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Absorption coefficients-part 2: is “edge effect” more important than expected?

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ABSTRACT

Attempting to correlate the measurements of “Absorption Coefficients” in ASTM-C423¹, ISO-354² and ISO-17497-1³ it was observed that the results were varying to a large degree. An experiment was set up as described in a paper titled “Absorption Coefficients Part 1: Is Square Area Enough?”. It was observed that the edges of the sample had a significant effect on the “Absorption Coefficient”. The results of these experiments are presented in numerical and graphic form in this paper along with conclusions and suggested corrections to the use of absorption in calculation using the variable known as “Absorption Coefficient”

1. INTRODUCTION

During the qualification of NWAA Labs to do ISO-17497-1 full scale scattering coefficient tests it was noticed that the absorption coefficients of a common material that was measured were significantly different when using the ISO17497-1, ISO 354 and ASTM C-423 tests. When people in the industry were asked about this they indicated that it must be because of “edge effect”⁴. This was also the reason given when “Absorption Coefficients” were being measured that were above 1.00¹. When asked what “edge effect” was an answer was never received that made sense or was consistent from one person to another. Some questions could be formed because of this lack of satisfactory answers. Why did a difference appear and what causes it? If there appeared to be a real difference, could we quantify it and use it to improve any calculations using these “Absorption Coefficients”? These questions were looked at by Northwood^{5, 6} and

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Bartel⁷. Nelson⁸ did some additional research on these effects but most of the research was oriented to uniting the impedance tube method with the reverberation room method. In Part 2 we will present the results of the measurements of the samples described in Part 1 and will hypothesize possible reasons for this effect and suggest ways it could be used to improve our calculations using absorption.

2. COMMON QUESTIONS

A. What are the types of absorption?

- a. Flow or mechanical resistance
- b. Diaphragmatic action

B. How do these types function?

a. Flow or Mechanical resistance converts acoustic energy directly to heat because of friction. It is caused by the friction of the air passing through different density materials.

b. Diaphragmatic action converts the acoustic energy by causing the energy to physically move a membrane thus converting the energy to heat based on bending of a material and the friction of the molecules in the bending membrane. Some absorption is based on the resistance caused by an increase in air pressure caused by the reduction in volume caused by the movement of the membrane.

C. How does area affect absorption and “Absorption Coefficient”?

ASTM-C423 calculates absorption based on the Sabine formula:¹

$$A = 0.9210 \frac{Vd}{c} \quad (1)$$

Where:

A = sound absorption, m² or Sabins,

V = volume of reverberation room, m³ or ft³,

c = speed of sound shall be calculated using equation (2), m/s or ft/s, and

d = decay rate, dB/s

The result of the calculation is also called the Sabine Absorption.

Speed of sound calculation:¹

$$c = 20.047 \sqrt{273.15 + T^{\circ}C} \text{ m/s}$$

or

$$c = 49.022 \sqrt{459.67 + T^{\circ}F} \text{ ft/s} \quad (2)$$

Where $T^{\circ}C$ and $T^{\circ}F$ are temperature in degrees Celsius and degrees Fahrenheit, respectively

The ASTM-C423 method requires a measurement of the absorption of the empty room and the absorption of the room with the sample in the room.¹

$$A = A_2 - A_1 \quad (3)$$

where:

A = absorption of the specimen, m² or Sabins.,

A₁ = absorption of the empty reverberation chamber, m² or Sabins, and

A₂ = absorption of the reverberation room after the specimen has been installed, m² or Sabins.

The increase in the absorption is divided by the area of the sample to create the “Absorption Coefficient”.¹

$$\alpha = (A_2 - A_1) / S + \alpha_1 \quad (4)$$

where:

α = absorption coefficient of the test specimen, no units or Sabins/ft².

S = area of the test specimen, m² or ft², and

α_1 = absorption coefficient of the surface covered by the specimen

The absorption coefficient, α_1 , of the room surface covered by the specimen should be added when it is significant. However, the absorption coefficients of a hard surface, such as the floor of a reverberation chamber, are so small that they may be neglected and no adjustment should be made for such a floor.

This coefficient is supposed to be dimensionless and is described in sabins per square foot, Sabins/ft².

D. How is this “Absorption Coefficient” used in practice?

The “Absorption Coefficient” is used in calculating the reverberation time of closed spaces such as auditoriums and churches. The equation for calculating the reverberation time is:⁹

$$RT_{60} = k \left(\frac{V}{S_a} \right) \quad (5)$$

where:

RT₆₀ = time needed for the reverberation energy in the room to decay in level 60dB

k = the speed of sound that equals 0.161 when units of measurement are expressed in meters and 0.049 when units are expressed in feet or meters.

S_a = the total surface absorption of the room expressed in m² or Sabins

V = the volume of the room

Total surface absorption of the room calculation is:

$$S_a = a_1 S_1 + a_2 S_2 + \dots \quad (6)$$

where:

S_a = the total surface absorption of the room expressed in m² or Sabins.

a₁ = the absorption coefficient associated with a given area S

S = The surface area of a single surface expressed in ft² or m²

E. How is perimeter size used at present?

At this time it is only used to calculate the surface area of individual surfaces.

3. RESULTS

A. Common Area vs. Variable Perimeter.

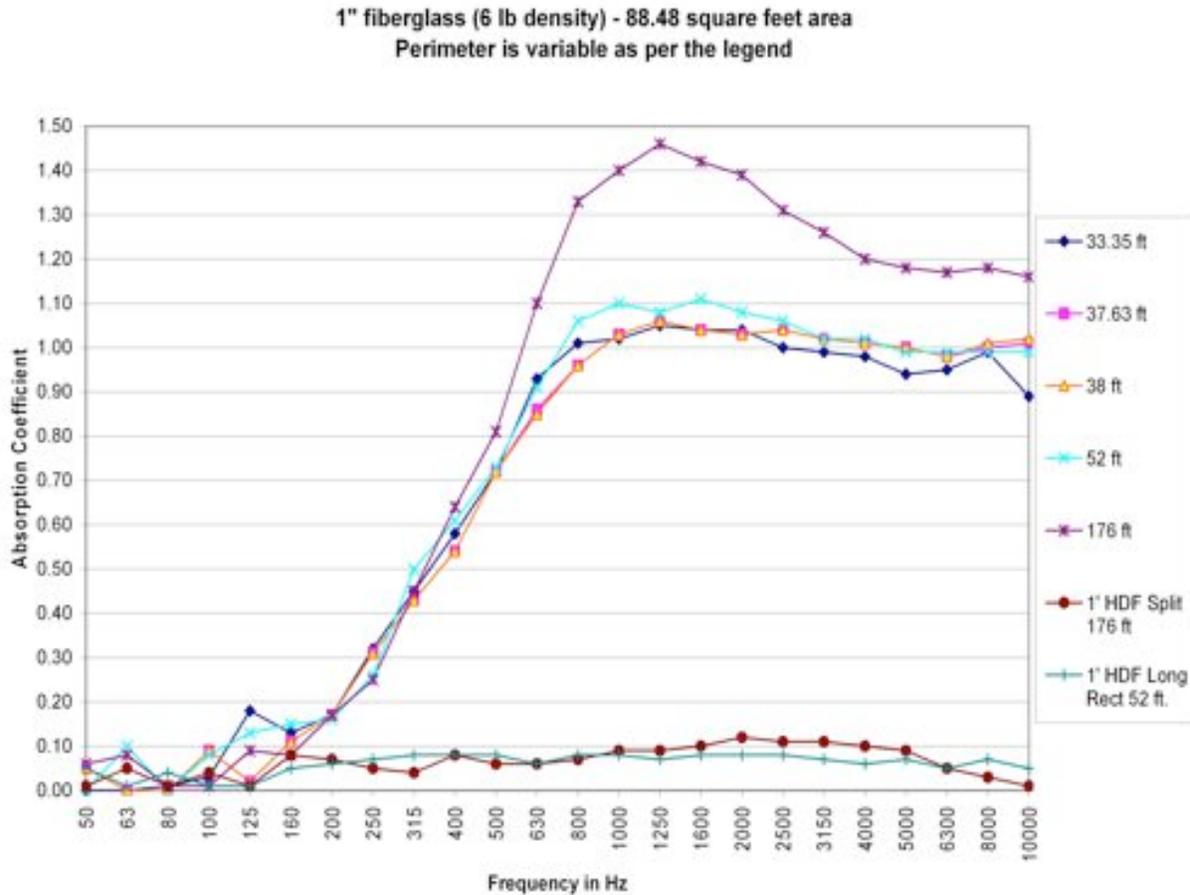


FIGURE 1: Absorption coefficients of main sample materials with a common area and a variable perimeter also the main hard material as per Part I

As can be seen in Figure 1, as the perimeter increases in length the absorption coefficient increases in a non linear manner over frequency. This indicates that there is a relationship between the edge length and the total absorption. Observing the absorption coefficient of the circular sample at 33.35 ft (10.17m) it will be noticed that the curve also has a different shape as well as a lower level than those of the square at 37.63 ft (11.47m). As the ratio of perimeter to area increases the absorption also increases in specific frequency ranges. Later in the paper it will be seen that the thickness of the material determines the frequency range where the maximum effects are observed.

The “edge effect” is also seen in the measurement of the hard impervious material in the last two curves. The material is hard, smoothed and sealed enough that the material itself should not have any measureable absorption, yet in the chart it can be seen that a significant absorption coefficient follows the frequency range where the effect is most felt. Coefficients as high as 0.12

A. Common Area vs. Variable Perimeter. (Cont)

at 2000 Hz in this chart for the 22 individual pieces can be seen. And yet the same pieces placed together in a long rectangle shows only 0.08 at the same frequency.

B. Common Perimeter vs. Variable Area.

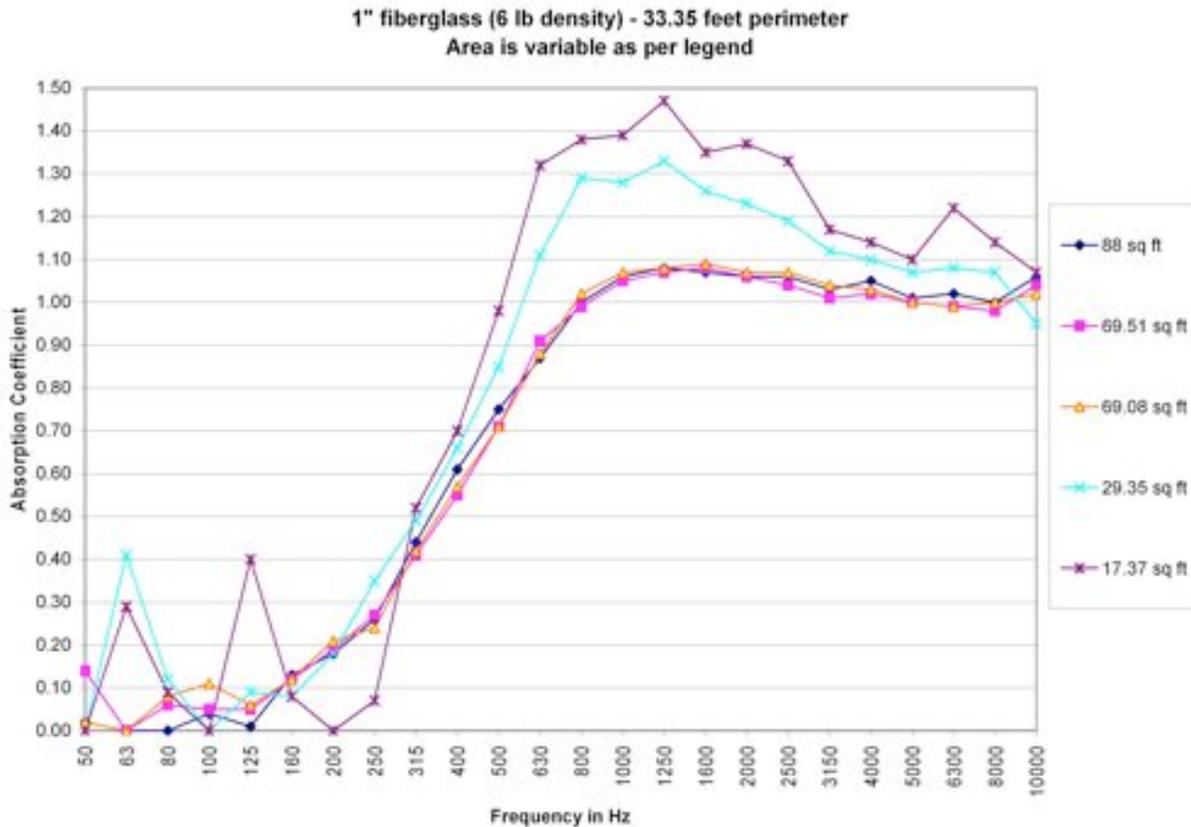


FIGURE 2: Absorption coefficients of main sample materials with a common perimeter and a variable area.

As Figure 2 is examined it can be observed that the same ratio of perimeter to area effects can be seen. The circular sample with the area of 88.48 ft² (8.22m²) has the lowest coefficient. It is only when the ratio is increased substantially that a difference is observed. This is shown when the areas have been reduced to 29.35 ft² (2.73m²) and 17.37 ft² (1.61m²). The “Absorption Coefficient” increases rapidly in the same frequency ranges observed in Figure1. The peaks at the low frequency end of either Figure 1 or Figure 2 are uncertainties that are expected in this size room and these sized samples.

Since this increase in “Absorption Coefficient” seems to be affected by the ratio of perimeter to area perhaps we should look to see if this is a predictable behavior.

4. CORELLATION OF TEST RESULTS.

It was decided to plot each data point of all of these measurements in a common chart to see if there are predictable patterns to the “Absorption Coefficients”. The results indicate that it may be possible to use the perimeter length to predict the total absorption of a particular sample.

4. CORELLATION OF TEST RESULTS. (Cont)

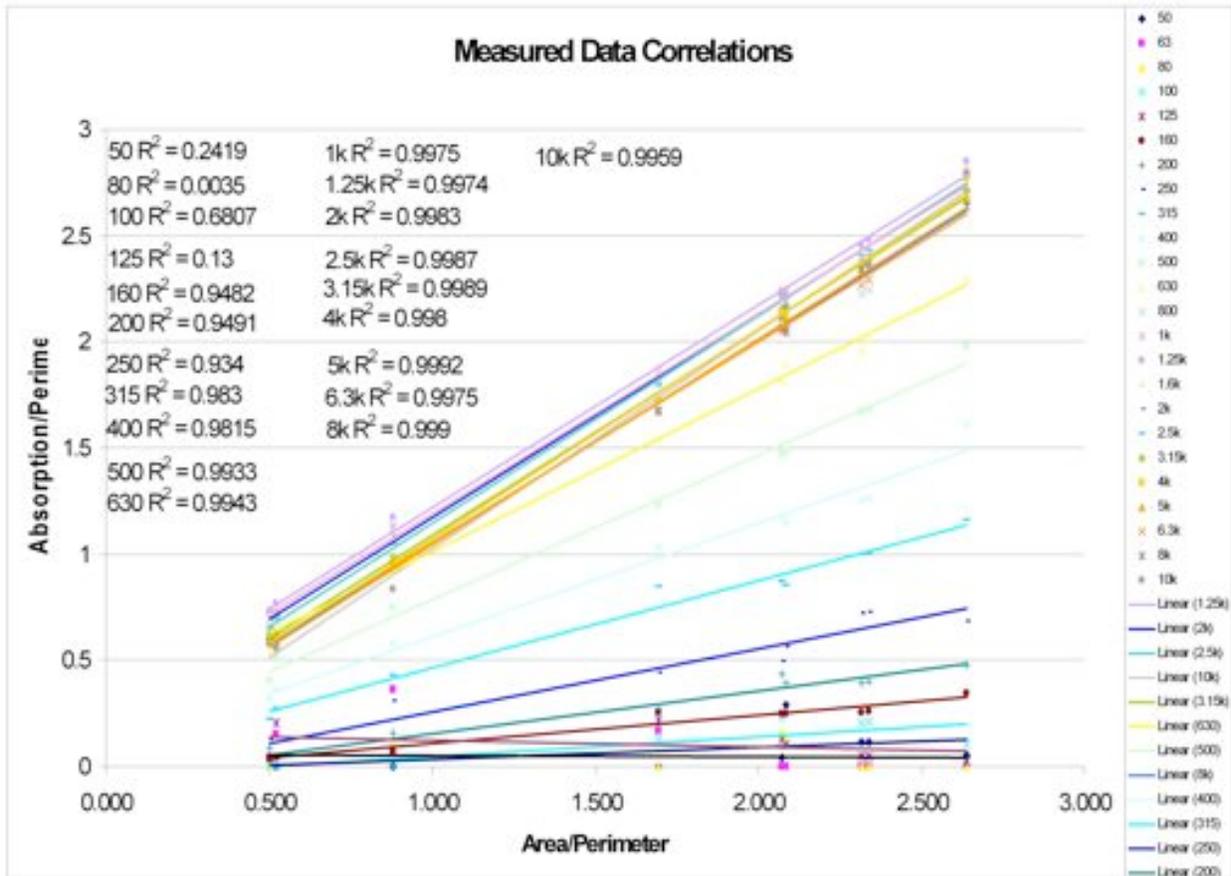


FIGURE 3: Linear regressions of all absorption data from Figures 1 and 2.

It can be seen in Figure 3 that the R^2 regression lines show the correlation of all of the measured data at each frequency. The correlation values of the lower frequencies, such as 50Hz to 125Hz show that the measurements and uncertainties at these frequencies do not allow a conclusion to be drawn. The correlation values from 160Hz to 10 KHz do allow a conclusion to be drawn about this data. The conclusion is that it is very likely that actual values can be calculated for the absorption of any size surface.

5. ADDITIONAL TESTS

A. Common area vs. Variable Perimeter (2 in (5.08 cm) Thk, 6lb, Fiberglass.

After test the main sample in the previous tests it was decided that testing a similar sample with double the thickness. This was done with the test calibration sample from Western Electro-Acoustics Lab. It is a sample previously described in Part 1 and was arranged in similar ways with a common area and a variable perimeter. The results are shown in Figure 4.

A. Common area vs. Variable Perimeter (2 in (5.08 cm) Thk, 6lb, Fiberglass. (Cont)

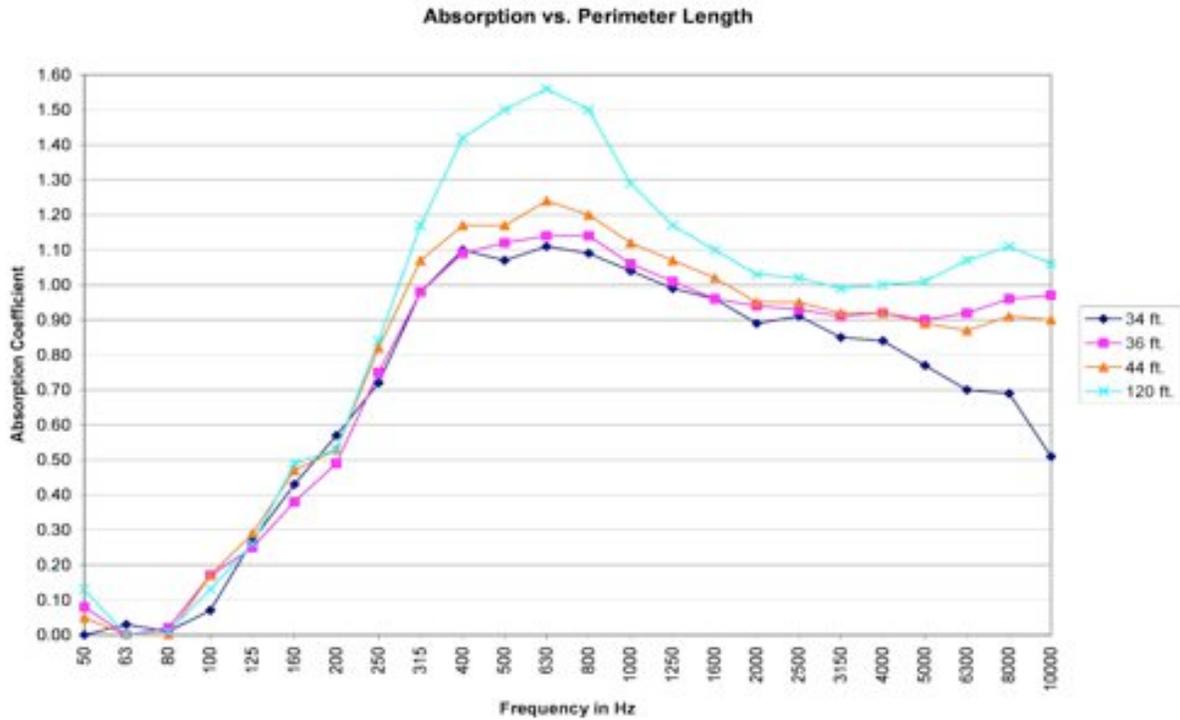


Figure 4: Absorption Coefficients of a 2inch (5.08cm) thick Fiberglass Sample (1st Test,2006)

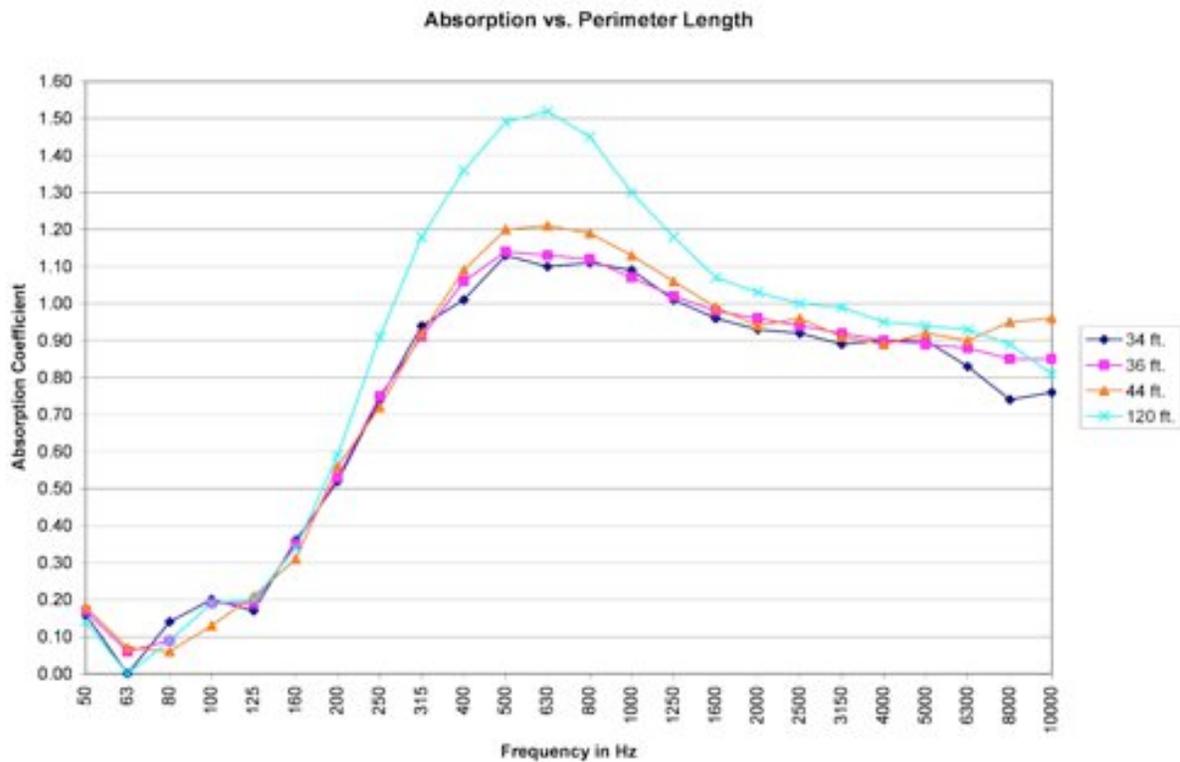


Figure 5: Absorption Coefficients of a 2inch (5.08cm) thick Fiberglass Sample (2nd Test,2008)

A. Common area vs. Variable Perimeter (2 in (5.08 cm) Thk, 6lb, Fiberglass. (Cont)

Looking at Figure 4 and Figure 5 it can be seen that the increase of “Absorption Coefficient” can also be seen. The main difference seems to be at what frequency range the increase covers. In Figure 1 the range of the increase ranges from 400Hz upward in frequency. This is also true in Figure 2 as well although the increase seem to start at 315Hz. This difference can be within the uncertainties of the process. In Figures 4 and 5 it can also be seen that the increase starts at 200Hz. This true in either Figure as well. A conclusion that may be drawn is that as the thickness increases the start of the increase in absorption is lower in frequency about the inverse multiplier. Thus a doubling of thickness reduces the start frequency by 0.5.

6. Conclusions

A. Is Area Enough?

Based on the results shown in this paper, it is believed that an area based “Absorption Coefficient” alone is not adequate to describe the total absorption of a surface.

B. Is Edge Effect More Important Than Expected?

Again, it can be seen in the prior data that “Edge Effect” is much more important than previously thought. It can introduce considerably more absorption to a specimen than just a surface area based calculation would indicate. The author now thinks that “Absorption Coefficients” that are calculated using the methods recommended in ASTM-C423 and ISO-354 may be inaccurate at best.

7. Recommendations

A. A New Method of Calculating Absorption.

It is thought that the best way, based on what we have found, of calculating absorption for a single surface is to calculate it using the combination of the area and the perimeter. This is laid out in the following equations. Equation (7) is based on the chart in Figure 3 and is a simple version that has been expanded in equation (8). This calculation should be used to calculate the absorption at each frequency of interest for each surface in a “room”.

$$A = \left(\frac{y_2 - y_1}{x_2 - x_1} \right) * Area + \left(y_1 - \left(\frac{y_2 - y_1}{x_2 - x_1} \right) x_1 \right) * Perimeter \quad (7)$$

or

$$A_{x(f)} = \left(\frac{\frac{A_{2(f)}}{P_2} - \frac{A_{1(f)}}{P_1}}{\frac{S_2}{P_2} - \frac{S_1}{P_1}} \right) * S_x + \left(\left(\frac{A_{1(f)}}{P_1} \right) - \left(\frac{\frac{A_{2(f)}}{P_2} - \frac{A_{1(f)}}{P_1}}{\frac{S_2}{P_2} - \frac{S_1}{P_1}} \right) * \frac{S_1}{P_1} \right) * P_x \quad (8)$$

where:

- A_x = absorption of the surface being calculated, m^2 or Sabins.
- A_1 = absorption of sample 1, m^2 or Sabins.
- A_2 = absorption of sample 2, m^2 or Sabins.
- S_x = area of surface being calculated, ft^2 or m^2
- S_1 = area of sample 1, ft^2 or m^2
- S_2 = area of sample 2, ft^2 or m^2
- P_x = perimeter of surface being calculated, ft or m
- P_1 = perimeter of sample 1, ft or m
- P_2 = perimeter of sample 2, ft or m
- (f) = frequency of interest in calculation

A. A New Method of Calculating Absorption. (Cont)

After calculating the absorption for each surface they should be combined using the simple calculation:

$$A_{(\text{total})} = A_1 + A_2 + A_3 \dots$$

where:

$A_{(\text{total})}$ = the total absorption of the room expressed in m² or Sabins.

$A_1, A_2 \dots$ = the absorption of a given surface expressed in m² or Sabins.

A paper written by DeWitt and Burnside¹⁰ about the edge diffraction of radar waves showed that when radar waves are bent over the edge of a wedge by diffraction there is a heating effect on the tip of the wedge and the air surrounding it. This author knows of nothing in physics that would restrict this effect from applying to acoustic energy as well. If this is the case then we would have to now include diffraction as a form of absorption and a type of absorber.

The next question to answer is why a circular sample has less absorption than a square of the same perimeter. It can be hypothesized that because diffraction has an absorptive function it might have a phase function as well. A square has four straight edges with each of the 4 edges going in 4 directions and any diffractions along that edge could have a common phase function and could be considered “coherent”. If they are “coherent”, then the energy contained could be additive.

A circle has an edge that is constantly changing direction and the diffractive energy could have different phase information and is not “coherent” and therefore may not be additive in its nature.

Because of this new information, the author also recommends that Standards ASTM-C423 and ISO-354 be revisited and additional tests be added to allow a slope and intersect to be calculated for each material and frequency combination.

8. ACKNOWLEDGMENTS

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