INFLUENCE OF UV IRRADIATED ON HIGH DOPING TIO_2 OF POLYMER FOAM FOR ACOUSTIC STUDY

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ABSTRAK

Beberapa tahun kebelakangan ini, bunyi adalah salah satu faktor-faktor fizikal alam sekitar yang mempengaruhi kesihatan kita pada hari ini. Bunyi boleh memberi kesan serius kepada orang di lokasi yang sensitif bunyi dan mengganggu keupayaan mereka untuk berehat, tidur, atau berkomunikasi, dan menyebabkan tekanan dan masalah. Kajian ini membentangkan eksperimen dan analisis penyiasatan untuk menentukan sifat-sifat penyerapan bunyi busa polimer poliuretana fleksibel tulen dan pendopan yang tinggi oleh titanium dioksida (TiO_2) iaitu 20 %, 40 %, 60 %, 80 % dan 100 %. Kajian akustik sampel telah diukur dengan menggunakan ujian tiub impedans mengikut ASTM E-1050 untuk menentukan pekali penyerapan bunyi (α) dan bunyi pengurangan kaedah pekali (NRC). Busa polimer sebagai terkenal sebagai bahan akustik dijangka akan bertambah baik dengan penambahan pendopan tinggi TiO_2. Titanium dioksida merupakan fotokatalis berkesan untuk air dan pembersihan udara dan permukaan pembersihan diri. Tambahan pula, ia boleh digunakan sebagai agen anti-bakteria kerana aktiviti pengoksidaan yang kuat dan superhidrofilik. Selain itu, kesan UV pada polimer digunakan untuk pengubahsuaian sifat-sifat (kekasaran, kehidrofobian) permukaan polimer. Pada akhir kajian ini, ia dijangka bahawa keputusan busa poliuretana fleksibel didopkan dengan peratusan yang tinggi TiO_2 yang digunakan boleh digunakan untuk menyerap bunyi lebih baik daripada busa polimer tulen. Tertinggi pekali penyerapan bunyi adalah 0.999 diperhatikan dari busa polimer fleksibel didopkan dengan 60 % daripada TiO_2 di tahap frekuensi tinggi 4000 Hz. Selepas penyinaran UV, frekuensi telah beralih kepada tahap frekuensi yang lebih tinggi busa polimer fleksibel didopkan dengan 60 % kepada 100 % daripada TiO_2.

ABSTRACT

In recent years, noise is one of the physical environmental factors affecting our health in today's world. Noise can seriously affect people in noise sensitive locations and interfere with their ability to relax, sleep, or communicate, causing stress and annoyance. This study presents experimental and analytical of an investigation to determine sound absorption property of polymer foam of pure flexible polyurethane and high doping of titanium dioxide (TiO_2) which are 20 %, 40 %, 60 %, 80 % and 100 %. The acoustic study of the samples was measured by using impedance tube test according to the ASTM E-1050 to determined sound absorption coefficient (α) and noise reduction coefficient method (NRC). Polymer foam as well-known as acoustical material expected to be improved by adding high doped of TiO_2. Titanium dioxide represents an effective photocatalyst for water and air purification and for self-cleaning surfaces. Additionally, it can be used as antibacterial agent because of strong oxidation activity and superhydrophilicity. Besides that, the impact of UV on polymers is used for modification of properties (roughness, hydrophobicity) of polymer surfaces. The highest sound absorption coefficient is 0.999 observed from the flexible polymer foam doped with 60 % of TiO_2 at high frequency level of 4000 Hz. After UV irradiation, the maximum frequency level has been shifted to the higher position level based on flexible polymer foam doped with 60 % to 100 % of TiO_2.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Noise is defined as unwanted sounds that prevent or disturb people from doing their routines and also affect people's health in negative ways. Efforts in reducing noise have become a major priority. There are a few ways that can be done in order to control noise. The focus is on two main ways to control noise. The first method is to control the sources of noise. This option is focused on the primary planning when developing a new facilities or products that will produce less or no noise at all. This method is effective, however, it is high cost or impossible to control all sources of noise with the current technologies that we have. The second option is to apply sound absorption and sound insulation materials, in order to diminish or eliminate the sound wave upon the way of transmission.

Sound absorption is one of the major requirements in industries where the sound insulation that is developed should be efficient to reduce the noise and to produce sound absorbing materials which as cheap and user friendly. Ultraviolet radiation (UV) and titanium dioxide (TiO_2) as the filler in appropriate concentration ratios of the polymer foam gives a reliable improvement in the mechanical and physic-chemical properties. Although the flexible polymer foam which has been used recently as a sound absorbing material, it is needs to be improved.

1.2 Background of study

Noise is one of the physical environmental factors affecting our health in today's world. Noise is generally defined as the unpleasant sounds which disturb the human being physically and physiologically and cause environmental pollution by destroying environmental properties (Harris, 1979). Noise can seriously affect people in noise sensitive locations and interfere with their ability to relax, sleep, or communicate, causing stress and annoyance. The general effect of noise on the hearing of workers has been a topic of debate among scientists for a number of years (Jansen, 1992, Johnson, 1991 & Alton, 1990).

Hearing losses are the most common effects among the workers as well as blood pressure increases, heart beat accelerations, appearance of muscle reflexes, sleeping disorders, etc. Known that hearing loss is a permanent disability, therefore, the employer had to pay a higher amount of compensation to workers who suffered it from the effects of too high noise in workplace. Indeed, this situation caused in significant losses to both sides. To overcome this problem, noise issues can be avoided or minimized by applying sound absorbing material installed in certain places function as a sound absorber. Sound absorbing materials absorb most of the sound energy striking them and making them very useful for the control of noise.

In order to boost and optimize the noise level provides a significant challenge to companies who supply materials into this market. Over the years, researchers have focused on improving the performance sound absorption material with the increase demand of quality in life. Sound absorption or insulation generally include the use of materials such as glass wool, foam, mineral fibers and other composites which has the ability to reduce or absorb sound. In the universe there enormous materials and all of those are useful for mankind by one way or another. Polyurethane (PU) foam are versatile engineering materials which find a wide range of applications because of their properties can be readily tailored by the type and composition of their component. The main market for PU foam is flexible and rigid (Verdejo, 2009). Flexible polymer foam recently has been researched extensively as a sound absorbing material and sound insulation. And it is also a major synthetic material applied for engineering practice to facilitate human need.

Acoustic material testing is the process by which acoustic characteristics of materials are determined in terms of absorption, reflection, impedance, admittance, and transmission loss. Many different methods can be used to determine the acoustic properties of materials. These methods mainly involve exposure to know sound fields and measuring the effect of the materials presence on the sound field, and in order to ensure accuracy and repeatability. There is a range of standards covering material testing that prescribed well-defined acoustical conditions and special instrument.

Other than that, many studies have reported that incorporated fillers to flexible polymer foam can improve its acoustic properties and thus reduce noise when it is applied in applications (Zaimy et. al., 2013). Many researchers found various kinds of fillers to improve the acoustic performance of polyurethane foams. Titanium dioxide (TiO_2) represents an effective photocatalyst for water and air purification and for self-cleaning surfaces (Anika, Nurulsaidatulsyida & Siti Rahmah, 2013). Additionally, it can be used as antibacterial agent because of strong oxidation activity and superhydrophilicity (Anika et al., 2013). Researcher also stated titanium dioxide also has good ultraviolet (UV)-blocking power and is very attractive in practical applications because such advantages as nontoxicity, chemical stability at high temperature, and permanent stability under UV exposure, for example (Yang et. al., 2004). While the UV rays on polymer foam are researched to improve the acoustic properties.

1.3 Problem statement

In recent decade, a great majority of people working in industry are exposed to noise pollution. Noise-control issues and the emergence of sound quality is becoming very important and are increasingly relevant to engineers, designers, manufacture to develop a healthier environment. Due to hearing problems and a variety of other problems among workers that hit the industrial sector, researchers have focused on minimized the sound level heard by employees by improving the performance of sound absorption material. Absorptive materials placed above the headliner, behind the door panel and pillar trim, and under the carpet have proven to be effective in industrial sectors.

In this current research, the aim is to study the effect of high doping of TiO_2 on flexible polymer foam microstructure to find a relation between corresponding parameters such as cell size and foam apparent density. Titanium dioxide represents an effective photocatalyst for water and air purification and for self-cleaning surfaces (Anika et al., 2013). Additionally, it can be used as antibacterial agent because of strong oxidation activity and superhydrophilicity (Anika et al., 2013). Furthermore, this project is also to modify the flexible polymer foam using filler for variety of reasons such as improved processing and mechanical properties such as hardness, tensile, tear resistance and many more reasons. This study also deals with the ultraviolet irradiation for the improvement of sound absorption of the flexible polymer foam with various exposure times. The research conducted to determine the foam's mechanical properties (sound absorption properties, α) and physical properties (porosity and density) of high doping filler of flexible polymer foam.

1.4 Objective

1. To fabricate high doping of filler with flexible synthetic foam for acoustic study
2. To study the characterization of high filler loading based on absorption coefficient and level of frequency, Hz
3. To study the characterization of UV irradiation exposure based on sound absorption coefficient

1.5 Scope of study

In this research, flexible polymer foam and incorporating with high doping fillers (20%, 40%, 60%, 80% and 100%) will be produced. The quality of these physical and mechanical properties of these high doping of flexible polymer foam will be analyze based on the acoustic property of the sound absorption coefficient (α) and the level of frequency by using impedance tube test. From that data obtained, noise reduction coefficient (NRC) could be examined. Scanning electron microscope (SEM) will be used to obtain a clear microscopic structure of the sample, as well as, Mettler Toledo X64 to perform the porosity and density test. Other than that, the samples were exposed to the UV irradiation in QUV Accelerated Weathering Tester HD-703 (Haida International Equipment Co., LTD) at different exposure time at 50°C to study the acoustic property. The UV exposure of the samples was carried out using an array of UV fluorescent emitting light in the region from 280 to 320 nm with a tail extending to 400 nm. The samples were exposed in different UV exposure times (250, 500, 750 and 1000 hours).

1.6 Expected results

At the end of this research, we will examine the performance of flexible polymeric foam doped with high percentage of TiO_2 as a sound absorbing material. Other than that, it can also be clarified on the characteristics of high loading filler of flexible polymer foam based on absorption coefficient and level of frequency. The result from the test will be compared with the pure flexible polymer foam. From the analysis of the result, we will know either high doping of TiO_2 of synthetic polymer foam is better than pure synthetic foam. Other than that, the performance of flexible polymeric foam doped with high percentage of TiO_2 as a sound absorbing material could as be tested with different UV irradiation times.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter comprises of the academic literatures and studies which have direct bearing include to the related theoretical practices and explanations relevant to this study being proposed including acoustic study, materials selection and characteristics, methods, equipment, etc. Reviews, analyzes and explanations of research's information from previous study of the subject of study will be used as a guideline to accomplish this project.

2.2 Sound absorption

Sound can comprise harmonious tones, music, bangs, noise, crackling, but also spoken words. Unwanted sound events can be named as noise. The general effect of noise on the hearing of workers has been a topic of debate among scientists for a number of years. Thus, the development of sound absorption system is very important to be researched. This definition shows that the perception of sounds has strong subjective aspects. Sound absorption is defined as the incident sound that strikes a material that is not reflected back. In other word, it is a process in which sound energy is reduced when sound waves pass through a medium strike a surface.

According to Warnock (1980), sound is the organized superposition of particle motion on the random thermal motion of the molecules. The speed of the organized particle motion in the air is typically smaller than the thermal motion. A sound absorber can absorb only part of the incident sound energy which is not reflected in its surface. However, sound absorption measurements of highly absorptive materials often yield sound absorption coefficients greater than 1.00 due to diffraction effects. These values are reported as required by the test standard. When using sound absorption coefficients in calculations, values above 1.00 should be reduced to values less than 1.00.

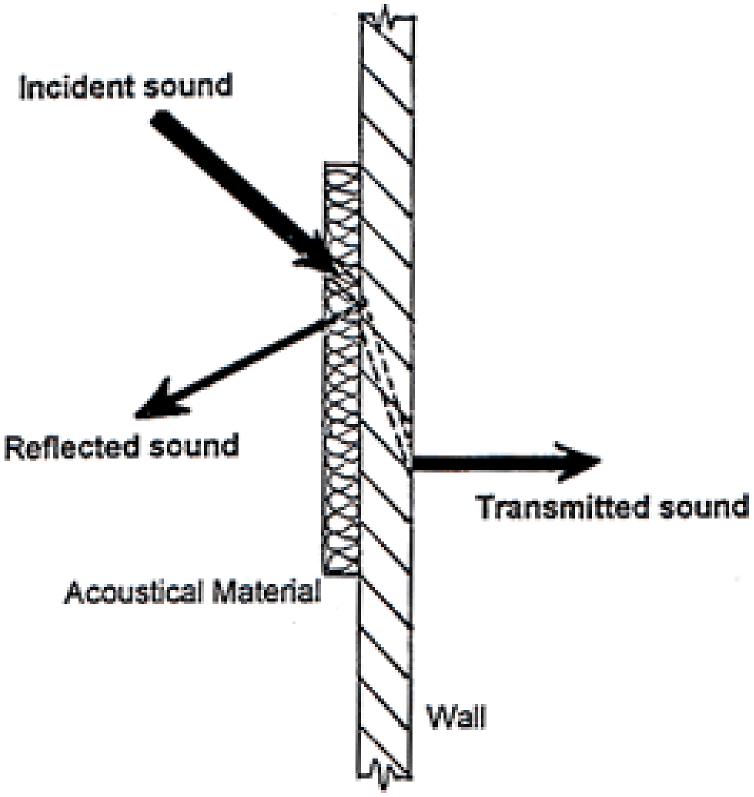

Figure 2.1: Sound absorption mechanism.

When sound waves travel through air and encounter another medium, the wall of a room, for instance, a portion of the sound will be absorbed by the wall while the remainder will reflect from the wall surface as shown in Figure 2.1. Add to the mix the other surfaces reflecting sound waves in various directions within the room, and the result is a jumble of sound reflections which interfere with the clarity of the original, intended sound. The presence of numerous hard, untreated surfaces is often to blame for the heightened noise in busy restaurants as the voices of multiple patrons reflect and produce background noise. Acoustical improvement and sound reduction projects often involve the implementation of treatments designed to absorb sound wave reflections as a part of a comprehensive sound control plan.

2.2.1 Sound absorption coefficient (α)

The sound absorption coefficient for a material is the fraction or percentage an incident sound energy that is absorbed by the material. Sound absorption coefficient is defined as the ratio of the sound energy absorbed to the incident upon a surface. It is a measure of the sound absorptive property of the material. The sound absorption coefficient of every material varies with frequency. It is common practice to list the coefficient of a material at frequencies of 125 Hz, 250 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

Generally, the higher coefficient number has better absorption. Sound absorption coefficient is usually expressed as a decimal varying between 0 and 1 with no unit. If 65 percent of the incident sound energy is absorbed, the absorption coefficient of the material is said to be 0.65. A material that absorbed all incident sound energy will have absorption coefficient of 1. There are two standardized method that is used to determine sound absorption coefficient, which are the Reverberation Room Method according to ASTM C423 and the Impedance Tube Method as refer to ASTM E 1050.

For automotive industries, sound absorption is the important issue where sound insulation developed should be efficient and effective by means of getting the sound reduced and in economically ways of producing sound absorbing material which is cheap, user friendly and moderate sound absorbent coefficient (Nik Normunira and Anika Zafiah, 2013). According to Jiejun, Chenggong, Dianbin and Manchang (2003) the sound absorption properties of materials have been expressed by sound absorption factor. Sound absorption coefficient is defined by equation 2.1.

$$Sound\ absorption\ coefficient, \alpha = (E_0 - E_1)/E_0 \tag{2.1}$$

Where,

E_0 is the whole energy of incident sound, and

E_1 is the energy of the reflective sound.

Sound absorption coefficient was measured by the standing wave method. Since the sound absorption is measured according to ASTM C384-98, the normal incidence of the sound absorption coefficient measured in an impedance tube will never exceed unity. According to the American Society for Testing and Materials, the ASTM C384-98 can be regarded as in equation 2.2.

$$\alpha_0 = \frac{4\zeta}{(\zeta+1)^2} \tag{2.2}$$

Where,

$\zeta = P_{max}/P_{min}$ is the ratio of the maximum and minimum standing wave sound pressure in the tube upstream of the sample.

Absorbing materials play an important role in architectural acoustics, the design of recording studios and listening rooms, and automobile interiors (seat material is responsible for almost 50% of sound absorption inside an automobile).

2.2.2 Noise reduction coefficient (NRC)

The noise reduction coefficient (NRC) is defined as a scale representation of the amount of energy absorbed upon striking the particular surface where the indication of zero from NRC shows that there is a perfect reflection upon the incidence and NRC of one shows there is a perfect absorption. NRC is an arithmetic value average of sound absorption coefficient at frequencies of 250, 500, 1000 and 2000 Hz indicating a material’s ability to absorb sound.

$$NRC = \frac{\alpha 250+\alpha 500+\alpha 1000+\alpha 2000}{4} \tag{2.3}$$

The average values of four sound absorption coefficients of the particular surface at the frequencies of 250 Hz, 500 Hz, 1000 Hz and 2000 Hz to calculate noise reduction coefficient can be referred in equation 2.3. These frequencies are the fundamental frequencies and first few overtones of typical human speech. Therefore, the NRC provides a decent and simple quantification of how well the particular surface will absorb the human voice (Harris, 1979).

2.3 Sound absorption material

Sound insulation materials change the path of sound propagation, and the sound absorption materials can reduce the energy of sound waves, thus, it is very important to search for sound absorption materials for noise controlling. In other words, materials that reduce the acoustic energy of a sound wave as the wave passes through by the phenomenon are called the sound absorptive materials. Sound absorbing materials are used to reduce reflections from surfaces and to decrease reverberation within spaces. Sound absorbing materials absorb most of the sound energy striking them and making them very useful for the control of noise.

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 (Seddeq, 2009). In other word, sound absorptive materials are commonly used to soften the acoustic environment of a closed volume by reducing the amplitude of the reflected waves either in the wall. It is usually fibrous, lightweight and porous. The most common types of absorbing materials are rock wool, fiberglass, polyurethane and cellulose fibers. The more fibrous a material is the better the absorption; conversely denser materials are less absorptive. The function of absorption materials is to transform the impinging sound energy into heat. In practice, they are used on ceilings, walls, and floors of rooms on panel surroundings noisy equipment within the cavities between walls or partition surfaces.

Every material that exists nowadays can absorb some acoustical energy. When a sound wave strikes an acoustical material, the sound wave causes the fibers or particle makeup of the absorbing material to vibrate. This vibration causes tiny amounts of heat due to the friction and thus sound absorption is accomplished by way of energy to heat conversion. The sound absorbing characteristics of acoustical materials very significantly with the frequencies where in general low frequency sounds are very difficult to absorb because of their long wavelength. The absorption is desired at lower frequencies, thickness and weight. However, we are less susceptible to low frequency sounds, which can be to our benefit in many cases.

Absorptive materials are generally resistive in nature, either fibrous, porous or in rather special cases reactive resonators. According to the research done by Lewis and Bell (1994), the classic examples of resistive material are nonwovens, fibrous glass, mineral wools, felt and foams. Porous materials are 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 according to Braccesi and Bracciali (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 heat. This action prevents a buildup of sound in enclosed spaces and reduces the strength of reflected noise (Lewis et al., 1994).

Besides that, the acoustical material plays a number of roles which is 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 hand, rigid and interior surfaces and thus help to reduce the reverberant noise levels as stated by Beranek (1960) and Bruce (1981). These materials are used as interior lining for apartments, automotive, aircrafts, ducts, enclosures for noise equipment and insulations for appliances stated by Knapen, Lanoye, Vermeir and Van Gemert (2003) and Youn and Chang (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 musical sound Frank (2001). Combining 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 Francisco and Jaime (2004) tell that sound absorbing materials are chosen in terms of material types and dimension, and also based on the frequency of sound to be controlled.

2.3.1 Sound absorption performance in porous material

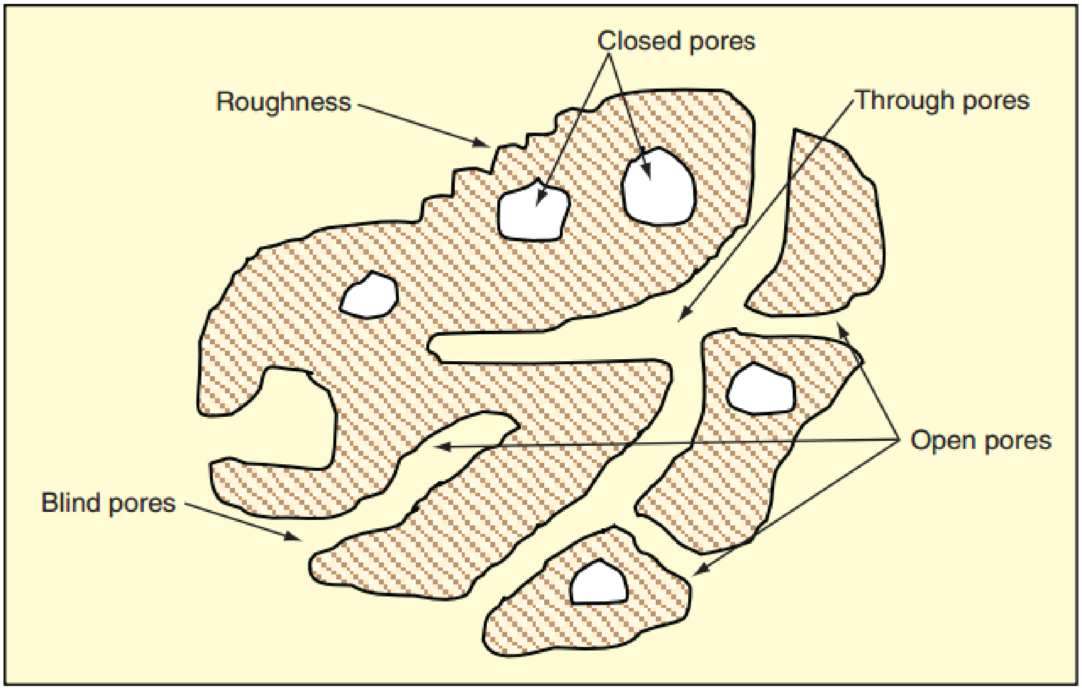

Figure 2.2: Schematic cross-section of a porous solid material. (Rouquerol, 1994)

According to Crocker and Arenas (2007), a porous absorbing material is a solid that contains cavities, channels or interstices so that sound waves are able to enter through them. The porous material mainly being used to investigate the sound absorption behavior based on energy dissipation behavior of sound waves while it's travelling through the media (Nik Normunira and Anika Zafiah, 2013). Sound absorption of porous materials along the propagation of the sound wave should be maximum value in the middle of the material (Kucukali et. el., 2010). A porous sound absorbing material is a solid which has a hall and channel or a small gap by which a sound can enter into the material (Jung et. al., 2013). A sound wave subjects air elements vibration force. These air elements hit the surface and cell of a porous sound absorbing material, increasing the temperature and viscosity of the material’s channel wall. As the result, original energy decreases. Therefore, the sound absorbing characteristic of a porous material can be evaluated according to the cell structure and channel of the material.

It is possible to classify porous materials according to their availability to an external fluid such as air. Figure 2.2 shows a schematic cross-section of a porous solid material. Sound absorption in porous materials absorbs most of the sound energy striking them and reflects very little. They are used in a variety of locations close to sources of noise, in various paths, and sometimes close to receivers. Porous absorbing materials can be classified as cellular, fibrous, or granular; this is based on their microscopic configurations.

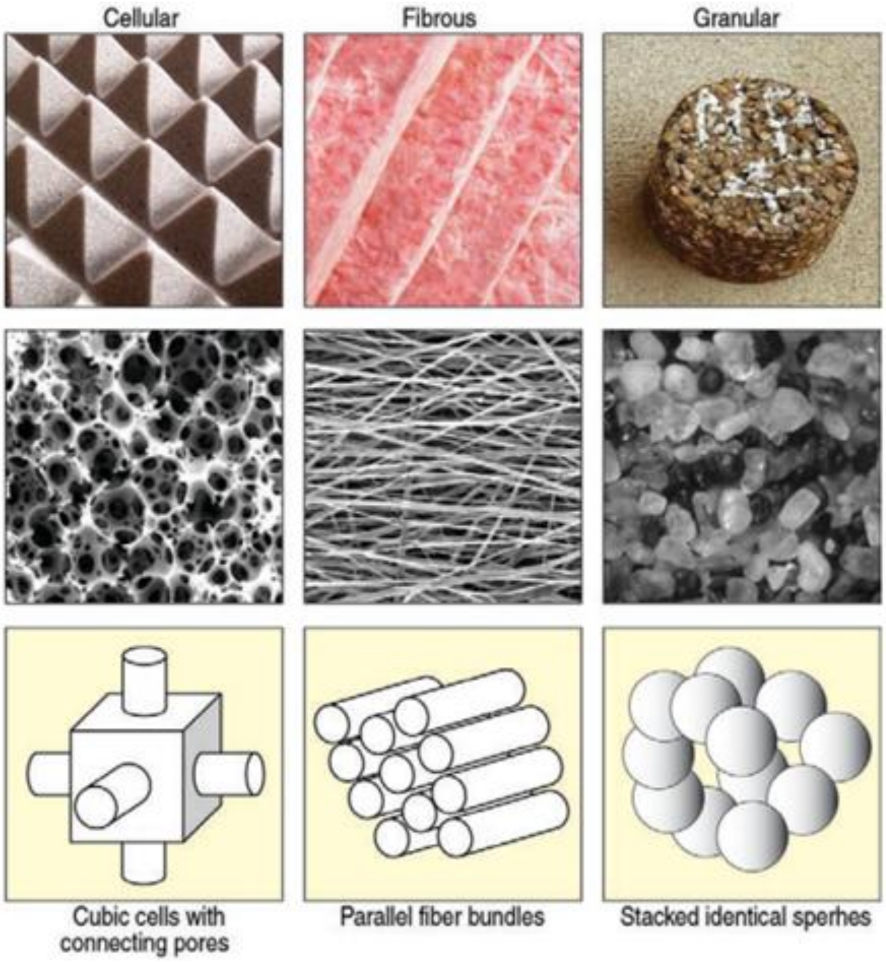

Figure 2.3: Three main types of porous absorbing materials: cellular, fibrous, granular (Jorge and Malcolm, 2010).

Figure 2.3 shows the three main types of porous sound absorbing material, their typical microscopic arrangements and some of the physical models used to describe their absorbing mechanisms. Porous materials are characterized by the fact that their surfaces allow sound waves to enter the materials through a multitude of small holes or openings. Although all materials absorb some incident sound, the term "acoustical material" has been primarily applied to those materials that have been produced for the specific purpose of providing high values of absorption. The major uses of absorbing materials are almost invariably found to include the reduction of reverberant sound pressure levels and, consequently, the reduction of the reverberation time in enclosures, or rooms.

A porous material with a non-porous barrier bonded to the face of the material carries the sound energy in the form of the structure-borne wave. The factors that have a strong influence on the structure-borne wave are the bulk stiffness and the structural loss factor. Besides that, the effectiveness of the sound absorption is directly related to the thickness of the material absorbers are most effective when their thickness is between one-fourth and one-half the wavelength of the sound, with the maximum performance where the thickness is one-fourth the wavelength. This means that sound absorbers does a very good job at high frequencies, which have short wavelengths. However, at low frequencies, very thick materials would be required to yield high sound absorption, which would be impractical on the interior of a car.

On the other hand, a porous material with an open face or with a porous scrim carries most of the sound energy in the form of the airborne wave. The exception is a porous material that has a structural stiffness less than that of air. In this case, the material behaves as a fluid. In either case, the sound energy can be thought of as being carried by the airborne wave. There are several factors that have a strong influence on the airborne wave, but usually the most important influence is due to the flow resistivity of the material. Most of the materials tested in this study were porous materials with an open or scrim covered face, so the airborne wave is dominant. A porous material with a non-porous barrier bonded to the face of the material carries the sound energy in the form of the structure borne wave. The factors that have a strong influence on the structure borne wave are the bulk stiffness and the structural loss factor.

Most of the porous sound absorbing materials commercially available are fibrous. Fibrous materials are composed of a set of continuous filaments that trap air between them. They are produced in rolls or in slabs with different thermal, acoustical, and mechanical properties. Fibers can be classified as natural or synthetic (artificial). Natural fibers can be vegetable (cotton, kenaf, hemp, flax, wood, etc.), animal (wool, fur, felt) or mineral (asbestos). Synthetic fibers can be cellulose (bamboo fibre), mineral (fiberglass, mineral wool, glass wool, graphite, ceramic, etc.), or polymer (polyester, polypropylene, Kevlar, etc.). According to Rouquerol (1994) a practical convention is used to make a distinction between porosity and roughness, which assumes that a rough surface is not porous unless it has irregularities that are deeper than they are wide. Porous materials are characterized by the fact that their surfaces allow sound waves to enter the materials through a multitude of small holes or openings. Materials made from open celled polyurethane and foams are examples of cellular materials.

When a porous material is exposed to incident sound waves, the air molecules at the surface of the material and within the pores of the material are forced to vibrate and, in doing so, lose some of their energy. This is because part of the energy of the air molecules is converted into heat due to thermal and viscous losses at the walls of the interior pores and tunnels within the material. From the studies of Zwikker and Kosten (1949) at low frequencies, these changes are isothermal, while at high frequencies, they are adiabatic.

In fibrous materials, much of the energy can also be absorbed by scattering from the fibers and by the vibration caused in the individual fibers. The fibers of the material rub together under the influence of the sound waves (Crocker and Arenas, 2007). The sound absorption mechanism in bulk granular materials is quite similar to that in rigid porous materials where the solid structure can be regarded as ideally rigid and stationary. Then the sound absorption is produced by the viscosity of the air contained inside the interconnecting voids that separate the granules. At low and mid frequencies, the solid structure interacts with the bulk of the gas through an isothermal heat transfer process. In addition, scattering from the granules also influences the absorption of sound energy inside the material.

The cell structure of a porous absorbing material can be classified as a close cell or open cell foam. Close cell foam affects the macroscopic property of the material, such as volume density, physical stiffness and thermal conductivity. But this form provides less effective sound absorption performance than the open cell form. On the other hand, the open cell form provides excellent sound absorption performance because of the channels that connect sequentially with the exterior surface of material; these channels help to dissipate sound wave energy.

2.3.2 Factors influencing sound absorption

The effectiveness of the sound absorption is resulting by several factors that are fiber size, airflow resistance, porosity, tortuosity, thickness, density, compression, surface impedance and so on. These factors need to be considered while its production to produce an optimum sound absorbing material.

2.3.2.1 Fiber size

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

2.3.2.2 Airflow resistance

One of the most important qualities that influence the sound absorbing characteristics of 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 and Finn, 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 equation 2.4.

$$Airflow\ resistance, R_1 = \frac{\nabla p}{\nabla Tu} mks. Rayls/m \tag{2.4}$$

Where,

R_1 = 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, newton/m^2 and

ΔT = Incremental thickness, m (Beranek, 1960)

Based upon the airflow test, ASTM D-1564-1971, flow resistance R of the samples obtained from the following equation 2.5.

$$Flow\ resistance, R = \frac{P}{vl} \tag{2.5}$$

Where,

P = Static pressure differential between both faces of the sample, dyn/cm^2 (10-1 Pa)

v = Air velocity, cm/s and

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. From the study in Uno (1994), 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.

2.3.2.3 Porosity

There is a decrease in the transmission loss at higher porosities since the damping effect of the pores reduces allowing more sound to pass through. From the academic and acoustic stand point, for the right porosity levels, an improvement in transmission loss is observed (Koizumi, 2002).

Number, size and type of pores are the important factors that one should consider while studying sound absorption mechanism in porous materials. In order 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, 1993). Equation below gives the definition for porosity (H).

$$Porosity(H) = \frac{V_a}{V_m} \tag{2.6}$$

Where,

V_a = Volume of the air in the voids

V_m = Total volume of the sample of the acoustical material being tested

Shoshani and Yakubov (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.

2.3.2.4 Tortuosity

Tortuosity is a parameter which is related to the fluid that fills the porous material (air), and indicates the complexity of apertures in the poro-elastic material. To be specific, it is determined in the ratio between the average length of the apertures in the poro-elastic material and the thickness of the material. As the inner structure becomes more complex and the tortuosity becomes higher, the same effect to the thicker material will be expected.

Tortuosity is dependent upon angles between pores in an object and macroscopic direction of sound propagation through the object and is sometime referred to as structural foam factor. Besides that, Wassilieff (1996) describes tortuosity as a measure of how far the pores deviate from the normal, or meander about the material. In addition (Horoshenkov and Swift, 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. According to Knapen (2003), tortuosity describes the influence of the internal structure of a material on its acoustical properties. 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 (Alireza and Raverty, 2007).

2.3.2.5 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 and Kierzkowski, 2002). Peak absorption occurs at a resonant frequency of one-quarter wavelength of the incident sound (Timothy, David, Robert, Phillip and Pranab, 1999). A study in Ibrahim and Melik (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.

In order to achieve one-quarter wavelength absorber effect, the longer the holes, the better the low frequency sound absorption due to the resonance in the holes. Thus the thickness of the headliner is a dominant parameter too in this sense. So we can conclude that the higher thickness, the better of the low level frequency performance (Shuo and Roland, 2003).

For instance, high frequencies (above 500 Hz) are easier to handle with 30–50 mm stone wool thicknesses as shown in Figure 2.4. More challenging are the sounds in frequencies below 500 Hz. It is indeed needed a thicker stone wool slabs to create better sound absorption. Material thickness can also be compensated for with air space behind an acoustic ceiling or wall panel to improve low frequency performance.

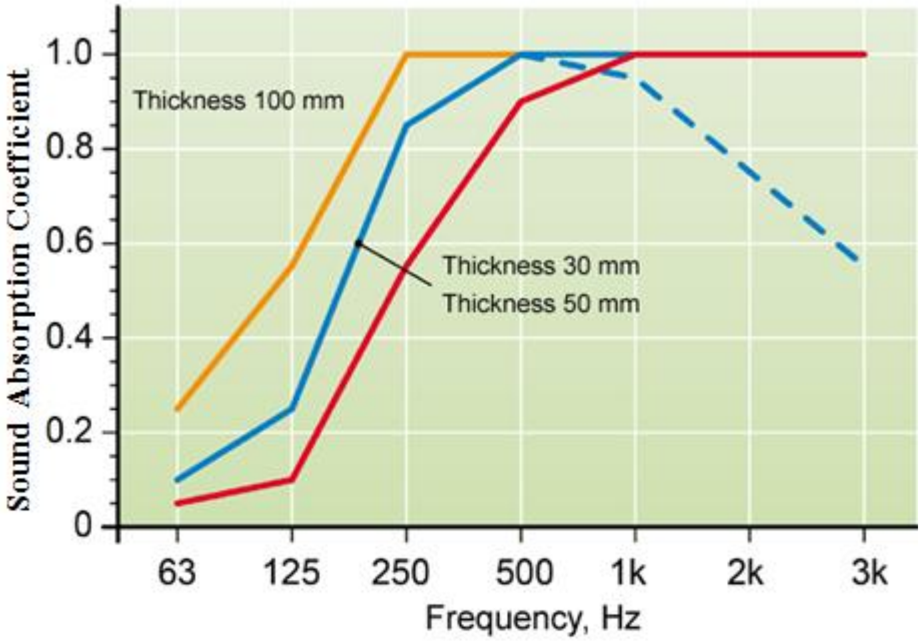

Figure 2.4: Influence of thickness in sound absorption coefficient.

2.3.2.6 Density

One of the important factors that influence the sound absorption behavior of a material is 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. According to He, Liu, Chen and Fang (2012), with air friction inside cells and viscous friction between adjacent polymer chains, materials with high cell density are good sound absorption materials because they can increase the friction and decrease the sound energy by dissipating it as heat energy.

2.3.2.7 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 and Jaime, 2004).

2.4 Polymer foam

Polymer foams are made up of a solid and gas phase mixed together to form a foam. This generally happens by combining the two phases too fast for the system to respond in a smooth structure. The resulting foam has a polymer matrix with either air bubbles or air tunnels incorporated in it, which is known as either closed-cell or open-cell structure. Closed-cell foams are generally more rigid, while open-cell foams are usually flexible. Polymer foams can be divided into either thermoplastics or thermosets, which are further divided into rigid or flexible foams. The thermoplastics can usually be broken down and recycled, while thermosets are harder to recycle because they are usually heavily cross-linked. The reason polymer foams are so widely used is that they have a lot of advantageous properties. The density is low, and so the weight reduction compared to other options is significant. Some polymer foams have very low heat transfer, making them optimal insulators. Many are flexible and soft, meaning they provide more comfort when used for furniture and bedding. Polymer foams can be categorized in two types which are polyurethane and biodegradable foams.

2.4.1 Polyurethane (PU)

Polyurethane foam are versatile engineering materials which find a wide range of applications because of their properties can be readily tailored by the type and composition of their component. Polyurethanes are any type of polymer containing a urethane linkage. The urethane linkage is -NH-CO-O-. The way to form polyurethanes is done by reacting isocyanates with compounds that have active hydrogen, such as diols, that contain hydroxyl-groups, in the presence of a catalyst. Since there are many compounds containing active hydrogens and many different diisocyanates, the number of polyurethanes that can be synthesized is also large. The specific properties of the polyurethane can be tailored to a specific need by combining the appropriate compounds. Polyurethane foam is most versatile polymeric and lightweight material used in applications such as insulation material, cushioning, and automotive part and energy absorption materials. Polyurethanes can exist as both rigid and flexible foams, and as a coating or adhesive material. According to Verdejo et al., (2009), the main market for polyurethane foam is flexible and rigid.

Since polyurethanes come in so many forms and can have a wide variety of properties, it is also used in many different applications. Rigid polyurethanes are used as insulation and flotation, while flexible ones are used for cushioning and packaging. Flexible and rigid polyurethane foams are two predominant application forms of polyurethane with coatings, sealants, elastomers, and adhesives being other common forms of applications. Polyurethane foam can be produced with open-cell structure to be more flexible or a close cell structure to be a more rigid (Hatchett, 2005). The characteristic of polyurethane foam is one of major production from urethane material.

Since polymer foams are used widely all over the globe the technology to produce foams is continuously being improved. Polymer foams have great thermal insulation properties and can also be tuned to have different mechanical strength and moisture absorption. From a study by Broos, Sonney, Thanh and Casati (2000), it is shows that polyurethane has been used as an automotive part is order to ensure the passenger compartment comfort. He proved that, polyurethane could reduce the sound absorption efficiently.

2.4.2 Fabrication of polymer foam

In producing and fabricating a good specimen for sound absorption, there is a need to consider the properties of each material chosen, thus the effects on sound absorption is keen to absorb most of the sound rather than to reflect the sound. There are some materials required to produce sound absorption foam, polyurethane, such as flexible isocyanate, polyol and titanium dioxide (TiO_2). The characteristic of polyurethane foam can be changes via adjusting the chemical composition of the raw materials, in particular polyol and isocyanate in which the polyurethane properties mainly depends on the types of polyol such as functionality and hydroxyl value (Lim, 2008).

The forming process of polyurethane foam consist three basic stages such as bubble initiation, bubble growth and cell opening (Klempner and Sendijarevic, 2004). The bubble initiation was initially introduced by physically bending air into the mixture. The bubble growth occurs when the gas diffused and expands the gas phase due to increasing the forming temperature. The gas may originate from sources such as a gas involved by water reaction, blowing agents, carbon dioxide and surfactant. The heat generated during the reactions due to exothermic process play an important role in expansion to form a cellular structure. The bubble continued to growth, it will begin the cell opening to produce polyurethane foam.

2.4.2.1 Flexible isocyanate

Isocyanate is the raw materials from which all polyurethane products are made. Isocyanate is the functional group of elements –N=C=O (1 nitrogen, 1 carbon, 1 oxygen). They react with compounds containing alcohol groups to produce polyurethane polymers. An isocyanate is an organic group, which when reacted with other chemical compounds, varies in toxicity and properties much like other organic groups like ketones, ethers, alcohol, etc. Modern moisture-cure urethane coatings are produced by the reaction of diisocyanate monomers such as HDI, IPDI, MDI and TDI with other larger molecules called polyols to produce polymeric isocyanate. Urethane foams were introduced to the public as an industrial insulation. The most-used isocyanates are TDI and MDI. TDI is used mainly to make soft, flexible foams, for padding or insulation. MDI is used mainly to make hard, rigid foams for insulation in buildings, vehicles, refrigeration equipment, and industrial equipment.

The repeating urethane linkage, an isocyanate group reacts with the hydroxyl groups of polyols. Urea linkage and carbon dioxide is produce as a byproduct when isocyanate reacts with water. Carbon dioxide is used as a blowing agent in order to produce polyurethane foams (Oertel, 1993). When polyols with three or more hydroxyl groups are reacted with a polyol, the resulting polymer is crosslinked. The stiffness of the polymer depends on the amount of crosslink. Different from the linear polymers, crosslinked polymers will not flow when heated. All structural adhesives are crosslinked because this eliminates creep (deformation under constant load).

The isocyanate must be added and mixed just before the coating operation. This is because, the crosslinking reaction starts at room temperature. In addition, the isocyanate is a highly unsaturated and extremely reactive group, containing two cumulative double bonds. It can react with both electron donor and electron acceptor functional groups. The most important groups that react with isocyanate are amino, hydroxyl and carboxyl groups.

In this study, flexible isocyanate has been applied to mix with the other raw materials to produce high doping of polyurethane. Maskiminate 8002, or Modified Polymeric-MDI, is a mixture of polyol-modified diphenylmethane diisocyanate and

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