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Factors Influencing Acoustic Performance of Sound Absorptive Materials

Hoda S. Seddeq

Housing & Building Research Center, Acoustic Department, Egypt.

Abstract: Today much importance is given to the acoustical environment. Noise control and its principles play an important role in creating an acoustically pleasing environment. This can be achieved when the intensity of sound is brought down to a level that is not harmful to human ears. Achieving a pleasing environment can be obtained by using various techniques that employ different materials. One such technique is by absorbing the sound. Fibrous, porous and other kinds of materials have been widely accepted as sound absorptive materials. This paper review and describes how the physical prosperities of materials like fiber type, fiber size, material thickness, density, airflow resistance and porosity can change the absorption behavior. The effect of surface impedance, placement / position of sound absorptive and compression, on sound absorption behavior of materials was also considered. The sound absorption of different fibrous materials was experimentally tested**.** The results shows the relationship between the sound absorption and airflow resistance**,** material thickness**,** air gap and attachment film. Higher airflow resistance always gives better sound absorption values but for airflow resistance higher than 1000 the sound absorption have less values because difficulty movements of sound wave through the materials. The creation of air gap, 5mm, 10 mm behind the absorptive material increases sound absorption coefficient values in mid and higher frequencies. There is not much difference seen between 5 mm air gap sample and 10 mm air gap sample. Moreover, maxima peak for different air gap is different (higher the air gap distance, maxima peak shift towards lower frequency

Key word: sound absorptive materials - sound absorption coefficient – fibrous materials - Porosity - Airflow Resistance-Tortuosity

INTRODUCTION

Materials that reduce the acoustic energy of a sound wave as the wave passes through it by the phenomenon of absorption are called sound absorptive materials. They are commonly used to soften the acoustic environment of a closed volume by reducing the amplitude of the reflected waves. Absorptive materials are generally resistive in nature, either fibrous, porous or in rather special cases reactive resonators Lewis H. Bell, (1994) Classic examples of resistive material are nonwovens, fibrous glass, mineral wools, felt and foams Porous materials used for noise control are generally categorized as fibrous medium or porous foam. Fibrous media usually consists of glass, rock wool or polyester fibers and have high acoustic absorption. Sometimes fire resistant fibers are also used in making acoustical products Claudio, (1998). An absorber, when backed by a barrier, reduces the energy in a sound wave by converting the mechanical motion of the air particles into low-grade heat. This action prevents a buildup of sound in enclosed spaces and reduces the strength of reflected noise Lewis H. Bell., (1994).

Application of Sound Absorptive Materials:

Acoustical material plays a number of roles that are important in acoustic engineering such as the control of room acoustics, industrial noise control, studio acoustics and automotive acoustics. Sound absorptive materials are generally used to counteract the undesirable effects of sound reflection by hard, rigid and interior surfaces and thus help to reduce the reverberant noise levels (Beranek Leo L., 1960; Bruce, 1981). They are used as interior lining for apartments, automotives, aircrafts, ducts, enclosures for noise equipments and insulations for appliances (Knapen and Lanoye, 2003; Youn Eung Lee, Chang Whan Joo, (2004).

Sound absorptive materials may also be used to control the response of artistic performance spaces to steady and transient sound sources, thereby affecting the character of the aural environment, the intelligibility of unreinforced speech and the quality of unreinforced musical sound Frank Fahy, (2001). Combining

Corresponding Author: Hoda S. Seddeq, Housing & Building Research Center, Acoustic Department, Egypt.
E-mail:hudasoliman@yahoo.com

absorptive materials with barriers produces composite products that can be used to lag pipe or provide absorptive curtain assemblies. All noise control problem starts with the spectra of the emitting source. Therefore, sound absorbing materials are chosen in terms of material types and dimension, and also based on the frequency of sound to be controlled Francisco Simon and Jaime Pfretzschner, (2004)

Factors Influencing Sound Absorption:
Fiber Size:

Koizumi *et al.* (2002) reported an increase in sound absorption coefficient with a decrease in fiber diameter. This is because, thin fibers can move more easily than thick fibers on sound waves. Moreover, with fine denier fibers more fibers are required to reach equal more fibers for same volume density which results in a more tortuous path and higher airflow resistance, Sun, Banks-Lee. and Peng, (1993). A study by Youn Eung Lee *et al.* (Youn Eung Lee and Chang Whan Joo, 2003) concluded that the fine fiber content increases sound absorption coefficient values due to an increase in airflow resistance by means of friction of viscosity through the vibration of the air. A study by Koizumi *et al.* (2002) also showed that fine denier fibers ranging from 1.5 to 6 denier per filament (dpf) perform better acoustically than coarse denier fibers. Moreover it has been reported by Koizumi, T. that, micro denier fibers (less than 1 dpf) provide a dramatic increase in acoustical performance.

Airflow Resistance:

One of the most important qualities that influence the sound absorbing characteristics of a fibrous material is the specific flow resistance per unit thickness of the material. The characteristic impedance and propagation constant, which describes the acoustical properties of porous materials, are governed to a great extent by flow resistance of the material Mingzhang Ren and Finn Jacobsen, (1993). Fibers interlocking in nonwovens are the frictional elements that provide resistance to acoustic wave motion. In general, when sound enters these materials, its amplitude is decreased by friction as the waves try to move through the tortuous passages. Thus the acoustic energy is converted into heat (Conrad, 1983). This friction quantity which can be expressed by resistance of the material to airflow is called airflow resistance and is defined in following equation as:

$$R_1 = \frac{\nabla p}{\nabla T u} mks.Rayls/m$$

where:
R1 = Specific flow resistance, mks Rayls/m
u = Particle velocity through sample, m/sec
Δp = Sound pressure differential across the thickness of the sample measured in direction of particle velocity, newtons/m^2
ΔT = Incremental thickness, m (Beranek Leo L., 1960).

Based upon the airflow test, ASTM D-1564-1971, flow resistance R of the sampleis obtained from the following equation:

$$R = \frac{P}{vl}$$

where: P = Static pressure differential between both faces of the sample, dyn/cm^2 (10^{-1} Pa)
v = Air velocity, cm/s
l = Thickness of sample, cm

The airflow resistance per unit thickness of a porous material is proportional to the coefficient of shear viscosity of the fluid (air) involved and inversely proportional to the square of the characteristic pore size of the material. For a fibrous material with a given porosity, this means that the flow resistance per unit thickness is inversely proportional to the square of the fiber diameter (Uno Ingard, 1994).

Porosity:

Number, size and type of pores are the important factors that one should consider while studying sound absorption mechanism in porous materials. To allow sound dissipation by friction, the sound wave has to enter the porous material. This means, there should be enough pores on the surface of the material for the sound to pass through and get dampened. The porosity of a porous material is defined as the ratio of the volume of the voids in the material to its total volume (Allard *et al.,* 1989). Equation (3) gives the definition for porosity (H).

$$Porosity(H) = \frac{V_a}{V_m}$$

where:
Va = Volume of the air in the voids
Vm = Total volume of the sample of the acoustical material being tested

Shoshani *et al.* (2003). stated that, in designing a nonwoven web to have a high sound absorption coefficient, porosity should increase along the propagation of the sound wave.

Tortuosity:

Tortuosity is a measure of the elongation of the passage way through the pores, compared to the thickness of the sample. According to Knapen *et al.* (2003), tortuosity describes the influence of the internal structure of a material on its acoustical properties. Con Wassilieff Con Wassilieff, (1996) describes tortuosity as a measure of how far the pores deviate from the normal, or meander about the material. Horoshenkov *et al.* (2001) stated that, tortuosity mainly affects the location of the quarter-wavelength peaks, whereas porosity and flow resistively affect the height and width of the peaks. It has also been said by the value of tortuosity determines the high frequency behavior of sound absorbing porous materials.

Thickness:

Numerous studies that dealt with sound absorption in porous materials have concluded that low frequency sound absorption has direct relationship with thickness. The rule of thumb rule that has been followed is the effective sound absorption of a porous absorber is achieved when the material thickness is about one tenth of the wavelength of the incident sound Michael Coates and Marek Kierzkowski, (2002). Peak absorption occurs at a resonant frequency of one-quarter wavelength of the incident sound (ignoring compliance effect) Timothy Hirabayashi, David J. McCaa, (1999).

A study by Ibrahim *et al.,* (1978). showed the increase of sound absorption only at low frequencies, as the material gets thicker. However, at higher frequencies thickness has insignificant effect on sound absorption.

Density:

Density of a material is often considered to be the important factor that governs the sound absorption behavior of the material. At the same time, cost of an acoustical material is directly related to its density. A study by Koizumi *et al.* (2002) showed the increase of sound absorption value in the middle and higher frequency as the density of the sample increased. The number of fibers increases per unit area when the apparent density is large. Energy loss increases as the surface friction increases, thus the sound absorption coefficient increases.

Moreover, they showed the following effect of density on sound absorption behavior of nonwoven fibrous materials.

- Less dense and more open structure absorbs sound of low frequencies (500Hz).
- Denser structure performs better for frequencies above than 2000 Hz.

Compression:

Not much has been published on the influence of compression on sound absorption behavior. A paper by Bernard Castagnede *et al.* (2000) showed that, compression of fibrous mats decreases the sound absorption properties. He explained that, under compression the various fibers in the mat are brought nearer to each other without any deformation (without any change in fiber size).

This compression results in a decrease of thickness. More interestingly he also found the other physical variation that occurs during compression. Castagnede *et al*. (2000) found that compression resulted in an increase in tortuosity and airflow resistively, and a decrease of porosity and thermal characteristic length (shape factor). Despite these physical parameter variations in the compressed material, he stated that the reason for a drop in sound absorption value is mainly due to a decrease in sample thickness. The influence of compression on sound absorption can play an important role in the field of automotive acoustics. The seat padding in the vehicle is subjected to compression / expansion cycles due to the passenger’s weight. This results in squeezing down the porous materials (fibrous or cellular) which in turn results in variation of the above physical parameters.

Surface Impedance:

The higher the acoustic resistively of a material, the higher is its dissipation, for a given layer of thickness. At the same time the surface impedance of the layer also increases with resistively, resulting in a greater amount of reflections on the surface layer, giving a lower absorptive capability. Moreover the whole process is frequency dependent, so that for lower frequency bands the necessary layer thickness increases as resistively decreases Francisco Simon and Jaime Pfretzschner, (2004).

Placement / Position of Sound Absorptive:

Placement / position of sound absorptive materials is a known fact that sound absorption of a material depends also on the position and placement of that material. It has been reported by Alton Everest, Alton, (2001). that if several types of absorbers are used, it is desirable to place some of each type on ends, sides and ceilings so that all three axial modes (longitudinal, transverse and vertical) will come under their influence. In rectangular rooms it has been demonstrated that absorbing material placed near corners and along edges of room surfaces is most effective. In speech studios, some absorbents that are effective at higher audio frequencies should be applied at head height on the walls. In fact, material applied to the lower portions of high walls can be as much as twice as effective as the same material placed elsewhere Everest Alton, (2001). Moreover, it is recommended that untreated surfaces should never face each other.

Performance of Sound Absorbing Materials:

For porous and fibrous materials, acoustic performance is defined by a set of experimentally determined constants namely: absorption coefficient, reflection coefficient, acoustic impedance, propagation constant, normal reduction coefficient and transmission loss. There are different methods available to determine these acoustical parameters but all of these methods mainly involve exposing materials to known sound fields and measuring the effect of their presence on the sound field.

The performance of sound absorbing materials in particularly is evaluated by the sound absorption coefficient (α) [Horoshenkov and Swift, (2001) Lewis, (1994). Alpha (α) is defined as the measure of the acoustical energy absorbed by the material upon incidence and is usually expressed as a decimal varying between 0 and 1.0. If 55 percent of the incident sound energy is absorbed, the absorption coefficient of that material is said to be 0.55. A material that absorbs all incident sound waves will have a sound absorption coefficient of 1. The sound absorption coefficient (α) depends on the angle at which the sound wave impinges upon the material and the sound frequency. Values are usually provided in the literature at the standard frequencies of 125, 250, 500, 1000 and 2000 Hertz (Takahashi *et al.,* 2005). Other important acoustic parameters that need to be considered while studying the acoustical absorptive properties are:

- Sound reflection coefficient: ratio of the amount of total reflected sound intensity to the total incident sound intensity.
- Acoustic impedance: ratio of sound pressure acting on the surface of the specimen to the associated particle velocity normal to the surface.

In comparing sound absorbing materials for noise control purposes, the noise reduction coefficient (NRC) is commonly used. NRC is the average usually stated to the nearest multiple of 0.05, of the coefficient at four frequencies 250, 500, 1000 and 2000 Hz. It is intended for use as a single number index of the sound absorbing efficiency of a material. This NRC values provides a decent and simple quantification of how well the particular surface will absorb the human voice (Harris, 1979).

Excremental work:

Measurement of Sound Absorption Coefficient:

A number of measurement techniques can be used to quantify the sound absorbing behavior of porous materials. In general one is interested in one of the following properties: sound absorption coefficient (α), reflection coefficient (R), or surface impedance (Z).

Measurement techniques used to characterize the sound absorptive properties of a material are Takahashi *et al.,* (2005):

- Reverberant Field Methods
- Impedance Tube Methods

Several of the fiber materials were needle punched blends of cotton or plastic fibers (“shoddies”) have been investigated. Many of these consist of post-industrial recycled fibers. Several blown plastic fiber materials were tested as well. Polyester and polypropylene are common plastic materials used in absorbers. Most of the plastic fiber absorbers tested in this study was made of polyethylene terepthalate (PET). Some of the materials were lightweight micro fibers. These materials also consist of blown plastic fibers, but have a higher loft and smaller fiber diameters. Many of the samples were materials with no scrims or embedded layers. However, many of them had scrim or film layers. Some had layers of scrim or barrier embedded inside the material. Fiberglass materials were also tested. Table 1 shows the tested fibrous materials and its prosperities.

Table 1: Tested sound absorptive materials

Material type	Material Type	Thickness Range (mm)	Flow Resistively (mks rayls/mm)
A	PET	8-26	21-2573
B	Lightweight Microfiber	7-24	279- 1643
C	Shoddy	11-27	124- 1426
D	PET	10-27	139.5- High
E	PET	7-21	139.5- 1333
F	PET	7-26	124- 2263
G	Fiberglass	6-23	62-682
H	Lightweight Microfiber	10-32	124- 1054
I	Shoddy	11-27	155-320
J	PET	7-37	83-816

The sound absorption coefficient is measured using the two-microphone method where a sample of the material to be tested is placed in a sample holder and mounted to one end of a straight tube. A rigid plunger with an adjustable depth is placed behind the sample to provide a reflecting surface. A sound source, typically a high-output acoustic driver, is connected at the opposite end of the tube. A pair of microphones is mounted flush with the inner wall of the tube near the sample end of the tube. The sound absorption coefficient is measured according to ASTM E1050

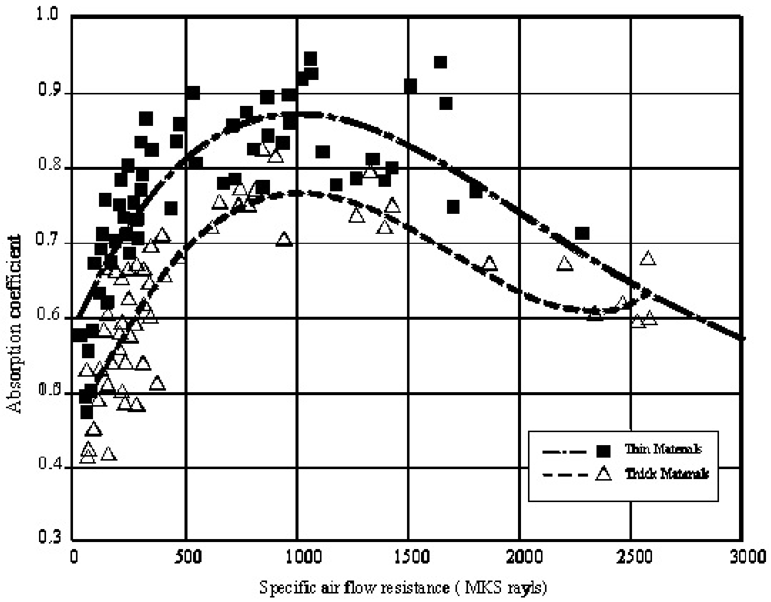

Fig. 1: Relationship between specific air flow resistance and sound absorption coefficient

RESULTS AND DISCUSSION

Influence of Specific Air Flow Resistance:

Figure 1 shows the relationship between specific air flow resistance and average sound absorption coefficient for thin (lower curve) and thick materials(the upper curve). It can be inferred that, higher airflow resistance always gives better sound absorption values but for airflow resistance higher than 1000 the sound absorption have less values because difficulty movements of sound wave through the materials.

Influence of Thickness:

Influence of felt thickness is demonstrated in figure 2 which shows that thicker the material better sound absorption values. Moreover, the importance of thickness on low frequency sound absorption that is based on the physics – low frequency means higher wavelength and higher wavelength sound can be absorbed if the material is thicker.

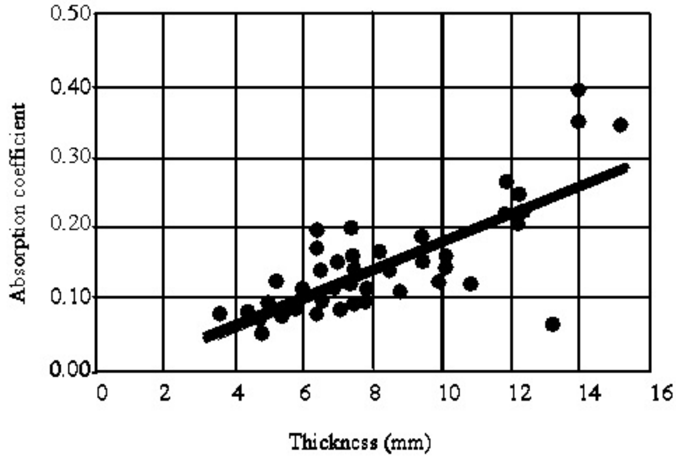

Fig. 2: Relationship between thickness and sound absorption coefficient

Influence of Film:

Perforated screens, woven fabrics and films are used to cover the porous and fibrous sound absorbing materials in order to prevent the material from detrimental environments or to meet the aesthetic performances Voronina, (1996). Sometimes these coverings are used to prevent the fall of fibers from product. Films are highly reflective to the sound waves and thus have a dramatic influence on absorptive properties of porous or fibrous materials. Therefore it is necessary to study the effect of film on sound absorption, when it is attached to fibrous or porous sound absorbing materials. In this study, two kinds of films namely polyvinyl chloride, PVC is used to analyze its influence on acoustic absorptive properties. The results of sound absorption of (PVC) film is given in the Figure 3.

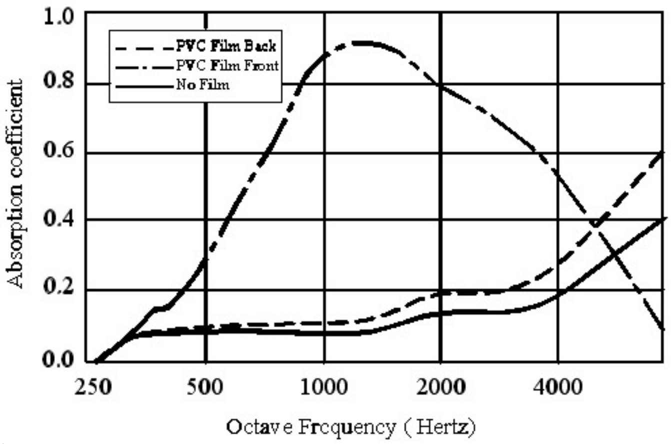

Fig. 3: Influence of film

Influence of Air Gap:

Sound absorption measurement calculations were performed with and without an air gap of 5 mm and 10 mm between the rear of sample and the backing of the movable plunger of the impedance tube. The results for the Figure 4, states that, for the same amount of material, it is much better to have an air gap behind the layer, which coincides with the results. The creation air gap increases sound absorption coefficient values in mid and higher frequencies, in spite of showing minima at certain frequencies. There is not much difference seen between 5 mm air gap sample and 10 mm air gap sample. Moreover, maxima peak for different air gap is different (higher the air gap distance, maxima peak shift towards lower frequency). This indicates that there is an optimum value for an air gap beyond which there is not much influence seen in sound absorption properties.

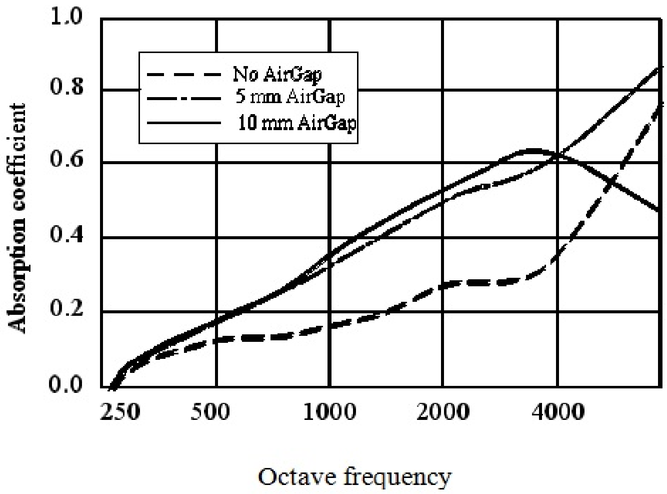

Fig. 4: Influence of air gap

Conclusion:

The influence of various factors of a fibrous material on sound absorption is presented in this paper. Some of the important conclusions of this research are:

- sound absorption coefficient increased with a decrease in fiber diameter, micro denier fibers (less than 1 dpf) provide a dramatic increase in acoustical performance
- one of the most important qualities that influence the sound absorbing characteristics of a fibrous material is the specific flow resistance per unit thickness of the material. In general, It can be inferred that, higher airflow resistance always gives better sound absorption values but for airflow resistance higher than 1000 the sound absorption have less values because difficulty of movements sound wave through the materials
- tortuosity mainly affects the location of the quarter-wavelength peaks, whereas porosity and flow resistively affect the height and width of the peaks. It has also been said by the value of tortuosity determines the high frequency behavior of sound absorbing porous materials.
- fiber surface area and fiber size have strong influence on sound absorption properties. higher surface area and lower fiber size increases sound absorption.
- less dense and more open structure absorbs sound of low frequencies (500Hz), denser structure performs better for frequencies above than 2000 Hz.
- the creation air gap increases sound absorption coefficient values in mid and higher frequencies. At the same time, creation of airgap will have minima at various frequencies for various airgap distances.
- films such as PVC attachment increase sound absorption at low and mid frequencies at the expense of higher frequencies

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