NONWOVEN ACOUSTIC TEXTILES – A REVIEW

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ABSTRACT

Noise or unwanted sound is perceived as disturbing and annoying in many fields of life. This can be observed in private as well as in working environments. Noise control and its principles play a major 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. One of the techniques to achieve pleasing environment is by absorbing sound. Fibrous and porous materials have been accepted as sound absorptive materials. This paper reviews and describes how the different fiber parameters, surface treatment, film covering, forming process, physical parameters, etc. of materials influence the absorption behavior.

Keywords: Acoustics, Air Flow Resistance, Porosity, Sound Absorption Coefficient, Sound Absorptive Materials, Tortuosity.

INTRODUCTION

Now-a-days the level of sound in our nearby environment is rising steadily leading to noise pollution. Noise pollution is the disturbing or excessive noise that may harm the activity or balance of any living bodies. The fundamental reason for noise pollution is that human society depends on many different machines and tools, most of them are quite noisy. These include aircrafts, road vehicles, ventilation systems in buildings, outboard engines, lawn movers, household machines, industrial machines and tools, etc.

According to the World Health Organization (WHO), noise has become serious environment pollution in our daily life. Noise can have adverse effects like hearing loss, sleep disturbances,
tiredness, cardiovascular and psycho-physiological problems, performance reduction, annoyance responses and adverse social behaviour. According to Occupational Safety & Health Administration (OSHA), the permissible level of noise in industrial environment is 90dB per shift. But in most of the industries, the level of noise is much higher than the permissible limit. Therefore unwanted and uncontrolled noise should be reduced by using noise absorbing system.

There are various noise controlling methods available, among them noise control using textile materials has emerged as an excellent alternative to conventional methods. Textile material is often used as a passive absorber due to its inherent sound dampening qualities as a porous material. The sound absorbing materials are called acoustic material.

NOISE CONTROL

The human life is surrounded by noisy elements in indoor, outdoor and service area. A noise system can be broken down into three elements:

- Noise source – The element which disturbs the air
- Noise path – The medium through which the acoustic energy propagates from one point to another
- Noise receiver – The person who could potentially complain about the quantity or level of noise as perceived at same point.

It is necessary to treat at least one element in the noise system if the level of the noise is to be reduced. Treatment of the noise path is conceptually the simplest and the most common approach to a localized noise problem. The approach is to place the material in the path of the noise, so that the level of noise at the receiver is reduced. In general four basic principles are employed to reduce noise: Isolation, Absorption, Vibration isolation and Vibration damping.

MECHANISM OF SOUND ABSORPTION IN FIBROUS MATERIALS

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. Hence, the sound disappears after striking the material due to its conversion into heat, as shown in Fig. 1.

![Figure 1: Mechanism of Sound Absorption](image-url)
The absorption of sound results from the dissipation of acoustic energy to heat. When sound enters porous materials, owing to sound pressure, air molecules oscillate in the interstices of the porous material with the frequency of the exciting sound wave. This oscillation results in frictional losses. A change in the flow direction of sound waves, together with expansion and contraction phenomenon of flow through irregular pores, results in a loss of momentum. Owing to exciting of sound, air molecules in the pores undergo periodic compression and relaxation. This results in change of temperature. Because of long time, large surface to volume ratios and high heat conductivity of fibers, heat exchange takes place isothermally at low frequencies. At the same time in the high frequency region compression takes place adiabatically. In the frequency region between these isothermal and adiabatic compression, the heat exchange results in loss of sound energy. This loss is high in fibrous materials if the sound propagates parallel to the plane of fibers and may account up to 40% sound attenuation.

The more fibrous a material is the better the absorption; conversely denser materials are less absorptive. The sound absorbing characteristics of acoustical materials vary significantly with frequency. In general low frequency sounds are very difficult to absorb because of their long wavelength. On the other hand, we are less susceptible to low frequency sounds.

FACTORS AFFECTING ACOUSTIC PROPERTIES OF NONWOVENS

There are various parameters that influence the sound absorption properties of fibrous materials or nonwoven fabrics, as shown in Fig. 2.
1. PRIMARY FACTORS

1.1 Fiber Parameters

i. Fiber Size
An increase in sound absorption coefficient with a decrease in fiber diameter is reported. This is because, thin fibers can move more easily than thick fibers on sound waves. A study showed that fine denier fibers ranging from 1.5 - 6 dpf perform better acoustically than coarse denier fibers. Moreover it has been reported that, micro denier fibers (< 1 dpf) provide an increase in acoustical performance.

ii. Fiber Type
The effect of fiber type on sound absorption is hard to detect as it is often accompanied by differences in fiber size and shape. Nonwovens made of acrylic and cotton fibers perform better compared to those made of polyester fibers in the medium and high frequency range, i.e. above 1000Hz. Surface properties of fibers also play an important role. Untreated Kenaf had a negative effect on the noise reduction performance compared to polyester and reclaimed polyester fibers however, this effect is less pronounced in high frequencies.

iii. Fibre Cross-section
There is a direct correlation between sound absorption and fiber surface area. A study explained the fact that friction between fibers and air increases with fiber surface area resulting in a higher sound absorption. Moreover it has been said that, in the frequency range 1125Hz – 5000Hz, fibers with serrated cross-sections (e.g. Kenaf) absorb more sound compared to ones with round cross-sections. Manmade fibers are available in various cross sectional shapes for instance: hollow, trilobal, pentalobal and other novel shapes like 4DG fibers. 4DG fibers have cross sections with several deep grooves that run along the length of the fiber as shown in Fig. 3.

![Figure 3: Different cross-sectional shapes: (a) Trilobal, (b) Hollow, (c) Multilobal, (d) 4DG](image)

iv. Fiber Blend
Comparing the sound absorption coefficient of nonwovens made up of cotton- polypropylene, flax-polypropylene and hemp-polypropylene blends for automotive applications, it was found that cotton-polypropylene blend showed higher sound absorption compared to other blends, probably due to the higher fineness of cotton fibers as compared to flax and hemp.

1.2 Process Parameters

i. Web Formation
In one of the research, higher value of airflow resistance was recorded due to random orientation of fibres as compared to aligned fibres of carded web. A random web of fibre creates more tortuous channels which increases sound absorption.
Random arrangement of fibres produce samples with small pores and a higher number of fibre to fibre contact points which leads to better sound absorption.

ii. **Web Bonding**

In a study it was found that the needled and needled with thermally bonded samples did not show much variation in sound absorption properties.

1.3 **Physical Parameters**

i. **Thickness**

Numerous studies that dealt with sound absorption in porous materials have concluded that low frequency sound absorption has direct relationship with thickness. 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. Peak absorption occurs at a resonant frequency of one quarter wavelength of the incident sound (ignoring compliance effect). A study 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. When there is air space inside and behind the material, the maximum value of the sound absorption coefficient moves from the high to the low frequency range.

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

iii. **Airflow Resistance**

One of the most important qualities that influence the sound absorbing characteristics of a nonwoven 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. 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.

iv. **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. In designing a nonwoven web to have a high sound absorption coefficient, porosity should increase along the propagation of the sound wave.
v. **Tortuosity**

Tortuosity is a measure of the elongation of the passage way through the pores, compared to the thickness of the sample. Tortuosity describes the influence of the internal structure of a material on its acoustical properties. Tortuosity is measure of how far the pores deviate from the normal. It was mainly affects the location of the quarter wavelength peaks, whereas porosity and flow resistivity 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.

vi. **Compression**

Compression of fibrous mats decreases the sound absorption properties. Under compression the various fibers in the mat are brought nearer to each other without any deformation. This compression results in a decrease of thickness. More interestingly, other physical variation occurs during compression. Compression resulted in an increase in tortuosity and airflow resistivity and a decrease of porosity and thermal characteristic length. Despite these physical parameter variations in the compressed material, it stated that the reason for a drop in sound absorption value is mainly due to a decrease in sample thickness.

vii. **Air Gap**

One of the research stated that, for the same amount of material, it is much better to have an air gap behind the layer. The creation of air gap increases sound absorption in mid and higher frequencies. Moreover, maxima peak for different air gap is different. This indicates that there is an optimum value for an air gap beyond which there is not much influence seen in sound absorption properties.

1.4 **Other Parameters**

i. **Flame Retardant Treatment**

In one of the studies, nonwovens prepared from flame retardant treated Kenaf fibres and untreated Kenaf fibres were compared for sound absorption for properties. It was found that the flame retardant Kenaf nonwoven showed a positive influence on sound absorption. This may be because the treatment of Kenaf fibres with flame retardant might change its fibre structure in such a way that it absorbs sound better than untreated Kenaf fibres. Also the treatment might increase the surface voids on the fibre which might entrap the sound.

ii. **Film Coverings**

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. 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.

The film attached samples when placed in such a way that film is at the rear side of sound always performs better at all frequencies than sample without film. This is due to the reflective phenomenon of sound waves by the film which makes the sound waves to pass through the material twice, resulting in better absorbency. At the same time, the influence of film when attached to the rear end of thicker absorbing material is less, which might be due to the larger amount of sound absorption by porous part before the sound hits the film of the porous material.

When film side of the sample is facing sound, absorption peak reaches its maximum till certain frequency and then drops down. Reason for this type of sound absorption might be due to the resonance effect of film.
When comparing two films: PVC and Aluminum for sound absorption properties, samples attached with Al film shows better results which might be due to the effect of physical properties of film like thickness, stiffness and bonding of film to the material.

iii. Placement of Acoustic Material

It has been reported 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 3 axial modes 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 twice as effective as the same material placed elsewhere.

2. SECONDARY FACTORS

In addition to the above properties, a sound absorbing material should also satisfy the following properties:

a) Structural and architectural: appearance, decorative effect, light reflectivity, maintainability, durability, etc.
b) Environmental: exposure, solvents, vibration, dirt, oil and grease, corrosive materials, erosive conditions, etc.
c) Regulatory: Restrictions on lead-bearing materials in food and drug areas, restriction on materials contacting food and drug products, requirements for disinfection/cleaning, firebreak requirements, ducts, shafts etc., restriction on shedding fibers, requirements for anchoring equipment and guarding equipment.

CONCLUSIONS

From the above discussion, following conclusions can be drawn:

• The surface area and fibre size have significant influence on sound absorption properties. Higher surface area and lower fibre size increases sound absorption.
• Using various fibres and their blends, one can enhance sound absorption properties.
• Random fibre orientation gives better sound absorbency due to small pores and higher number of fibre to fibre contact points.
• Thicker, less dense and more open structure, absorbs sound of low frequencies (500Hz), denser structure performs better for frequencies above 2000Hz.
• Increase in air gap, porosity, air flow resistance and tortuosity value results in better sound absorption. On the other hand, material compression adversely affects sound absorption.
• Flame retardant treatment, type and position of film covering and placement of acoustic material have a significant effect on sound absorption properties.

REFERENCES


