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NONWOVEN SOUND ABSORPTION MATERIALS

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ABSTRACT

Noise is a major cause of industrial fatigue, irritation, reduced productivity and occupational accidents. Continuous exposure of 90dB or above is dangerous to hearing. Installation of noise absorbent barriers (made from wood and textiles) between the source and the subjects is one of the main methods of noise control. Measurement techniques used to characterize the sound absorptive properties of a material are reverberant field method, impedance tube method and steady state method. Noise absorbent textile materials especially nonwoven structures or recycled materials have low production costs, low specific gravity and are aesthetically appealing. Acoustic insulation and absorption properties of nonwoven fabrics depend on fiber geometry and fiber arrangement within the fabric structure.

KEYWORDS: Noise Absorption**,** Textile industry**,** Noise control.

INTRODUCTION

Sound is an important part of our life but unpleasant and unwanted sound is considered as noise. Noise may cause sensori-motor, neuro-vegetative and metabolic disorders. Noise is a major cause of industrial fatigue, irritation, reduced productivity and occupational accidents. Continuous exposure of 90dB or above is dangerous to hearing. Installation of noise absorbent barriers (made from wood and textiles) between the source and the subjects is one of the main methods of noise control. Hard, rigid materials like concrete and brick have almost no sound absorption. Other building materials (lightweight plaster walls, windows and different panels or floors on studs) work as membrane absorbers and contribute significantly to the low-frequency absorption. Carpet, velour fabric and heavy curtain show good acoustic property (Hankuk, 2011).). Textile materials are used in many sound insulation applications in interior design products (panels and upholstery), automotive insulation (carpet, trunk liners and roof paneling) and machine sound insulation (duct liner and trunk). Polyester panels are a great choice for better sounding classrooms. Acoustical wall panels made from 100% polyester (60% PET-recycled fiber and 40% PET-virgin fiber), are recyclable and provide great sound absorption (Acoustical Solutions Inc., 2011). Acoustic ceilings made of fiberglass, mineral fiber, wood, or metal control the sound quality by absorption and diffusion of sound waves. In automobiles textile materials are used to enhance comfort, thermal insulation, cabin air filters, safety and sound insulation. Silk weavers have developed lightweight, translucent curtain materials known as 'sound quenching curtain', which are excellent in absorbing sound. With a gap of 15cm between curtain and wall, it can absorb up to five times more sound than typical lightweight curtains (Acoustical Surfaces Inc., 2012). Nonwoven absorbent materials especially recycled materials have low production costs, low specific gravity and are aesthetically appealing.

MEASUREMENT OF SOUND ABSORPTION

Sound is an alternation of pressure that propagates through an elastic medium such as air which produces an auditory (Figure 1). Scientific study of sound involving the effect of reflection, refraction, absorption, diffraction and interference is known as "Acoustics".

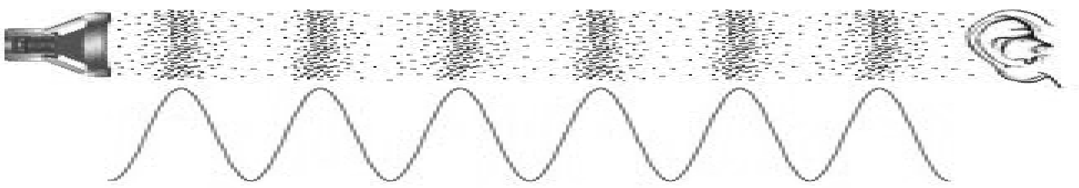

Figure 1: Alternative patterns of dense and sparse particles

Sound absorption is an energy conversion process. The kinetic energy of the sound (air) is converted to heat energy when the sound strikes the cells or fibers. Whereas diffused reflection splits the reflected sound wave in many directions. Diffusive surfaces are used to avoid echoes and sound concentrations especially in rooms designed for music [1]. Sound wave reaches a surface of acoustic material during its propagation in air and gets divided into three components: a reflected part, a transmitted part and an absorbed part (Figure 2). A receiver on the same side as the sound source can receive both the incident and reflected sound waves. The ability of the acoustic material to absorb the incident sound wave can be evaluated by comparing the sound power levels between the reflected sound wave and the incident sound wave. The absorption coefficient α is expressed as:

$$\alpha = \frac{\text{transmitted + absorbed energy}}{\text{total incident energy}}$$

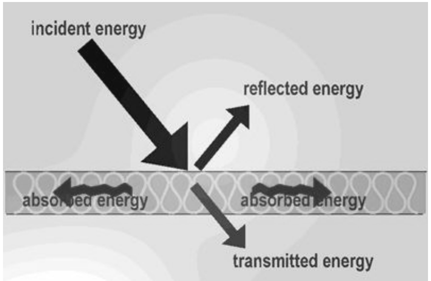

Figure 2: Sound wave propagation

Measurement techniques used to characterize the sound absorptive properties of a material are reverberant field method, impedance tube method and steady state method. Reverberant field method is used to measure the performance of a material exposed to a randomly incident sound wave, which technically occurs when the material is in diffusive field. Impedance tube method uses plane sound waves that strike the material straight and so the sound absorption coefficient is called normal incidence sound absorption coefficient (NAC). Steady state method (ASTM E336-71) is used to measure the transmission coefficient of the materials. A third microphone or even a second pair of microphone can be placed behind the test sample in a second impedance tube.

Acoustical properties of fabrics are measured by impedance tube method (ASTM C 384-98). The impedance tube method uses very small test samples. For large test samples, large reverberation rooms are used and the method is known as acoustic chamber method (Tascan & Vaughn, 2008). The measurement of sound absorption of the nonwoven is based on ASTM E 1050 using a tube, two microphones and a digital frequency analyzer as shown in Figure 3. A sound source is mounted at one end of the impedance tube and the material sample is placed at the other end. The loudspeaker generates broadband, stationary random sound waves. These incident sound signals propagate as plane waves in the tube and hit the sample surface. The reflected wave's signals are picked up and compared to the incident sound waves. The frequency of waves is tested by the diameter of the tube. A large tube (100mm diameter) is used to measure the sound absorption in the low frequency range (50 to1600Hz), whereas a small tube of 29 mm diameter is used for high-frequency sound waves.

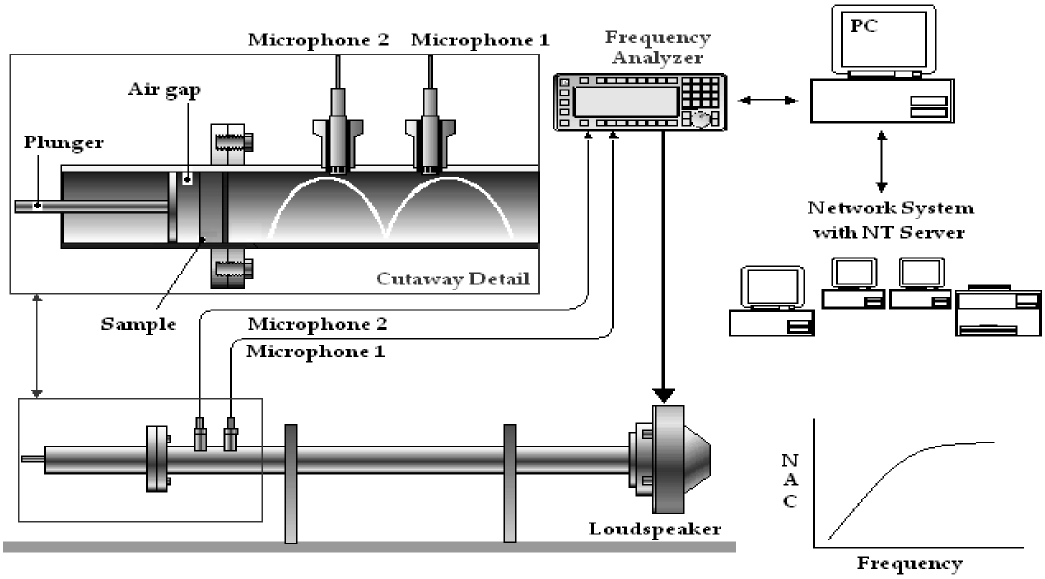

Figure 3: Impedance tube setup

ABSORBENT MATERIAL

POROUS ABSORBERS

Porous absorbers are the most commonly used absorbing materials, where thickness plays an important role in sound absorption. These materials allow air to flow into clear structure where sound energy is converted to heat energy. Common porous absorbers include carpet, draperies, spray-applied cellulose, aerated plaster and fibrous mineral wool/glass fiber (Figure 4).

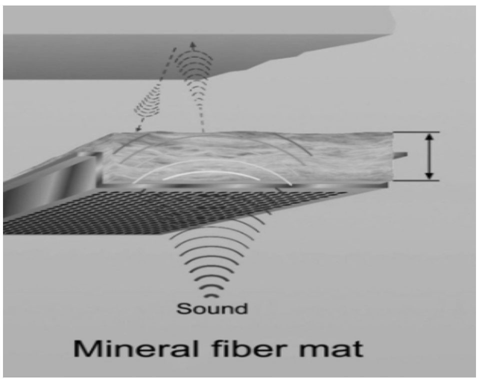

Figure 4: Porous absorbers

RESONATORS

Resonant absorption does not depend on the properties of the material in the same way as for porous absorption. The absorption is obtained by energy losses in an oscillating system**.** There are two main types of resonators: Membrane and Cavity (Helmholtz) Resonators. Cavity resonators as shown in Figure 5, typically act to absorb sound in a narrow frequency range. These resonators include some perforated materials; e.g. HELMHOLTZ resonator. It has the shape of a bottle and the resonant frequency is governed by the size of the opening, the length of neck and the volume of air trapped in the chamber.

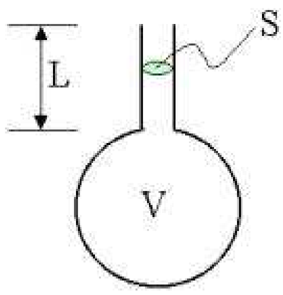

Figure 5: Cavity resonator

Panel absorbers or membrane resonator is a thin, solid panel at a distance from a rigid wall with an enclosed air volume in between. Panel absorbers are non-rigid, non-porous materials which are placed over an airspace that vibrates in a flexural mode in response to sound pressure exerted by adjacent air molecules. Common panel absorbers include thin wood panels over frame, lightweight impervious ceiling and floors, glazing and other large surfaces capable of resonating in response to sound.

SMART ABSORBING MATERIALS

More recently, the use of active noise control has been combined with passive control to develop hybrid sound absorbers. Active control technologies appear to be the only way to attenuate the low-frequency noise components. Therefore, a hybrid absorber can absorb the incident sound over a wide frequency range (Arenas & Crocker, 2010). Figure 6 shows the principle of a hybrid absorber, which combines passive absorbent properties of a porous layer and active control at its rear face, where the controller can be implemented using digital techniques.

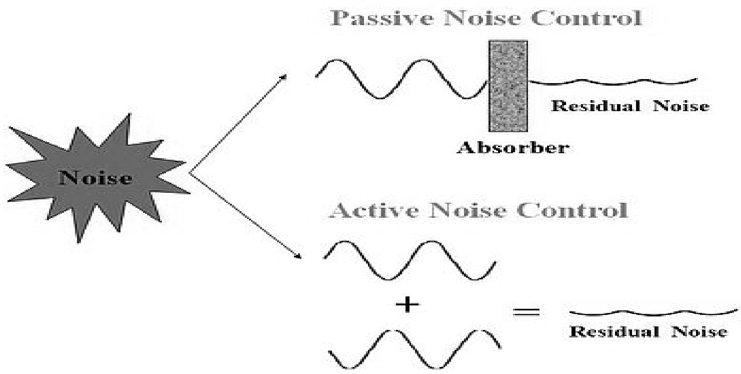

Figure 6: Hybrid sound absorber

FACTORS INFLUENCING SOUND ABSORPTION OF NONWOVEN MATERIALS

The efficacy of a material as a sound (noise) barrier depends on frequency of the sound wave to which material is exposed, fabric weight per unit area, air permeability of the substrate, thickness and construction. Acoustic insulation and absorption properties of nonwoven fabrics depend on fiber geometry and fiber arrangement within the fabric structure (Lee & Joo, 2003). A summary of the factors influencing sound absorption of nonwoven materials is shown in Figure 7.

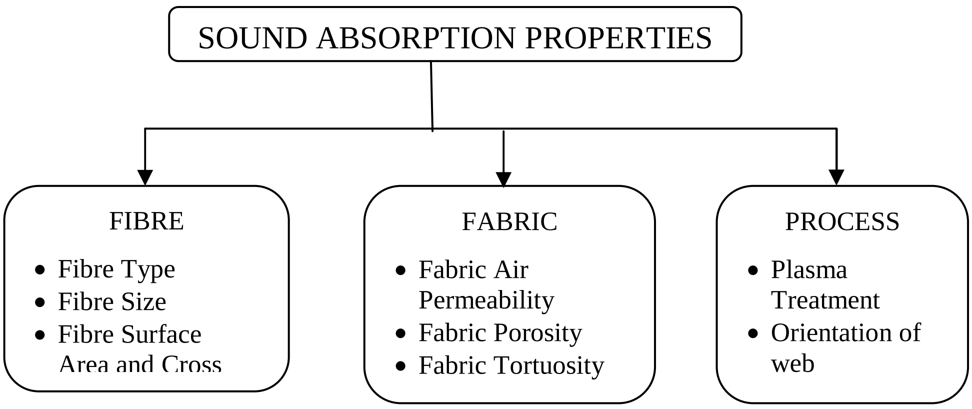

Figure 7: Factors influencing sound absorption of nonwoven materials

FIBRE TYPE

In a study on polyester, polypropylene, cotton and viscose sound absorbent material of different fabric weight per unit area, it was reported that polyester fibre fabrics show highest sound absorption followed by cotton fibre fabrics, polypropylene/cotton fabrics (Teli et al., 2007). Among hollow polyester fibres, solid polyester fibres and jute fibres, hollow polyester fibre fabric shows highest sound absorption, whereas solid polyester fibres show the lowest. Wide range of fibre length, diameter, crimp and spirally of wool fibres enable it to absorb sounds over a wide range of frequencies (Thomann & Jackson, 2009).

FIBER SIZE

Thin fibers can move more easily than thick fibers on sound waves. A study showed that fine denier fibers (1.5-6 dpf) perform better acoustically than coarse denier fibers. At the same time micro denier fibers (<1 dpf) provide a dramatic increase in acoustical performance.

FIBER SURFACE AREA AND CROSS SECTION

Fibre surface area has direct correlation with sound absorption. This is due to the reason that friction between fibers and air increases with increased fiber surface area. The sound absorption in porous material is due to the viscosity of air pressure in the pores or the friction of pore walls. Therefore, sound absorption increases with increase in specific surface area of fiber (Tascan & Vaughn, 2008). Among nonwoven fabrics made from fibres of different cross section, i.e. 4DG, trilobal, and round, 4DG fiber shows highest sound insulation, whereas round fibre fabrics show the lowest sound insulation. 4DG fibres have deep groves and channels along their longitudinal axis, which offer three times more surface area as compared to round fibres.

Samples produced with high percentage of hollow fibers also recorded the higher rates of sound absorption because of higher surface area, whereas samples produced with 100% polyester fibers recorded the lowest rates (Mahmoud et al., 2011).

The different structures of the fibers result in different total surface areas of nonwoven fabrics. Nonwoven fabrics such as vertically lapped fabrics are ideal materials for use as acoustical insulation products, because they have high total surface (Tascan, M. 2008).

AIR PERMEABILITY

One of the most important qualities that influence the sound absorption characteristics of a nonwoven material is the specific flow resistance per unit thickness. 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 energy (Jayaraman, 2005) The airflow resistance per unit thickness 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, flow resistance per unit thickness is inversely proportional to the square of the fiber diameter (Atwal, 1982).

In general, with the increase in frequency, fabric weight and the distance from the source, the extent of sound reduction increases while with the increase in air permeability, the extent of sound reduction by the material is decreased (Atwal, 1982).

POROSITY

Number, size and type of pores are important for the sound absorption mechanism in porous materials. 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. Generally porous sound absorbing materials are having porosity more than 90% to allow sound wave easily pass through and get attenuated. Such materials can be considered as noise control elements in a wide range of applications.

TORTUOSITY

The actual microscopic path followed by fluid through the void space is complicated and is often quantified by the parameter, tortuosity. Determination of tortuosity therefore provides a good understanding of the mechanism of fluid flow and the void space complexity (Vallabh et al., 2010). Tortuosity is defined as the ratio of actual flow path length to the length (thickness) of the porous medium in the direction of macroscopic flow. Higher value of tortuosity would therefore indicate longer, more complicated and sinuous path thus resulting in greater resistance to fluid/sound wave flow. Tortuosity also directly influences the heat and electric conductivity, propagation of acoustic waves, filtration and absorbance efficiency in fibrous porous media. It has also been said that the value of tortuosity determines the high frequency behavior of sound absorbing porous materials. Tortuosity in nonwoven structures increases with increase in punch density or web thickness and decrease in fiber diameter.

THICKNESS

Low frequency sound absorption has direct relationship with thickness. Sound absorption for low frequency sound waves increases as fabric thickness increases, whereas fabric thickness does not affect the sound absorption of high frequency waves. The rule of thumb states that effective sound absorption of a porous absorber is achieved when the material thickness is about one tenth of the wavelength of the incident sound (Jayaraman, 2005). The average sound absorption coefficients over frequencies of 125, 250, 500, 1000, 2000 and 4000 Hz increased with the thickness of the composites, but decreased with increase in fabric density (Lou et al., 2005).

Effect of low melting-point polyester contents in the nonwoven fabrics on sound absorption properties was also studied (Tascan, & Vaughn, 2008); low melting-point polyester was used for bonding and better strength. The melted low melting-point polyester fibre inside the nonwoven caused a decrease in nonwoven thickness and made the structure in the web shrink during the bonding process, which also resulted in the destruction of the micro-pore of the nonwoven structure. The increase of the low melting point polyester contents caused the noise absorption coefficient (NAC) to decrease (visible especially within the range 2000-3500Hz) because of the decrease in the nonwoven thickness.

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. Less dense and more open structure absorbs sound of low frequencies (500 Hz). Denser structure performs better for frequencies above than 2000 Hz (Teli et al., 2007).

ADDITION OF A WOVEN FABRIC LAYER IN NONWOVEN FIBER WEBS

The noise absorption by combinations of several layers of nonwoven fiber webs of high noise-absorption coefficients and a layer of woven fabric of high noise-reflection coefficient has been studied. The measured sound absorption coefficients, in the audible-frequency range, of such combinations were significantly higher than those of the fiber-web layers by themselves (Shoshani, 1991). In order to determine experimentally the optimal location of the woven fabric relative to the fiber-web layers, the NAC of a combination of six layers of cotton fiber web and one layer of woven fabric made of Kevlar have been measured. The highest sound absorption was obtained when the layer closest to the source of noise was the woven fabric. In this case, the contribution of the woven fabric to the noise-absorption capacity of the nonwoven fiber webs was most significant (20-40%) in the lower-frequency range (f<500 Hz).

PLASMA TREATMENT

The plasma treatment on nonwoven fabrics changes their sound absorption, viscoelastic behavior, fabric weight and pore size by changing the fibre surface morphology. Plasma treatment has both chemical and mechanical effects on fibers, surface etching and ionic charging. Etching occurs when the ions with high kinetic energy hit the surface, remove the weak part or contaminated region of fibers. Hollow polyester fabric shows the increased sound absorption and viscoelastic behaviour after the treatment with increased pore sizes, while regular polyester fabric displays insignificant changes. The cellulose fabrics are affected more by plasma treatment as compared to polyester fabrics in terms of fabric weight loss and pore size. Jute fabric demonstrates the decreased sound absorption and viscoelastic behaviour, while kenaf fabric shows the increased sound absorption with the unchanged viscoelastic behaviour after the treatment (Na & Cho, 2010).

ORIENTATION OF WEB

The nonwovens absorber which has an unoriented web in the middle layer has a higher NAC than nonwovens which have a totally oriented web structure, but the difference is marginal (Lee, Y., & Joo, C. 2003).

Web orientation effects were analyzed through the nonwoven composed of the same fibre contents, but with different orientation angles (0°, 35°, 45° and 90°), manufactured and controlled during the carding process. The NAC (Noise absorbing coefficient) of multi-angle layered web is shown in Figure 10. LAY-4 showed the highest NAC, which means the higher orientation angle variation gives smaller pore sizes. Not only the pore size but also air resistance is linked with web layering properties, although the difference in the NAC is marginal in the low and high frequencies, and even at middle frequency it did not show any great difference. So, the difference of NAC between samples was insignificant for the given specimen and frequency conditions (within a very broad range).

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