Parametric Study of Factors Affecting Sound Absorption Characteristics of Acoustical Materials

N. Garg and C. Gautam

Abstract The paper reports the parametric sensitivity of the factors affecting the sound absorption characteristics of the acoustical materials tested in the reverberation chambers. The various factors affecting the sound absorption characteristics such as air-gap, thickness, bulk density, porosity, tortuosity and air flow resistivity have been discussed based on the previous studies. The study also reports some of the recently developed acoustical sound absorbing materials having higher sound absorption characteristics for noise control applications.

Keywords Sound absorption · Sound absorption coefficient · Acoustical materials

1 Introduction

The sound absorption coefficient of a material is defined as the fraction of the incident sound energy absorbed by it. It depends upon the nature of the material, frequency of the sound waves and the angle at which the sound waves strike the surface of the material and is measured at frequencies of 100–5000 Hz. There are numerous sound absorbing materials that can be used for acoustical treatment of buildings, dwellings, offices, theatres, halls and auditoriums. The choice of a suitable absorbent material depends, however, upon the requirements of the low or middle frequency acoustical treatment, durability, maintainability and availability of the material. The majority of the sound absorbing materials are either fibrous or porous in nature, Fibrous materials are in the form of boards or tiles while porous materials are in the form of tiles, blankets and resin-bonded slabs. Acoustic tiles are available in various textures and resin-bonded mineral or glass wool is available in the form of semi-rigid slabs, mats, etc. The cavity of Helmholtz resonators is also typical sound absorber used in auditoria or noisy rooms in a narrow region of the low frequency band. The use of wedge-shaped fibrous materials is extensively used for constructing anechoic chambers [1]. There had been numerous studies in the past on reverberation chambers

N. Garg (✉) · C. Gautam
CSIR-National Physical Laboratory, New Delhi 110 012, India
e-mail: ngarg@nplindia.org

S. Yadav et al. (eds.), *Recent Advances in Metrology*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-99-4594-8_10

method and sound impedance tube method that had analyzed the parametric analysis of the factors affecting the sound absorption characteristics of the various acoustical materials. However, the reverberation chamber method has proved to be the best method having lesser uncertainty and employing a larger specimen size for evaluating the random incidence sound absorption coefficient. A proper understanding of the factors affecting sound absorption characteristics and mounting considerations shall be indispensable in the design and development of better acoustical materials for noise control.

2 Mounting Considerations

The mountings test specimens during sound absorption tests as recommended by ASTM E795-16 standard as follows [2]:

- Type A Mounting-Test specimen laid directly against the test surface
- Type B Mounting-Test specimen cemented to gypsum board and laid directly against the test surface
- Type C Mounting-Test specimen comprising sound absorptive material behind a perforated, expanded, open facing or other porous material
- Type D Mounting-Test specimen mounted on wood furring stripes
- Type E Mounting-Test specimen mounted with an air space behind it
- Type F Mounting-Test specimen mounted with an air space behind it
- Type G Mounting-Test specimen is a drapery, window shade, or blind hung parallel to the test surface
- Type H Mounting-Test specimen is a drapery suspended away from any vertical surface Type I Mounting-The specimen is a spray- or trowel-applied material on an acoustically hard substrate
- Type J Mounting- The specimen is a sound absorbing unit or set of sound absorbing units
- Type K Mounting-Test specimen is an office screen
- Type L Mounting-This mounting is for use with concrete blocks or block-like specimen that are normally assembled using mortar
- Type M Mounting-Test specimen is theatre seats

Type C, D, E, and G Mountings are further designated by a numerical suffix which indicates the distance (in millimeters from the specimen to the test surface rounded to the nearest integral multiple of 5 mm. For example, a Type E-400 mounting is a plenum mounting in which the face of the test specimen is 400 mm away from the test surface. In case of G mounting, the test specimen shall be drapery, window shade, or window blind hung parallel to the test surface. The suffix of the mounting designation shall be the distance from the test surface to the centreline of the hangers rounded to the nearest integral multiple of 5 mm. The preferred distance between the centreline of the hangers and the test surface is 75 mm. In the case of Type J Mounting, the test specimen shall be a sound absorbing unit or set of sound absorbing units that are directly attached to or hanging from a ceiling, wall or other room surface. If the units are suspended flat panels (baffles), and an installation pattern is not specified, it is recommended that the following panel size and arrangement be tested. The total absorptive area (all exposed surfaces) of the sound absorbing units shall be at least 10 m^2. The distance between any sound absorbing unit and any reflective surface (other than the test surface), rotating vane or diffuser panel shall be consistent with the requirements of Test Method C423. The measured sound absorption is in square meters per unit or Sabins per unit [2]. The analysis of the observations made for different mounting considerations is shown in Figs. 1 and 2. The following observations associated with various mounting considerations as presented by Sharma and Singal [1] are as follows [1]:

- With increasing thickness, the absorption coefficient of porous soft materials at any frequency increases and for a slab of thickness 100 mm of mineral wool, the absorption coefficient attains a maximum value at 500 Hz which is maintained more or less uniformly at higher frequencies also.

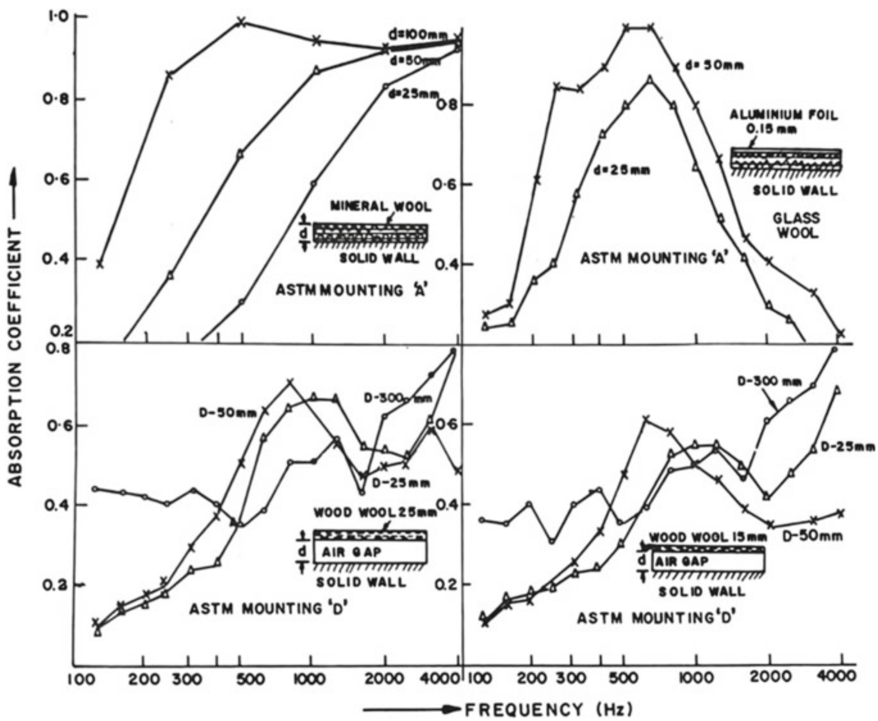

Fig. 1 Sound absorption characteristics of absorptive material in ASTM mountings A and D [1]

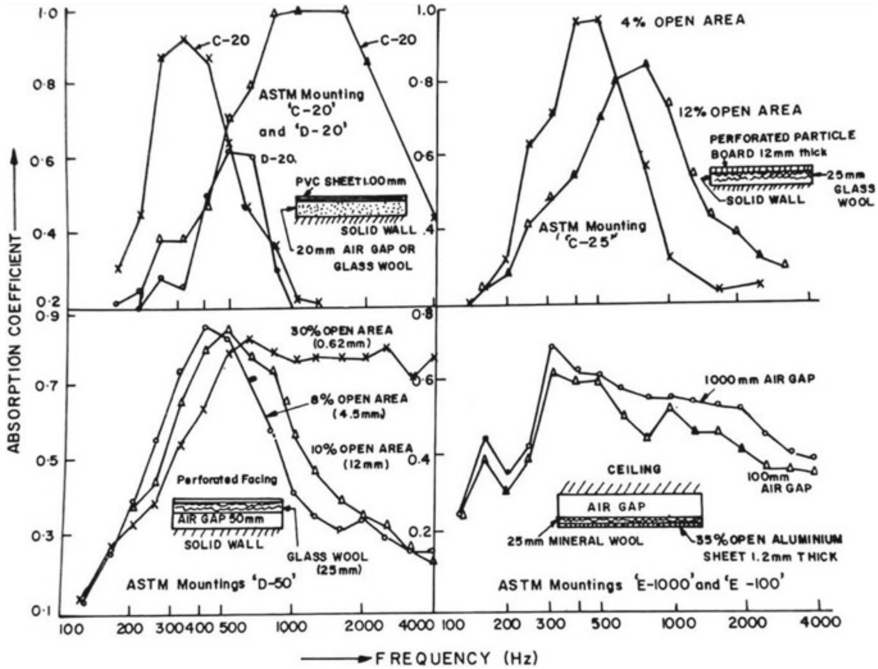

Fig. 2 Sound absorption characteristics of absorptive material in ASTM mountings C, D and E [1]

- With air-gap between the porous absorption material and the solid wall backing, the absorbing material and the solid wall backing, the absorption coefficient becomes more or less uniform in the mid frequency range 500–2000 Hz.
- The addition of the air-gap between the paneled absorbing material and the solid wall increases the maximum absorption coefficient while the increase in the open area in this situation not only shifts the resonance frequency but for a certain percentage of the open area (perforated 30%), absorption coefficient becomes uniformly high over a wider frequency range [1].

3 Edge Effect in Sound Absorption

The diffraction from the edges at low frequencies causes reflected waves to diffract that produces edge effect whereby more sound absorption occurs near the edges of an absorber than its centre. Thus, the wave diffraction at the edges of the specimen causes the sound absorption coefficient greater than unity. The amount by which the absorber's effective area increases is proportional to the ratio of the perimeter of the edges to the area of the absorber. The effect increases with decreasing frequency, decreasing specimen size and increasing aspect ratio [3–5].

4 Parametric Study

The parametric sensitivity of the various factors affecting the sound absorption characteristics of acoustical materials are enlisted in Table 1 based on exhaustive literature surveys of various previous studies carried out in this field [6–13]. It may be noted that several factors such as perforation of the material, air-gap behind the absorptive material, thickness and density of the absorptive material, airflow resistivity etc. play a vital role in determining the sound absorption characteristics. The diffusivity characteristics of the reverberation chamber are also an important aspect in the determination of the sound absorption characteristics.

Table 2 describes the details of some of the sandwich constructions tested and observed to show higher sound absorption characteristics in the entire measurement frequency range. The sandwich constructions in many cases show enhanced sound absorption coefficient as shown in Fig. 3.

5 Conclusions

The paper reports the parametric sensitivity of the factors affecting the sound absorption characteristics of the acoustical materials while these are tested in the Reverberation chambers. The various factors affecting the sound absorption characteristics such as air-gap, thickness, bulk density, porosity, tortuosity and air flow resistivity etc. have been highlighted in the study that has a significant role in determining the sound absorption characteristics in the entire measurement frequency range. The study shows the application of sandwich absorptive materials showing enhanced sound absorption characteristics that can be used widely for noise control applications. Future studies shall focus on the parametric sensitivity analysis of all the factors affecting the sound absorption characteristics using the analytical and experimental evaluation.

Table 1 Effects of various parameters of acoustical materials on sound absorption characteristics [6–13]

Parameter	Basic definition	Effect on sound absorption characteristics
Bulk density	Total mass of the porous material per unit volume	• As the density increases, the sound absorption coefficient shifts to the higher frequency range • In case fibers are too densely packed, it reduces porosity that restricts sound waves to penetrate the absorber [6, 7]
Thickness	Thickness plays a pivotal role at lower frequencies	• The thicker the absorber, the more the low frequency components can be absorbed • The peak absorption of an absorber is indicated by equivalent quarter wavelength. The material thickness should be a quarter of the wave length of the sound wave to be an effective absorber [6, 7]
Porosity	Relative fraction, by volume of the air contained within a porous material	• Value ranges between 0 and 1 for porous materials • Some studies reported that for natural fibers, the sound absorption coefficient increased as porosity is decreased [8]
Airflow resistivity	Resistivity of a material against airflow is a measure of sound to be dissipated inside sound absorbing material	• Airflow resistivity has an inverse relation to air permeability • Moreover, as the airflow resistivity of the material increases, then it is difficult for sound waves to enter the material. Hence, sound absorption shows a significant decrease [9–11]
Tortuosity	It is a dimensionless structural parameter that shows the influence of the internal pore structure on the macroscopic velocity of fluid flow through a porous material	• According to Mamtaz, the more tortuous the material, the greater the sound absorption [12] • Higher tortuosity implies the pores are very curly causing higher interaction between sound and fibers of materials resulting in higher dissipation [13]
Air-gap	Air-gap improves absorption at lower frequencies	• Sound absorption shifts to the lower region by increasing the depth of back cavity [9]

Table 2 Description of sound absorptive materials of higher sound absorption characteristics

S1	Woodwool Fiber cement composite panel with rockwool padding of 50 mm, 48 kg/m^3 density
S2	Perforated composite metal alloy sheet filled with 50 mm thick glasswool of 48 kg/m^3 density
S3	12.5 mm thick gypsum board with a geometric array of 3 mm square perforations (total 9% perforation) and 50 mm thick rockwool (48 kg/m^3 density) filled with 1.5 mm thick gypsum backing
S4	Hexagonal Stretch Ceiling with 12 mm HDF boards, LED in between and 25 mm thick mineral wool HDF boards in between having 47 mm and 60.5 mm air-gaps maintained with 0.17 mm HDF board and acoustic fabric

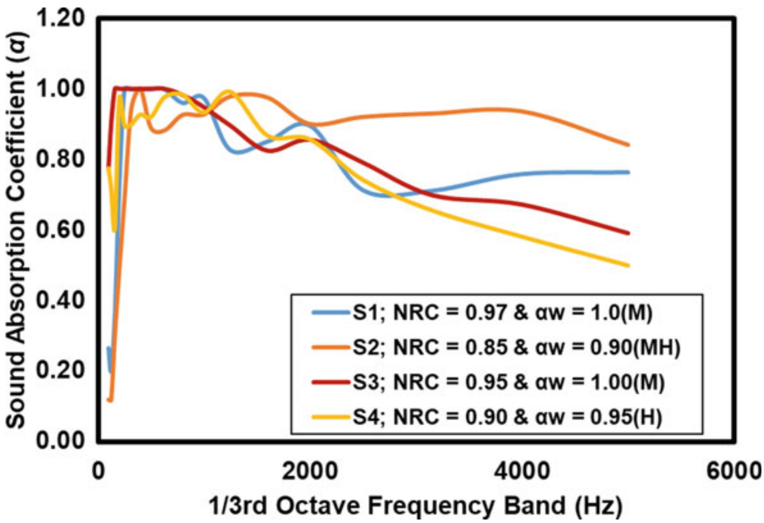

Fig. 3 Sound absorption coefficient of various sandwich acoustical materials of higher sound absorption characteristics tested in Reverberation chambers

References

1. Singal SP, Sharma O (1987) Acoustics of buildings part ii: materials and their characterization. Res Ind 32:14–24
2. ASTM E795-16, Standard practices for mounting test specimens during sound absorption tests
3. McGrory M, Cirac DC, Gaussen O, Cabrera D (2012) Sound absorption coefficient measurement: re-examining the relationship between impedance tube and reverberant room methods. In: Proceedings of acoustics 2012, 21–23 November 2012. Australian Acoustical Society, Fremantle
4. Bartle TW (1981) Effect of absorber geometry on apparent sound absorption coefficients as measured in a reverberation chamber. J Acoust Soc Am 69:1065–1074
5. Honeycutt R (2020) Progress on calculating edge effect of acoustical absorption. Audioxpress. https://audioxpress.com

6. Dunne R, Desai D, Sadiku R (2017) A review of the factors that influence sound absorption and the available empirical models for fibrous materials. Acoust Aust 45:453–469
7. Lim ZY, Putra A, Nor MJM, Yaakob MY (2018) Sound absorption performance of natural kenaf fibres. Appl Acoust 130:107–114
8. Fouladi MH, Nassir MH, Ghassem M, Shamel M, Peng SY, Wen SY, Xin PZ, Nor MJM (2013) Utilizing Malaysian natural fibers as sound absorber. In: Modeling and measurement methods for acoustic waves and for acoustic microdevices. Intech, pp 161–170
9. Hassan T, Jamshaid H, Mishra R, Khan MQ, Pteru M, Tichy M, Muller M (2021) Factors affecting acoustic properties of natural-fiber-based materials and composites: a review. Textiles 1:55–85
10. Czigany T (2006) Special manufacturing and characteristics of basalt fiber reinforced hybrid polypropylene composites: mechanical properties and acoustic emission study. Compos Sci Technol 66:3210–3220
11. Cherradi Y, Rosca IC, Cerbu C, Kebir H, Guendouz A, Benyoucef M (2021) Acoustic properties for composite materials reinforced on alfa and wood fibers. Appl Acoust 174:107759
12. Mamtaz H, Fouladi MH, Al-Atabi M, Namasivayam SN (2016) Acoustic absorption of natural fiber composites. J Eng. https://doi.org/10.1155/2016/5836107
13. Raj M, Fatima S, Tandon N (2020) Recycled materials as a potential replacement to synthetic sound absorbers: a study on denim shoddy and waste jute fibers. Appl Acoust 159:107070