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Chapter

Textiles for Noise Control

Mallika Datta, Srijan Das and Devarun Nath

Abstract

This chapter includes the mechanism of sound absorption and the classes of sound absorbing material to control the noise. The basic phenomena related to the reduction of sound by allowing it to soak in and dissipate also were introduced first, which, can be realised by viscous effects, heat conduction effects, and internal molecular energy interchanges. Porous absorbers are materials where sound propagates through an interconnected pore network resulting in sound energy dissipation. They are only effective at the mid-to-high frequency range, which is most sensitive to the human ear. The applications of different textile fibres and their various forms were identified later in the chapter. Finally, specific discussions are given to sound parameters, noise absorption coefficient, and its measurement technique. The chapter also deals with various factors influencing sound absorption.

Keywords: noise absorption coefficient, noise control, nonwoven, porous absorber sound absorption

1. Introduction

"The International Committee of Standardization of Acoustical Terms" has defined noise as 'sound not desired by the recipient' i.e. 'unwanted sound'. Generally, the machines that have been developed for industrial purposes, for high speed transportation, or improved livelihood of human beings are accompanied by noise [1, 2]. A noise system is comprised of three component [1, 3].

Noise Source: The component which perturbs the air;

Noise Path: It is the medium that promotes the propagation of the acoustical energy from one point to other

Noise Receiver: The component which has the potential to adjudge the quantity or level of noise at a point of interest.

The unwanted noise can be reduced by [4, 5]: 1) Source Treatment 2) Transmission Path Treatment 3) Receiver Treatment. In general, there are four basic principles involved in noise control: isolation, absorption, vibration isolation, and vibration damping [6–8]. The noise control options are thus said to be: 1) Absorbers 2) Barriers 3) Composites 4) Enclosures 5) Lag Treatment.

2. Mechanism of sound absorption

Sound absorbers are soft, porous, open-celled materials such as Baffles or Quilted fibrous system blankets that reduce the reflection of sound waves by allowing them to soak in and dissipate also. The dissipation mechanism of sound absorption results in the conversion of acoustic energy to heat energy. Attenuation or dissipation of acoustic energy as a sound wave moves through a medium attributed to three basic mechanisms [4, 6]: Viscous effects, Heat conduction effects, Internal molecular energy interchanges. Dissipation of acoustic energy due to fluid friction while moving through the medium is a thermodynamically irreversible propagation of sound responsible for viscous effects. In Heat conduction effects, heat transfer between high and low temperature regions in the wave results in non-adiabatic propagation of the sound. The sum of these two mechanisms, viscous and heat conduction, is called the classical attenuation, α_n is given by

$$\alpha_n(classical) = \frac{2\pi^r f^2}{\rho c_p^3} \mu \left(\frac{4}{3} + \frac{\varphi - 1}{P_r}\right) \tag{1}$$

where,

 μ is fluid viscosity, φ specific heat ratio (1.667 for monatomic gases and 1.400 for diatomic gases), Pr is Prandtl number and equals to μc_p ,/ k_t where k_t = thermal conductivity c_p = specific heat at constant pressure ρ is the density of the fluid and f is frequency [4].

Attenuation of sound energy in fluid results from the finite time required converting translational kinetic energy into internal energies. This is associated with the rotation and vibration of the molecules. The attenuation coefficient can be written in terms of the sum of the individual contributions as follows [4]:

$$\alpha = \alpha_n(classical) + \sum \alpha_{ij} \tag{2}$$

where, the α_{ij} are the contributions of the various vibration energy relaxation effects.

3. Sound absorbing material

The sound absorption performance of the material is influenced by the amount of acoustic energy absorbed and reflected by the same. The concept of a perfect absorber can be understood by an open window that transfers all the incidence energy to the other side of the window, thereby results in 100% absorption (α = 1.0). An open window of 1 m² area gives 1 Sabine of absorption [5]. The maximum absorption of sound is found when the natural impedance of the material is equal to the characteristic impedance of the air (medium). Thus the sound absorbing capacity of a material is the function of its natural impedance (Zc). The sound absorption phenomenon of an acoustic material varies with the frequency and angle of incidence of the sound waves impinge upon the material.

There are mainly four types of sound absorption materials [2] available to achieve sound absorption namely porous absorber, Helmholtz resonator, membrane absorber and perforated panel absorber [7, 8] as discussed below which are

3.1 Helmholtz resonator

Helmholtz resonator can be used to estimate sound absorption at a lower frequency range [4, 8]. The quality factor (Q) indicates the quality of the resonator. The bandwidth in Hz is estimated from resonance frequency in the case of the Helmholtz resonator following the equation as described below [5].

$$Q = \frac{f_{res}}{\Delta f}$$
(3)

where Q is the quality factor, f_{res} is resonance frequency in Hz and Δf is bandwidth in Hz

A Helmholtz resonator is a cavity filled with air with a small opening or neck. The resonator is considered to be undamped when no porous fibres are found in the cavity. Equation (4) is used to determine the undamped resonance frequency of a Helmholtz resonator [9].

Under the condition of no porous fibres inside the cavity,

$$f_{res} = \frac{1}{2\pi\sqrt{BC}} \tag{4}$$

where,

B is inertance and C is an acoustical capacitance

$$B = \frac{\rho_0(L+1.7R)}{\pi R^2}$$
(5)

where,

 ρ_0 = Density of the air kg/m³ (L+1.7R) = Effective length of the neck, m πR^2 = Area of the opening, m²

R = Radius of the hole in m

$$C = \frac{V}{\rho_0 c_0^2} \tag{6}$$

where,

C = Acoustical capacitance

V = Volume of the chamber, m³.

 c_0 = Speed of sound in air, m/sec.

 ρ_0 = Density of air, kg/m³

Alternatively, the approximate resonance frequency, fres (for nonporous fibrous material) could be calculated using the following equation [9]



 c_0 = Speed of sound, m/s

D = Area of the neck, m²

v = D (L + 1.7R) Effective volume of the neck, m³

V = Volume of the chamber, m³

The sound absorption performance of the Helmholtz resonator at its resonance frequency can be then estimated using the following equation

$$\alpha_B = 0.159 \left(\frac{c_0}{f_{res}}\right)^2 \tag{8}$$

where,

 $\alpha_{\rm B}$ = Sound absorption, m² (Sabine)

 c_0 = Speed of sound in air, m/sec

3.2 Membrane absorber

A Membrane absorber [5] or diaphragmatic absorber is used to absorb low frequencies sound energy. The membrane absorber offers resistance to rapid flexing and the surrounding enclosed air also shows resistance to compression during vibration at the low frequencies of sound and converts that to heat energy. A membrane type absorber is made of plywood or rubber stretched and attached to a rigid support/panel placed at some distance with respect to a solid wall. The stiffness of the panel and the method of fixing of membrane on the panel influence performance of the absorber as the panel itself tends to vibrate.

3.3 Perforated panel absorber

A perforated panel absorber [5] is the rigid thin perforated sheet with a circular opening/aperture. An air cavity is found behind the perforated panel absorber (PPA) as it is mounted at a distance from the wall. The performance of PPA is improved to tackle broader frequency range when the cavity is filled with porous fibre. The resonance frequency of the perforated panel can be estimated using the following equation [9].

$$f_{res} = \frac{c}{2\pi} \left\{ \frac{P}{d(L+1.7R)} \right\}$$
(9)

where

c = Speed of sound in air, m/sec

P = Perforation ratio (hole area/plate area)

d = Distance of the perforated panel from the wall, m

L = Perforated panel thickness, m

(L + 1.7R) = Effective length of the neck

R = Radius of the hole, m.

An air gap between the porous fibre and the wall increases the thickness of the perforated panel and also the depth of the air gap lowers its resonance frequency. Therefore, by varying the depth of the air space and the thickness of the perforated panel, the broader frequency range of sound absorption performance could be achieved. A perforation ratio of more than 20% with a small aperture does not affect the sound absorption of porous fibre. However, a smaller perforation ratio reduces the higher frequency sound absorption performance of porous fibre [7].

The thickness of the PPA increases with cavity depth or the air gap between rigid wall and absorber which in turn lowers its resonance frequency. Thereby, the change in cavity depth/depth of the air space and the thickness of the perforated panel make PPA more suitable for the broader frequency range of sound absorption performance. The small aperture/perforation with more than 20% perforation ratio has no effect on sound absorption by PPA. However, a smaller perforation ratio reduces the higher frequency sound absorption performance of porous fibre [7].

3.4 Porous absorber

In porous absorbers [10, 11], sound propagates through an interconnected pore [12] network resulting in sound energy dissipation. They are only effective at the mid-to-high frequency range, which is most sensitive to the human ear [12]. The porous absorbers are found their applications in noise control for industries, auto-mobiles, building acoustics, and sound recording studios. The magnitude of unde-sirable sound/noise reflected from hard interior surfaces and reverberant noise level

is reduced in presence of such absorbers [8]. The various classes of porous absorbers are i) cellular ii) granular, and iii) fibrous materials. The cellular absorbers are made of foam of polyurethane and sometimes metal like aluminum [8]. Sound absorbing foam with an open structure allows the propagation of air from one to the other face through the interconnected pores [12]. The polymer based foam is associated with fire hazard and the generation of combustible toxic gases while the metallic foam offers higher mechanical strength [13]. Some common examples of granular absorbers are panels made of wood chips, pervious road, and, porous concrete. The granular absorber can be used in the form of a consolidated structure made with the suitable binder(s) or in the loose form [13]. The used tires, rubber particles, and waste foam have been identified in making granular absorbers [12, 14]. Fibrous materials as reported compose of glass, mineral, or organic fibres in the form of nonwoven fabrics, boards, or preformed elements. The granular materials can achieve a broadband absorption limited to around 0.8, while in the case of fibrous absorbent, the value can rise to unity [12]. Fibrous and granular absorbers are often produced by bonding the fibres or granules with a binder. They are generally covered with a thin perforated sheet such as highly perforated panels of metal, wood or gypsum giving better aesthetic value protecting from damages and prevent the particles from polluting the air which may harm the eco-system [8].

4. Textile materials as porous absorber

4.1 Textile fibre

The textile fibre based porous absorber may be made of felt, glass wool, rock wool, polymer foams, waste cloth fillers [15–21]. The structure of the absorber consists of cavities that promote internal reflection of sound of waves, trap the sound energy and dampen the oscillation of the air particles by friction with absorber material [22]. They are, however, effective for the medium to high frequency range only [23]. The type of fibrous porous absorber is based on the raw material viz., metal, synthetic polymer, and natural. The fibrous forms of metal and its alloy viz., stainless steel, nickel, aluminum, etc., are also identified as suitable noise absorbers in harsh environments [19, 23, 24].

Presently, synthetic fibres have largely been used owing to some advantageous attributes viz., large specific surface area, good mechanical strength, and good permeability [23, 25, 26]. The various structural forms of such fibre as acoustic absorber include the felt, woven cloth, and fibre reinforced composites [23]. The various synthetic fibre options in noise control are glass wool, rock wool, basalt, carbon fibre [15, 17, 19, 20, 24, 27–30]. The crude based fibres like polyester [26, 31–38], polypropylene [39–41], nylon [42, 43] were also used for noise control study. Polyester microfibre felts showed improved noise absorption in the middle frequency, ranged from 1200 Hz to 4000 Hz [44]. The study on polyester and nylon microfibre fabric concluded that sound absorption increased with fabric density up to 0.14 g/cm [17, 45]. Synthetic fibres and their blend at different ratios towards the optimised acoustic absorption coefficient have been identified by several researchers [37, 38, 40, 46–50].

The use of metallic fibre in noise controls is limited due to their poor flexibility, heavyweight, poor formability [23], while the synthetic polymer fibres are nonbiodegradable and cause serious health hazards during manufacturing, installation, and disposal [10]. The limitation of metallic and synthetic based fibrous porous absorbers wrenches the researcher in the exploration of suitable alternatives from a renewable resource.

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Different works had been reported on exploration of using various natural fibres [51–53] viz., wool [54], cotton [50, 55], kapok [56], kenaf [57], hemp [58–60], ramie [61], flax [57, 61–63], banana [64], broom [65], coir [66], jute [51, 61, 67–70], tea leaf [71], combination of Luffa fibres with cotton layer [72] and agro residues viz., straw, oil palm [57] for producing sound absorbers. Most of the fibres showed encouraging sound absorption property.

The textile materials in various forms viz., woven [73–76], carpet [77, 78], non-woven [70, 76, 79–88], knitted [89], and composite [31, 48, 59, 68, 90–93] were used for control of noise.

The major disadvantage associated with fibrous absorbers is in tackling long wavelengths of low frequency sound energy. Different approaches were attempted by various researchers to improve the noise control performance of porous absorbers. Some works are available in the literature on the improvement of absorption performance of noise of low frequency range by adjusting the nonacoustical parameters viz., thickness, areal density, and bulk density of porous absorber [94].

4.2 Forms of textiles in noise control

4.2.1 Nonwoven fabric

The use of nonwoven or felt structures developed from different fibres and their blend or in composite form is gaining interest to use as a noise control solution [3, 13, 26, 31, 81, 84, 87, 95]. Effect of fibre fineness, fibre cross section, structure parameters of nonwoven viz., total surface area, the density of fibre packing, thickness and physical parameters including fibre mixing ratio (blend ratio), bulk density [51, 70, 96, 97] were investigated. The results revealed that total surface and fabric density determined sound absorption positively, and fibres with profiled cross-section shapes show a higher noise reduction coefficient [26]. The acoustic absorption coefficient increased with the increase of thickness of nonwoven/felt [98, 99]. Pore diameter [100], porosity, and the air gap behind the mounted nonwoven samples influenced the sound absorption at low frequency [101]. Absorption behaviour changes with different fibre content in their blend [46, 47, 98, 99] and there was an optimum bulk density for noise reduction [98]. The use of fibre with a larger lumen in the mix of natural with synthetic fibres enhanced the noise control performance [98, 99]. The increase in hollow fibre percentage in nonwoven fabric was directly related to its thickness and sound absorption efficiency [85]. The use of nonwoven made from natural fibres was suitable for application in vibration control for the automobile industry due to their excellent strength and renewable properties [102] and offered excellent absorption in the mid-to-high frequency ranges [86]. The work revealed [40] that the orientation of fibres in nonwoven did not affect acoustic absorption whatever might be the pile orientation of 0°/90° and 45°/45° [40]. The smaller size of aerogel embedded in a nonwoven fibre matrix has positive effects on acoustic absorption [103]. Introduction of nano fibre in making nonwoven improve both sound absorption and sound transmission loss [104]. Acoustical nonwovens with activated carbon fibre on the surface exhibited improved acoustic properties [79-81].

4.2.2 Woven fabric

The use of woven structure in noise control was identified by various researchers [105–107]. The study on the effect of weave type, weft yarn linear density, thickness created by the layering of test fabrics, yarn spinning system, and depth of air

space at the back of samples revealed that the sound absorption coefficient of woven fabrics is influenced by both density and porosity of fabrics. The weight and cover of woven cloth as an upshot thread density and thread count [107, 108] influenced transmission loss of sound transmitted through the structure. Higher thickness of woven fabric associated with improved noise reduction coefficient [106]. The plain weave structure offered higher sound absorption in comparison to other weave designs. Higher absorption woven structure was found with finer and low twisted weft yarns [109]. The woven structure made of fabrics rotor-spun yarns exhibited the highest absorption in comparison to structure made with ringspun or compact yarns.

Pile carpet as noise control material was investigated [77] and it was found that pile thickness and weight of carpet have a minor influence on transmission loss of sound moving through the carpet. Effect of pile parameters namely fibre type, pile height, and carpet construction, pile density, air gap behind the mounted tufted carpets was studied which identified suitability of various factors in controlling sound at audible frequency range [78]. The air gap behind the carpet enhances the noise absorption capacity at low to medium frequencies.

4.2.3 Knitted fabric

NAC for plain knitted structures with the same thickness but different pore changes with the size of pore diameter. The smaller diameter pore under the influence of smaller stitch sizes with lower porosity offers a higher degree of sound absorption sizes [110]. For the same value of pore radius and porosity, the NAC changes with thickness in the case of knitted structure [111]. Introduction of spacer fabric inside the knitted structure improved the noise control performance of the knitted structure.

5. Factors influencing sound absorption

Studies on various parameters that influence the sound absorption properties of fibrous materials have been published widely in the literature [7, 10, 12, 94, 112, 113]. The factors in detail can be described as follows:

5.1 Textile factor

5.1.1 Fibre Size

The sound insulation behaviour of wool fibre based material sound absorption coefficient increase with a decreasing fibre diameter [54]. It is found that thin fibres can move more easily than thick fibres on sound waves. Moreover, with fine denier, more fibres are required for the same volume density which generates a more tortuous path and higher airflow resistance [94]. Studies of Tancan [82] revealed that the fine fibre increases sound absorption coefficient values due to an increase in airflow resistance through increased viscosity resulting from the vibration of the air.

5.1.2 Thickness

The thickness of the porous absorber directly influences the low frequency sound absorbing performance [94, 114]. The material with an apparent thickness (includes cavity depth from the rigid back) equal to the one-quarter wavelength at a resonant frequency gives peak absorption [94], however, the threshold thickness for effective absorption is one-tenth of wavelength. A study also showed that sound absorption increases with the increase in thickness of the material only in the case of low frequencies. Thickness becomes insignificant at higher frequency.

5.1.3 Density

The sound absorption performance of a material is a function of the bulk density of the material [10, 54]. It is to be kept in mind that the density of the acoustic material affects its cost. The sound absorption value of the absorber at the middle and higher frequency (> 500 Hz) increases with the density of the sample [115]. When the number of fibres increases per unit area, the apparent density (considering the entrapped air) is high. Conversion of sound energy to heat increases as the surface friction at the viscous boundary layer increases [12] and so the sound absorption coefficient, especially for nonwoven fibrous materials [23, 53, 94]. Open and light porous structure absorbs the sound of low frequencies (<500 Hz), while denser structure suitable for frequencies above 2000 Hz.

5.1.4 Porosity

The sound absorption mechanism of the porous absorber can be explained in the light of, pore parameters viz, number, size, and shape [100]. Dissipation of sound energy is owing to frictional resistance offered by the pores that allowing the propagation of sound through it. The porosity is generally thus defined as the ratio of the volume of the voids in the material to its total volume [12, 116]. Equation (9) defines porosity (Ø) [53, 117].

Porosity =
$$(\emptyset) = \frac{V_a}{V_m}$$
 (10)

where:

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

5.1.5 Tortuosity

Tortuosity is a measure of the crookedness of the passageway through the pores, compared to the thickness of the sample. Tortuosity enumerates the influence of the internal structure of a material on its acoustical properties. Con Wassilieff [118] describes it as a measure of the deviation of the pores from the normal, or meander about the material. The location of the quarter-wavelength peaks of sound energy is influenced by tortuosity, while the height and width of the peaks are persuaded by porosity and flow resistivity. The degree of crookedness/tortuosity determines the behaviour of absorbing porous materials at the high frequency level.

5.1.6 Compression

The porous fibrous textile structures are compressible in nature and experience compression on the application of load and thickness decreases. The factors like density, porosity, tortuosity, airflow resistivity, porosity, and density also vary with changes in thickness. The studies [119, 120] found that in the event of reduction of the thickness of a homogeneous layer of porous fibrous porosity and characteristic lengths (shape factor) [12, 94] decrease while the density and tortuosity or crookedness in the structure increase. The effect of compression of fibrous structure is found to be more profound in the case of automotive acoustics. The weight of the passenger causes cyclic compression and expansion of the seat padding that results in squeezing down the porous materials (fibrous or cellular) which in turn results in the variation of the above mentioned physical parameters [3].

5.1.7 Airflow resistance

One of the most important parameters that influence the sound absorbing characteristics of fibrous material is the specific flow resistance per unit thickness of the material [12, 32, 94, 116, 121]. The characteristic impedance and propagation constant, which describes the acoustical properties of porous materials, are governed to a great extent by the flow resistance of the material [94].

The presence of fibrous peg (due to interlocking of fibre at the time of needling) as frictional elements in the case of a needled nonwoven, provide resistance to acoustic wave motion. As the sound wave enters a fibrous nonwoven structure, its amplitude is decreased by friction while moving through the tortuous path, and sound energy is converted into heat [94]. The friction resistance of the material to the flow of air is called 'airflow resistivity' and is expressed as:

$$\sigma = \frac{\Delta P}{\Delta T} \times \frac{1}{u} \operatorname{Pa.s/m^2}$$
(11)

where,

 σ = airflow resistivity Pa.s/m²

u = Air velocity through sample m/sec

 Δp = Sound pressure differential across the thickness of the sample measured in direction of particle velocity, N/m²

 ΔT = Incremental thickness [3, 94]

Based upon the airflow test following ASTM D737 [122], flow resistivity σ of the sample is obtained from the following equation:

$$\sigma = \frac{P}{ct} \tag{12}$$

where,

P = Static pressure differential between both faces of the sample, dyne/cm² (10⁻¹ Pa)

c = Air velocity, cm/s

t = Thickness of sample, cm

The airflow resistance per unit thickness of a porous material is proportional to the coefficient of viscosity of the fluid (air) and inversely proportional to the square of the pore size of the material. For a fibrous material with a given porosity, the flow resistance per unit thickness is inversely proportional to the square of the fibre diameter

5.1.8 Surface impedance

For a given layer of thickness, the acoustic resistivity of an absorber is directly related to its ability to dissipate sound energy. Moreover, the surface impedance [123] of the layer increases with the degree of air resistance offered by the structure that results in a more reflection of sound from the surface layer. Thereby, sound absorption by the fibrous structure reduces. The mechanism of sound absorption is

frequency dependent, thus at a lower frequency as the thickness of the layer increases resistivity decreases.

5.2 Other factor

5.2.1 Placement/position of sound absorptive materials

The placement/position of sound absorptive materials is known to affect the sound absorption of the material. It has been reported by Alton Everest [5], that if several types of absorbers are used, material applied to the lower portions of high walls can be as much as twice as effective as the same material placed elsewhere [124]. The porous structure behaves like a frequency dependent membrane of a certain mass under the influence of an air cavity behind a material. The presence of air inside the cavity has an analogy to a mechanical spring. The absorption property of the porous fibrous absorber enhances significantly with the air filled cavity between the absorber and the rigid back wall [125].

5.2.2 Temperature

The study [126] revealed that the sound absorption characteristics of mineral wool remained unaffected by the change in temperature in the range of 10–50 °C. Least square method was used to develop a theoretical relation between the noise reduction coefficient and the thermal conductivity at different temperature conditions.

5.2.3 Process parameters

Process parameters during absorbent material formation have an important impact on sound absorption due to their effects on the characteristics of the absorbent material. It reported that 'air laid' web based nonwovens offered higher sound absorption compared to carded ones irrespective of the fibre content. This might be due to higher flow resistivity of air laid nonwovens because of relatively random placement, and thus, higher tortuosity, the higher number of pores with smaller sizes, higher number of fibre to fibre contact points, and gradient in porosity due to gravity. Among web bonding methods [3], did not find a significant difference between needled and needled plus thermally bonded nonwovens. Thermal bonded and needle punched nonwoven (punching density of 28 cm^{-2}) from polypropylene and needle punched polyamide nonwoven offered maximum absorption of sound at a material density of 100 kg/m³ over a frequency range of 63 to 8000 Hz [88]. The fibres of diameter 10 to 40 μ m were used to manufacture the nonwovens with thickness varying from 3 to 20 mm. The study revealed that the needle punched nonwovens had more dependency on the frequency of sound energy as well as on the diameter of fibres compared to thermally bonded webs.

6. Testing and characterisation of sound absorbing material

6.1 Absorption coefficient

When a beam of sound wave (E_i) strikes against a barrier, gets divided into three parts: i) E_r is reflected part ii) E_a is the part absorbed in the barrier iii) E_t is transmitted part to the other side of the barrier as shown in **Figure 1**. These phenomena can be written as



Figure 1. *Typical behaviour of sound wave striking a wall.*



Figure 2. *Reflection and transmission at the boundary between two media.*

$$E_i = E_r + E_a + E_t \tag{13}$$

Then the sound absorption coefficient,
$$\alpha$$
 is defined as follows [7, 93].

$$\alpha = \frac{E_i - E_r}{E_i} = \frac{E_a + E_t}{E_i}$$
(14)

Equation (13) shows that all portion of the sound energy which is not reflected is considered to be absorbed.

When an infinitely large boundary plane presents between two media, the path of movement of the sound wave traveling from Medium 1 to 2 is normal to the boundary plane, as shown in **Figure 2**. The relation of reflected and transmitted sound can be expressed as:

$$P_i + P_r = P_t \tag{15}$$

$$V_i + V_r = V_t \tag{16}$$

where, P_i is incidence sound pressure, P_r is reflected sound pressure, V = P/Z and Z is the inertance or impedance

$$Z_1 = \rho_1 c_1$$
 and $Z_2 = \rho_2 c_2$

The sound pressure reflection coefficient r_p is

$$r_p = \frac{P_r}{P_i} = \frac{Z_2 - Z_1}{Z_2 + Z_1} \tag{17}$$

The relationship between the absorption coefficient and sound pressure reflection coefficient between two media is given by:

$$\alpha_{\rm r} = \frac{E_{\rm r}}{E_{\rm i}} = \left(\left| \frac{P_{\rm r}}{P_{\rm i}} \right| \right)^2 = \frac{\left(Z_2 - Z_1 \right)^2}{\left(Z_2 + Z_1 \right)^1}$$
(18)
$$\alpha = 1 - \left| r_{\rm p} \right|^2 = 1 - \frac{E_{\rm r}}{E_{\rm i}} = 1 - \left(\left| \frac{P_{\rm r}}{P_{\rm i}} \right| \right)^2 = 1 - \frac{\left(Z_2 - Z_1 \right)^2}{\left(Z_2 + Z_1 \right)^1}$$
(19)

6.2 Principles of sound absorption measurement

Two standards and one relative measurement technique are used to measure the noise control property of absorbing material and describe in detail as follows.

6.2.1 Impedance tube method

This technique (Normal Incidence Technique) [4, 7, 127] is based on normal incident sound energy and requires a tube (**Figure 3**) where its diameter is smaller than the wavelength. The absorption coefficient can be measured in impedance tube as per ASTM E 1050-12 and ISO 10534-2: 1998 standards [128, 129]. The circular sample of φ 30 mm and φ 100 mm are tested against the rigid back wall using two tubes. The larger diameter tube (φ 100 mm) is used to measure the absorption coefficients in the frequency range, 63–1600 Hz, and a smaller diameter tube (φ 30 mm) for measuring in the frequency ranges from 1000 Hz–6300 Hz. The samples are tested five times to minimize the influence of variation of thickness and areal density.

6.2.2 Reverberant field method

Measurement of sound absorption is concerned with the performance of a material exposed to a randomly incident sound wave, which technically occurs when the material is in a diffusive field (Random Incidence Technique) [7, 130]. EN ISO 354 (2003) testing standard method [131] is employed to measure the



Figure 3. *Schematic diagram of impedance tube.*

reverberation time (RT) to determine the absorption coefficient. This technique requires a reverberation chamber with a volume of 200 m³. The diffused acoustic field is created inside the room to test the sample with an area between 10 m² and 12 m². The absorption coefficient α_r is calculated using the following formula from RT.

$$\alpha_r = \frac{KV}{s} \left[\frac{1}{T_m} - \frac{1}{T_0} \right] + \overline{\alpha}$$
(20)

Where,

V = Volume of reverberation chamber, m³

S = Surface area of the material tested, m²

 T_m = time with tested material, sec.

 T_0 = time empty, sec

 $\overline{\alpha}$ = Average sound absorption coefficient of reverberation chamber *K* = constant=0.16

6.2.3 Clemson-Boston differential sound insulation method

Clemson-Boston Differential Sound Insulation (CBDSI) Tester [95] is used to measure sound insulation of the material as shown in **Figure 4**.

CBDSI is comprised of a computer to process sound signal, an amplifier to amplify the sound signal, sound source, sound chamber, sample holder to mount the test sample, and a detector to detect the sound. The sound source generates white noise [7] in the frequency range of 73 Hz to 20,000 Hz for testing the sound insulation property of the material under investigation. The signal amplifier amplifies the signals generated by the computer which are then converted into sound waves via the sound source. The material under investigation mounted on the sample holder interferes with sound energy as it is in the path of sound. The sound moves through the sample and strikes the detector, which changes the received sound signals to electric signals that are then analyzed by the signal-processing computer. The test is also conducted with no sample in the sample holder to measure the insulation property of the material in reference to the background.



Figure 4. Schematic diagram of Clemson-Boston differential sound insulation tester.

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CBDSI tester provides a direct comparative analysis of various types of samples as they are tested under the same conditions. Sound insulation property in terms of 'Transfer Function Magnitude' in dB unit is evaluated by this instrument.

7. Commercial players and market overview

Currently, a wide range of synthetic fibres is taken for noise reduction applications. Various structural forms of synthetic fibre use in noise control are woven, nonwoven, knitted, fibre felts, and fibre reinforced composites. The different crosssections of synthetic fibre such as hollow [35, 85], and triangular, trilobal are beneficial to improve acoustic absorption properties. It has been reported that hollow fibre has higher sound absorption and of lighter weight. Superior mechanical responses [23] of synthetic fibre and their various cross sectional in combination with natural fibre [22, 52, 53, 72] make them suitable for optimized applications in noise control. The use of recycled synthetic fibre [38] as a noise control solution addresses the concern related to the disposal of hard generated after the use of virgin nonbiodegradable synthetic fibre.

The forecasted growth size of the global noise control system market will be nearly 200% during 2017-2027 [132]. The noise control materials generally used in residential, industrial, and commercial applications in the form as follows

Acoustic panels Acoustic tiles Sound curtains Acoustic surface Sound insulating flooring Sound barrier walls Baffles Sound blanket Sound doors

8. Conclusion

In this chapter, the mechanism of sound absorption has been discussed first followed by a detailed description of the type of sound absorbers such as Helmholtz resonator, membrane absorber, perforated panel absorber, porous absorbers with emphasis on textile materials as sound absorbers. Then the effect of fibre size, thickness, density, porosity, tortuosity, compression, etc. on sound absorption has been discussed followed by a brief description of the principles of sound absorption measurement.

Conflict of interest

The authors declare no conflict of interest.

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Author details

Mallika Datta^{*}, Srijan Das and Devarun Nath Government College of Engineering and Textile Technology, Serampore, Serampore, India

*Address all correspondence to: dattamallika8@gmail.com

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