coefficient at areas around the standardized areas, which are larger areas, 14 m^2, 12 m^2 and 10 m^2. while the other areas need corrections especially at low frequencies.

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