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Considerations while designing Acoustic Home Textiles: A Review

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ABSTRACT

The aim of this paper is to provide the idea of the level of the research being carried out worldwide in the area of acoustic home textiles. This paper covers the brief introduction of various aspects being analyzed in 21st Century, where the research methodology is booming day and night. The critics on the papers is omitted and everyone's research related to sound or noise absorbing home textile or even general textile material suitable for home textiles is warmly welcomed. The final summary is presented in the conclusion section after the extensive available research in the area of sound or noise insulating home textiles. This review depicts the acoustical property and factors affecting the acoustical property of home textile material from raw materials to the finished goods. Moreover, the measurement of acoustic property and sound absorption mechanism of home textiles have also been described. The significance of textile materials and making the better acoustic home textiles have also been presented. A large variety of textile raw material being used in the area of acoustic home textiles is quoted and described.

Keywords: Home textiles, sound absorption mechanism, parameters affecting sound insulation, acoustical performance, measuring acoustical efficiency

1. Introduction

Noise pollution is going to be increased day by due to mechanization and industrialization of the today's world. Even in developed countries the noise level are at their limits where strict regulation for controlling the noise are being employed. This condition is even worse in the developing country, where the control of noise pollution is far to be adopted. Noise causes various health and psychological effects on the people health. Noise-induced hearing loss, insomnia, heart attack and hypertension are some common diseases as the result of longer exposure to noise. Growth in population and urbanization is also one of the big reasons of increase in the environmental noise pollution. Not only big cities, but also small cities even countryside such as agricultural farms due to tractors and electric motors are gaining increase in the noise population nowadays. Various researches are being done to mitigate the noise generated by motors, one of the researcher has published his work in order to lessen tractor noise in agricultural lands (Aybek, Kamer, & Arslan, 2010). Thus it is essential to find out practical approach to get the rid of this excessive noise. In well developed countries a nice quality of floor coverings and curtains are being used to minimize the noise levels inside the home. 97% of Britons had been used fixed carpets in their dwellings, as the carpets were considered as most excellent floor coverings because of their excellent noise insulation property ("The naked truth about British carpets," 1999). Moreover, built in floor coverings for homes have been proposed but it is complicated to control impact sound transmission by floor systems, as floor coverings do not give the same degree of improvement on all types of floors (Warnock). Thus it suggests the need of analyzing and characterizing the various sound absorbing home textile materials. The majority of the sound energy in the sound wave is absorbed when it strikes sound absorbing home textile materials, this makes sound absorbing home textile materials to be useful for the control of noise (Arenas & Crocker, 2010). Several empirical equations for several sound absorbing materials have been proposed (Fernández, Soriano, Sanchis, & Silla, 2007).

There are two types noise problems faced in the homes i.e. airborne noise problems and structure-borne noise problems. Air borne noise problems at home may be due to higher traffic load, proximity to airport or power plants, construction in the nearby street or a neighbor using loud speakers, etc. whereas structure-borne noise problems at home may be due to electric motor, mechanical tool or any manual instrument being used within or nearby home. airborne noise problems and structure-borne noise problems can be solved by sound absorbers or sound barriers, and sound dampers or sound isolators respectively (P. Saha, 2002). Viscoelastic damping for controlling structure-borne noise problems is being used in automobiles and commercial airplanes (Rao, 2003), thus this or similar strategy may also be used for structure-borne noise problems at home. Remedies for the structure-borne noise problems are beyond the scope of acoustic home textiles, thus here mainly remedy to minimize the air-borne noise problems at homes are discussed. It should be noted that during testing of the acoustic property, the noise and the vibration must be separately understood in order to analyze airborne noise and structure-borne noise pathway separately (Pranab Saha, 2011).

The acoustic home textiles may be classified in terms of the form they are present. The acoustic home textile material may be acoustic home textile panels, acoustic underlay, acoustic carpets, acoustic curtains, acoustic sofa covers, acoustic wall papers, acoustic textile nonwovens mainly used in interlining, acoustic coated textile fabrics and acoustic textile composites. Textile materials are possible to be used for reducing interior noise (of home) due to their porous fibrous structures; moreover, they are environment-friendly, cheaper and lighter than many other materials (Fung & Hardcastle, 2001). Depending upon the end use performance of acoustic home textile, the type of textile material may be chosen whether knitting, weaving, composites or nonwovens. Weaving offers a lot of advantages over other newly industrialized fabric manufacturing methods; as it is well developed and cost effective fabric manufacturing process. Weaving offers a large variety of weave designs due to its different structures plain, twill, satin, etc. with all types natural or synthetic yarns or filaments; offering wide range of properties including open, light, heavy, dense etc. by different weaving machines tappet, dobby, jacquard, etc. (Mankodi & Mistry, 2014). Woven fabrics allow special finishes to be applied to make them soil resistant, flame retardant, water repellant, etc. Sound absorbers are essential requirement of sport halls such as acoustical banners have been investigated keeping the arena of sports (Splain, 2008). The consequence of weave type (Soltani & Zerrebini, 2012), pick densities (Soltani &

Zarrebini, 2013), pile height of carpet and pile density of carpet (Y. Z. Shoshani & Wilding, 1991) have been determined on the acoustical properties of acoustic home textiles. Moreover, the different structures of woven fabrics jacquard woven (134 g/m^2), jacquard woven (188 g/m^2), plain woven/open structure, printed curtain, velvet with knitted back-up, jacquard woven two side fabric, velvet with woven back-up, denim and one side laminated fabric used for curtains have been analyzed (Mankodi & Mistry, 2014).

Knitting may also be used to make acoustic home textiles. Knitting is also one of the developed fabric manufacturing methods; as well as it is cost effective fabric manufacturing process. knitting also offers a large variety of knitting designs due its different structures interlock, single jersey, double jersey, etc. also with all types natural or synthetic yarns or filaments; thus it also offers wide range of properties including open, light, heavy, dense etc. by weft knitting or warp knitting machines. Knitting machines whether they are circular knitting machines or flat knitting machines both provides enough better fabric to be used as acoustic home textiles. Knitting may be applied to make the acoustic curtains. In one research in the area of acoustic knits, plain knitted outer layers and one textured polyester multifilament spacer layer were used to make weft-knitted spacer fabric that behaved as a porous sound absorber. Outer layer with mesh structure having monofilament yarn in the spacer layer was used to make warp-knitted spacer fabric that behaved a micro perforated panel sound absorber (Yanping Liu & Hu, 2010). Jacquard knitted home textiles are preferred over plain knitted home textiles in the curtains, thus the comparison of jacquard knitted home textiles and plain knitted home textiles in terms of their acoustic property (Ozturk, Nergis, & Candan, 2010) and the effect of stitch size on the acoustic property of plain knitted home textiles (Dias & Monaragala, 2006) have been done. The simulation analysis and comparison for spacer knitted home textiles and conventional knitted home textiles (Dias, Monaragala, & Lay, 2007) and experimental comparison of resonance frequency of interlock knitted home textiles and rib knitted home textiles (Dias, Monaragala, & Soleimani, 2007).

Advantages for using acoustic textiles made of nonwoven in the acoustical environment has been discussed in detail (Fatma & Goel, 2013). The nonwovens are preferred for their excellent sound absorbing properties, as most of the nonwovens are fibrous thus they offer better acoustical property. Moreover, the nonwoven technology is industrially available and bulk production is possible by using this technology. Random laid nonwovens, cross laid nonwovens, parallel laid nonwovens and woven fabrics made up of Jute (100%) of needle punched nonwovens (Sengupta, 2010b), anisotropic webs in their structure of nonwovens (Y. Lee & Joo, 2003) and nonwoven fiber webs and woven fabrics together have been investigated (Y. Shoshani & Rosenhouse, 1992). Nonwoven composites made by thermal bonding of polyester and cotton mixture and wool and bi-component polyester composite have also been investigated (Kucuk & Korkmaz, 2012). These all researches prove that nonwovens are suitable option to make them used in the area of acoustic home textiles.

Acoustic home textiles may also be made from sound absorbing panels, plates, composites and fiber assemblies a large number of researches have been done in the area of sound absorbing panels (Bastos, Vieira de Melo, & Soeiro, 2012; Fadzlita, Yeo, Choong, & Melvin, 2014; P. Ricciardi, Belloni, & Cotana, 2014; Zulkifli, Mohd Nor, Ismail, Nuawi, & Mat Tahir, 2009), sound absorbing plates (Fadzlita et al., 2014), sound absorbing composites (Bravo, Toubal, Koffi, & Erchiqui, 2014; Colom, Cañavate, Carrillo, & Lis, 2014; Hao, Zhao, & Chen, 2013; C.-H. Huang, Lin, & Chuang, 2014; Jayamani & Hamdan, 2013; Jayamani, Hamdan, Rahman, Heng, & Bakri, 2014; C.-W. Kang, Oh, Lee, Kang, & Matsumura, 2012; Koizumi, Tsujiuchi, & Adachi, 2002; Kucuk & Korkmaz, 2012; T.-T. Li, Wang, Lou, & Lin, 2012; J.-H. Lin, Li, & Lou, 2014; Lou, Lin,

& Su, 2005; Mueller & Krobjilowski, 2003; Netravali, 2002; Sengupta, 2010a; W. D. Yang & Li, 2012) and sound absorbing fiber assemblies (S. Yang, Yu, & Pan, 2011) made of textile fibers. The researches that have been done in the area of acoustic textiles, mostly includes the insertion of natural fibers or waste material into textiles material. The detailed descriptions of these two areas are coming next sections.

2. Characterization of acoustical properties of home textiles

The characterization of acoustical properties of home textiles includes the measurement or calculation of acoustic properties of home textiles and sound absorption mechanism of home textiles.

2.1. Measurement or calculation of acoustic properties of home textiles

The measurement of acoustic home textiles may be done in terms of sound absorption coefficient, noise reduction coefficient, sound absorption average, sound insulating index, and sound transmission loss. The sound absorption coefficient may be mathematically termed as the ratio of intensities of incident wave to reflected waves, and can be denoted by α.

$$sound\ absorption\ coefficient = \frac{intensity\ of\ incident\ wave}{intensity\ of\ reflected\ wave}$$

$$\alpha = I_i / I_r \quad (1)$$

The noise reduction coefficient, (NRC) is the average value of the sound absorption coefficients of materials at frequencies of 250, 500, 1000 and 2000 Hz, expressed to the nearest 0.05. The sound absorption average (SAA) of a material is the average value of its one third octave sound absorption coefficient values ranging from 200 to 2500 Hz. The sound insulating index generally referred to the difference of reflected decibels and transmitted decibels. The total sound insulating efficiency of any textile material at given frequency may be mathematically described as follow:

$$sound\ insulating\ index = sound\ absorbing\ index + sound\ transmitting\ index$$

$$I_s = A_s + T_s$$

and, the sound absorbing index may be mathematically written as follow:

$$sound\ absorbing\ index = 1 - sound\ reflecting\ index$$

$$A_{ind} = 1 - R_{ind}$$

where sound reflecting index is,

$$sound\ reflecting\ index = \frac{reflected\ decibel}{incident\ decibel}$$

$$R_{ind} = \frac{dB_{ref}}{dB_{inc}}$$

and sound transmitting index may be mathematically written as,

$$sound\ tranmitting\ index = \frac{tranmitted\ decibel}{incident\ decibel}$$

$$T_{ind} = \frac{dB_{tra}}{dB_{inc}}$$

Thus, despite of extensive research various authors have presented the calculation of acoustic textiles differently. But most of the researchers have considered sound absorption coefficient, noise reduction coefficient and sound transmission loss mainly to describe the acoustical characteristics of acoustic textile material.

2.2. Sound absorption mechanism for acoustic home textiles

Home Textiles that decrease the acoustic energy of a sound wave as the wave passes through it by the absorption phenomenon are called sound absorptive home textiles or acoustic home textiles. From the law of conservation of energy we know that, energy can neither be created nor destroyed; it can be transformed from one from to another. Consequently, the kinetic energy possessed by the sound waves cannot be destroyed, yet it is converted in to heat energy. Thus when sound wave strikes to sound absorbing home textiles, the sound disappears. It is actually due to the conversation of the kinetic energy possessed by the sound wave in to heat energy. This kinetic energy of the sound may also be termed as acoustic energy.

The sound possessing sound pressure starts oscillation of air molecules with same frequencies as of sound wave entered into the interstices of acoustic home textiles and that sound wave faces some frictional losses due to irregular interstices of porous acoustic home textiles. Moreover, loss of momentum is occurred due to continuous changes in the flow direction of sound wave and contractions and expansions of flow path in the acoustic home textiles. Compressions and expansions of air molecules in the pores occurs periodically resulting change in the temperature. Up to 80% of sound attenuation may be achieved if the sound propagates parallel to the axis of textile fibers. The probability of the propagation of sound parallel to the axis of fiber is more in fibrous home textiles, thus fibrous home textiles are better sound absorbers and preferred in the application of acoustic home textiles.

Three heat exchanges are occurred simultaneously in to porous home textiles depending upon the frequency of sound. In the region of lower frequency, heat exchange occurs isothermally. It might be due to larger surface to volume ratios. In the region of higher frequencies heat exchange occurs adiabatically. It might be due to poor thermal insulation of home textiles even at longer contact time. In the region of medium frequency, heat exchange results loss of acoustic energy. This loss is the combined result of frictional loss, momentum loss and exchange in temperature in the structure of acoustic home textiles.

3. How to make better acoustic home textiles

The better acoustic home textiles means that product that have higher noise absorption coefficients, higher sound reduction values, higher sound insulation indices, larger noise reduction coefficients and bigger sound absorption averages. This could be achieved by selecting suitable strategies while manufacturing acoustic home textiles. The following strategies should be followed in order to better acoustic performance of acoustic home textiles.

- Selection of suitable textile material
- Selection of appropriate physical parameters
- Selection of appropriate processing parameters
- Layering acoustical textiles
- Chemical finishing
- Consider incident sound parameters
- Placement of acoustic textiles

3.1. Selection of suitable textile material

It is quite important to select suitable textile material for designing acoustic home textile. If the acoustic home textile is woven or knitted the textile material will be yarn, and if the acoustic home textile is composite, panel or nonwoven the textile material will be fiber. Hence, the selection of suitable textile material is dependent on the end-use requirements, and thus this selection can be categorized into selection of textile fiber and selection of yarn.

3.1.1. Selection of suitable textile fiber

Although there have done several researches that have compared the sound insulation properties of different fibers, yet there is not any rule of thumb to select any textile fiber to be the most suitable for acoustic textile material. This is due to various factors affecting the final acoustical property of textile material. These factors include fiber type, fiber fineness and diameter, fiber surface area and fiber blending (component). In addition these factors are necessary to keep in mind while selecting suitable textile material

a. Fiber type

Different researchers have made comparison of two or more fibers in terms of their acoustical property such as in one research, it was concluded that acrylic fiber showed better noise absorption coefficient than wool (Y. Z. Shoshani & Wilding, 1991). The significance of different fibers to absorb different noises has been analyzed in one study, signifying that PU to be supportive in reducing noise of the engine within the cab, needle-spun felt prepared up of polypropylene can reduce the noise generated chassis; PET and cotton might not be appropriate for lower and middle frequency range yet it is appropriate to absorb high frequency (Yan Liu, Zhang, & Liu, 2013). Sound reduction of Jute-PP (1:1), Jute-PP (1:3), Jute-PP (3:1), PP (100%), PET (100%) and Jute (100%) of needle punched nonwovens follows the order of their respective names (Sengupta, 2010b). A large amount of literature is available for acoustic textile material; this whole literature can be categorized into three sections natural fibrous acoustic textile material, fibrous acoustic textile material from waste and synthetic fibers for acoustic textile material.

i. Natural fibrous acoustic textile material

Different materials possess different sound absorption properties. It is essential to determine the significance of using newly known fibers on the acoustical property, thus; the use of natural materials mainly natural fibers to enhance the acoustical properties of textile are being researched. A large number of researches have been done in analyzing newly known natural fibers material for acoustic textiles. such as the use of one newly known cellulosic fiber i.e. estabragh and polypropylene blend as nonwoven has been analyzed (Hassanzadeh, Hasani, & Zarrebini, 2014). Three dissimilar layers of tea-leaf-fiber waste materials without and with backing granted by one layer of woven textile has been analyzed (Ersoy & Kucuk, 2009). In one other research, natural tea-leaf fibers and luffa cylindrica (LC) loaded in polyurethane (PU) foams has been analyzed (Ekici, Kentli, & Kucuk, 2013). There are lot of publications available on the newly known natural fibrous acoustic textile material as sound absorbing panels. The sound absorbing panels of newly known natural fibrous acoustic textile material covers sisal/palm/coconut/acai fibers (Bastos et al., 2012), coir fibers (Fadzlita et al., 2014; Nor, Ayub, Zulkifli, Amin, & Fouladi, 2010; Zulkifli et al., 2009), date palm fibers (Elwaleed Awad Khidir, Nik Mohamed, Mohd Nor, Mat Tahir, & Zulkifli, 2014), self-facing date palm fibers (Elwaleed A. Khidir, Nikabdullah, Nor, Tahir, & Nuawi, 2014), date palm fiber and oil palm fiber (ALRahman, Raja, Rahman, & Ibrahim, 2014), paddy waste fibers as a usable biomass (Putra, Abdullah, Efendy, Mohamad, & Salleh, 2013) and many other newly known natural fibrous acoustic textile materials. The sound absorbing panels from fir sawdust and polyurethane binder and surface layer of cork with and without perforations has also been analyzed (Tiuc, Rusu, & Vasile, 2013).

The sound absorbing composites have also been made from these newly known natural fibrous acoustic textile materials. The composite boards made up of rice hull sawdust (C.-W. Kang et al., 2012), composite of poplar wood fiber and polyester (Peng, Song, Wang, & Wang), ramie, flax and jute fibers (W. D. Yang & Li, 2012), sunflower stalk/stubble fibers/cotton waste/textile waste into urea–formaldehyde adhesive resins with plaster (Binici, Eken, Dolaz, Aksogan, & Kara, 2014) and ecofriendly composites of soybean protein and plant-based ramie fibers (Netravali, 2002) have been thoroughly investigated. In addition to the composites, the sound absorbing nonwovens have also been made from these newly known natural fibrous acoustic textile material. The flax/kenaf/jute/cotton waste needle-punched with polypropylene/polyester as nonwoven (Parikh, Chen, & Sun, 2006) and the banana/jute/bamboo needle punched with polypropylene as nonwoven has been investigated (Thilagavathi, Pradeep, Kannaian, & Sasikala, 2010). Moreover, nonwoven composites made up of kenaf and polypropylene have also been analyzed (Hao et al., 2013). The analysis of wet-laid nonwoven of flax with thermoplastic binding fibers of PA6/CoPA (Fages et al., 2013), spun-laced nonwoven of flax with polypropylene (J. Y. Chen, Müller, König, Nießen, & Müssig, 2010), random-laid/cross-laid/parallel-laid needle punched nonwovens of Jute fiber (Sengupta, 2010b) and detailed study on biodegradable nonwovens (Yilmaz, 2009) have also been made.

Other than panels, composites and nonwovens of newly known natural fibrous acoustic textile materials the plates made up of pine sawdust and polyurethane binder

((Tiuc), Rusu, Ionescu, Cretu, & Ionescu, 2011) has also been analyzed. The detailed study on cashmere/kapok/acrylic fiber/goose down as fiber assemblies has also been made (S. Yang et al., 2011). Kenaf core fiber using adhesive of HN 100 and Kenaf core fiber with PP matrix materials using coupling agent of PVA has also been studied (Jayamani & Hamdan, 2013).

ii. Fibrous acoustic textile material from waste

It is worth full to recycle or reuse the material to make new products. Much of the researches have been reported offering the recycled or reused material to make acoustical textiles such as recycled polyester into fibrous assemblies (Y. Lee & Joo, 2003), compress molded composites from the nonwoven selvages of polyester (Lou et al., 2005), recycled PP selvedge for noise insulting material (J. H. Lin et al., 2012), different layers of two types of polyester fiber and recycled nonwoven selvages of polypropylene at various thicknesses of thermoplastic polyurethane as nonwoven composite (C.-H. Huang et al., 2014), underlay made of recycled carpet waste (Rushforth, Horoshenkov, Miraftab, & Swift, 2005), sound absorber have been made from recycled fibers of end of life tires (ELTs) (Maderuelo-Sanz, Nadal-Gisbert, Crespo-Amorós, & Parres-García, 2012), porous sound insulating materials made of recycled foam (Rey, Alba, Arenas, & Sanchis, 2012), light in weight screeds made of recycled polymers and concrete (Asdrubali, D'Alessandro, Schiavoni, & Baldinelli, 2011), porous inorganic silica foam synthesized from glasses waste using low-temperature hydrothermal ion-exchange reaction (Ji et al., 2014), different plied orientations of polypropylene spun laced selvages into recycled Kevlar selvage/Nylon/low-melting polyester composite nonwoven fabrics (J.-H. Lin et al., 2014), rubber composites were made from recycled PVC/plasticized PVC and a reinforcement of ground tire (Colom et al., 2014), different panels were made from waste paper and textile fibers joined by different glues (P. Ricciardi et al., 2014), chipboards produced with cotton waste, barite and fly ash (Binici, Gemcib, Kucukonder, & Solak, 2012), wet-laid nonwovens from textile powder remainders (Berto, Rey, Alba, & Sanchis, 2012), and elastomeric waste residue (particulates possessing grain and fiber) of rubber or PVC obtained from tire and carpet shreds bound with different PU binders (Benkreira, Khan, & Horoshenkov, 2011). Not only waste recycling have been adopted to make acoustical textile products from conventional textile fiber waste or conventional textile, but strategies have been made to recycle high-modulus and high strength fibers into recycled acoustic textile material. In one study, the high-modulus glass fabric and Kevlar fabric were respectively inserted between double layer of needle-punched nonwoven fabric of Kevlar fibers from recycled unidirectional selvages, nylon 6 fibers and sheath-core low-melting polyester fibers in to ratio of 2:5:3 to form G-Ply and K-Ply respectively; then different layers of G-Ply and K-Ply were hot pressed by a twin-roller hot-presser, laminated by flat hot presser and remained untreated to make H-composite, L-composite and N-composite respectively (T.-T. Li et al., 2012).

iii. Synthetic fibers for acoustic textile material

The acoustical textile researchers are not only limited to natural fibers or waste recycling, but also they have done lot of research on new synthetic fibers such the use of micro-fiber of polyester and nylon into different fabrics (Na, Lancaster, Casali, & Cho, 2007). It has been well known that finer fibers are well suited for acoustic textile material, thus the researchers are going to the optimum fineness of the fiber keeping the cost of fiber in the mind for acoustical textile material. In one research very fine fiber with larger surface area have been studied, in this research the finer reclaimed PET, and different types of PET including round (1.6 Dtex/16 Dtex)/hollow/4DG/low-melt and kenaf fibers (Jayaraman, 2005) have been studied. As the synthetic fibers allows researchers to make changes in the profile of the fiber to make better acoustical textile material, thus in one research the finer fibers with a variety of cross-sectional profile such as round, trilobal and 4DG have been investigated (Tascan & Vaughn, 2008). In one research it has been established that the micro denier fibers less than 1 dpf results better acoustical properties (Koizumi et al., 2002). The fineness of the fiber for acoustical textiles is not limited to micro level but it has surpassed and has reached to nano level. In one research, the use of nanofiber layers into the nonwoven materials have been analyzed and it has been established that the use of nanofiber layers into the nonwoven materials to enhance acoustical properties (Rabbi, Bahrambeygi, Shoushtari, & Nasouri, 2013). Bamboo wool has the better sound absorption property than wool fiber possessing better sound absorption property than bamboo fibers alone (Tsujiuchi, Koizumi, Ohshima, & Kitagawa, 2005).

The high performance all polyester possesses better acoustic property than conventional ones (Watanabe, Minemura, Nemoto, & Sugawara, 1999). The absorption behavior was nearly same up to 3000 Hz for 100% polyamide and 100% wool, beyond 3000 Hz polyamide lost its acoustic performance (Paola Ricciardi & Lenti, 2010). Among composite nonwovens made up of three different types of base-layer i.e. pure cotton nonwoven, pure ramie nonwoven, and pure polypropylene (PP) nonwoven and two different types of surface layer i.e. rayon-precursor activated carbon fiber (ACF) and glass fiber, activated carbon fiber with pure cotton nonwoven showed the better noise absorption (Y. Chen & Jiang, 2007). One other study also finalized that activated carbon fiber composite demonstrates better ability to absorb sound waves than the composites with glass fiber or cotton fiber (Nan Jiang, 2008; N. Jiang, Chen, & Parikh, 2009). The presence of large quantity of silica aerogel of further homogeneous and lesser size in the cell wall material offers better sound absorption property (Oh, Kim, & Kim, 2009). The biodegradable composites made from soybean protein and plant-based ramie fibers could lessen the trouble of the giant amount of waste plastic generated yearly and can also are substituted for wood; this environmentally compatible composite can be used as interior panels for automobiles and railway trains and computer cases to replace plastics and it can also be used as crates or building studs. Beyond the large advantages of these composites including cheaper price, biodegradability, easy accessibility, heat insulation they also offer better noise insulation property (Netravali, 2002). A hollow-fiber yarn “Insulyte” offers enhanced thermal and noise insulation properties because its empty interior work as a heat-transfer barrier, moreover it provides improved bulkiness and cover without rising textile mass; thus possess better noise insulation properties ("Unifi unveils antimicrobial and hollow-fiber yarns," 2001).

b. Fiber fineness and diameter

Although different fibers possess different linear density, yet researchers have studied the fiber fineness and fiber diameter particularly, concluding it as major parameter affecting the sound insulating property of acoustic textiles. Decrease in fiber diameter may cause an increase in sound absorption coefficient because, the movement in fine fibers is easier than coarse fibers on sound waves; thus, finer fibers in between 1.5 to 6 denier per filament (dpf) presents better acoustic insulating property than coarse denier fibers (Koizumi et al., 2002). Fiber diameter has important effect on the sound absorption property of sound insulating panels made up of coir fibers (Nor et al., 2010). Increase in fiber fineness, at a given volume density causes an increase in the number of fibers, resulting more chance to contact sound waves and more indirect path elevating airflow resistance by rise in frictional viscosity through the air vibration; hence increases in sound absorption coefficient (Shahani, Soltani, & Zarrebini, 2014). Nonwovens with higher amount of fine fibers can dissipate more sound due to more hindrance due an increase in airflow resistance causing more frictional viscosity as the product of air vibration (Y. Lee & Joo, 2003). If the fibers will be fine, thus more fibers would accumulate in same thickness and volume density of the fabrics, the more number of fibers will make in a more tortuous path and higher airflow resistance resulting better sound insulating property (Sun, Banks-Lee, & Peng, 1993). Moreover, it has been studied that the micro denier fibers even less than 1 denier per filament (dpf) results better acoustical properties (Koizumi et al., 2002).

c. Fiber surface area

There exists direct relation between fiber surface areas, thus fibers having serrated cross section possess better sound absorption property than round fibers between 1125 Hz to 5000 Hz (Narang, 1995). Finer fibers with a variety of cross-sectional profile such as round, trilobal and 4DG were better sound insulators and absorbers than those made up of coarser fibers due to larger surface area (Tascan & Vaughn, 2008). smaller fiber diameter offering higher specific surface area results increase in the noise absorption coefficient of nonwoven fabrics (Jayaraman, 2005). The nonwovens made up of 4DG and trilobal fibers are better sound insulators than nonwovens made up of round fibers due to larger surface area (Tascan & Vaughn, 2008). The high performance all polyester possess better acoustic property than conventional ones, due to larger greater surface area than that of conventional polyester possessing same weight (Watanabe et al., 1999).

d. Fiber blending (component)

It is obvious that by changing the ratio of any component of fiber the acoustical property of the total fiber will be altered. In one research it has been determined effectively. The result of this research yielded that the larger bi-component percentage yielded better sound absorption in lower frequencies (Lindström, 2014). It is also obvious that sound absorption property will be changed by changing the blending ratio of fiber in any textile specimen. It has been found that the noise absorption coefficient increases by increasing ratio of estabragh fibers in the blend, this is due to hollow structure of estabragh fibers (Hassanzadeh, Zarrebini, & Hasani, 2014).

3.1.2. Selection of suitable textile yarn

The selection of suitable yarn is also important to get the better acoustical properties of acoustic home textiles. There have been large researches taken place to assess the various parameters of yarns affecting the final acoustical property of textile material. From the extensive literature survey, the parameters of yarns affecting the final acoustical property of textile material include yarn linear density, yarn twist, yarn texture and yarn spinning system. Yarn linear density affects the acoustical property of woven fabric. In one research it has been well studied, the effect of yarn linear density on the acoustical property of textile were determined using same twist factors, and it was found that decrease in linear density of one set of yarn (weft yarns) in the woven fabrics results the marginal effect on noise reduction coefficient between 59 tex to 14.8 tex; at the linear density of 24.5 tex (Soltani & Zerrebini, 2012). In same research, noise absorption coefficient of 24.5 tex yarn was the larger nearly at all frequencies.

Yarn twist also affects the sound insulating property of textile material. In one research the effect of yarn twist on the sound insulating properties have been analyzed, it was concluded that the increase in weft yarn twist causes decrease in sound absorption coefficient of woven fabric (Soltani & Zarrebini, 2013). This might be due to decrease in the bulkiness of yarn due to increase in the yarn twist, causing the decrease in sound absorption coefficient of woven fabric. Texturizing the process is applied on the filament yarns to increase their waviness. Yarn texture also plays the significant role on affecting the final acoustical property of any textile material. In one research it was found that the fabric whose upper and lower layers were knitted from textured polyester multifilament yarn had most favorable sound absorbency (Dias, Monaragala, Needham, & Lay, 2007). Thus, yarn texturizing affect positively on to the sound absorbing property of textile material.

Yarn spinning system also plays an important role on the acoustical property of textile materials, thus three spinning system i.e. ring spinning system, compact spinning system and rotor spinning system, were compared in one research (Soltani & Zerrebini, 2012). It was found that the noise reduction coefficient of woven fabric made up of rotor spun yarn is far better than ring spun and compact yarns, due to better bulkiness of rotor spun yarns (Soltani & Zerrebini, 2012).

3.2. Selection of appropriate physical parameters

Only selection of right material is not enough in order to make acoustic home textiles, but selection of right physical parameters to make the better acoustic textile is very important. The physical parameter of any textile products are mass, density, thickness and compression, porosity and perforation, air permeability and flow resistivity and tortuosity.

3.2.1. Mass

The heavier textile products are supposed to resist more noise passing through their structure than lighter textile product. For any noise resistant product sound insulation index rises about 6 dB by doubling its mass per unit area or frequency, and the relation between its transmission loss (TL) is in the unit of decibels (dB), mass per unit area or surface mass (m) is in the unit of pounds per square feet (lb/ft^2) and frequency of sound (f) is in the unit of (Hz) may be described by this equation (Everest & Pohlmann, 2009).

$$TL = 20\log(fm) - 33 \quad \ldots (1)$$

Sound transmission loss increases as the fabric weight increases for the nonwovens made up of Polypropylene (Ghorbani, Zarrebini, Hasani, & Saghafi, 2014). Increases in the nonwoven mass resulted more sound absorption in the lightly needled estabragh nonwovens (Hassanzadeh, Zarrebini, et al., 2014). Oblique incidence sound absorption coefficient of thin woven fabrics backed by an air cavity and of thin woven fabrics used for curtains have been critically analyzed where specific airflow resistance and its surface mass density are considered as the significant factors for the acoustical property (Pieren, 2012a, 2012b).

3.2.2. Density

Density is mostly considered as important factor in analyzing the acoustical property of textile material. Fabric density is increased by increasing the number of fibers keeping same thickness. Increasing number of fibers yields increase in the energy dissipation of sound waves and thus offering better acoustical property of the textile material. It has direct relation with fabric sound insulation as of needle punched nonwoven fabrics (Tascan & Vaughn, 2008). Yet the fabric density of needle punched nonwovens of Jute affected negatively (Sengupta, 2010b). When density of bamboo wool composite was increasing sound absorption coefficient was decreasing (Tsujiuchi et al., 2005). Interlock fabrics possessing higher fabric density shows lesser resonance frequency with marginal difference than rib fabrics possessing lesser fabric density (Dias, Monaragala, & Soleimani, 2007). In one study, the effect of fabric density on acoustical property has been considered as the dependent of the frequency of sound wave i.e. at lower frequencies, less dense fabrics possess better sound insulation properties whereas at higher frequencies denser fabrics possess better sound insulation properties (Koizumi et al., 2002). Fabric density had positive effect on sound absorption property of spacer knitted fabric (Ozturk et al., 2010). Appropriately selected fibers along with appropriate quantity of density can enlarge the sound absorption for the identical layer thickness, it would be very practical for narrow space structure (Nor et al., 2010).

3.2.3. Thickness

Whether it would be any textile material, nonwoven, knitted, woven, composite or panel it possess some thickness, this thickness has profound effect on the acoustical property of final product. In one research, it has been found that panel layer thickness of coir fibers have important effect on sound absorption (Nor et al., 2010). One other research determined that sound absorption behavior of nonwoven material depends generally upon the fabric thickness (Hirabayashi, McCaa, Rebandt, Rusch, & Saha, 1999). One another research also determined that the sound absorption ability of nonwovens depends primarily on the thickness of the fabric (Y. E. Lee & Joo, 2004). Similarly, an improvement in acoustical property can be achieved with the increase in the thickness of nonwoven (Carvalho, Rana, Fangueiro, & Soutinho, 2012). The study of acoustical performance relating to the fabric thickness is not limited to nonwovens textiles only, yet it has been done in other types of textiles too. In one study, it was found that thicker carpets made up of wool and polyamide yielded better acoustical property (Paola Ricciardi & Lenti, 2010). In general, cotton based composites showed better acoustical properties due to their fibrous structure, composite basing cotton hybrid fleeces and epoxy binder showed better acoustical property when the thickness of composite was increasing (Mueller & Krobjilowski, 2003). In a study on noise insulation of plain knitted structures, was found that sound absorbency of fabrics were higher when they had higher thickness (Dias & Monaragala, 2006). One research compared various physical parameters and found out that among various factors such as fabric weight, constructions and thickness of home textile fabrics, thickness had the maximum effect on sound absorbency (Zafirova & Uzunovich, 1998). One study found that the acoustical property of nonwoven fabrics was improved by increasing the thickness at all frequencies, because of more frictional losses causing sound wave energy losses (Hoda Soliman Seddeq, Aly, A, & Elshakankery, 2012).

When materials get thicker sound absorption values gets better; moreover, lower frequency (higher wavelength sound) can be absorbed if the material is thicker (Hoda S. Seddeq, 2009). It has been exposed that the thicker the fabric the higher the sound absorption coefficient (α) at low frequency level (Rus, Normunira, & Rahim, 2013). Sound absorption for porous material generally depends upon thickness of the material only at low frequencies whereas it is insignificant at higher frequencies (Ibrahim & Melik, 1978). Contrary, the thickness of the nonwoven made up of bicomponent fibers presented better sound absorption for the entire frequency range (Lindström, 2014). A large number of studies have concluded that there exist direct relationship in between fabric thickness and sound absorption property particularly at lower frequencies (Everest & Pohlmann, 2009). Moreover, one research considered thickness as important factor and optimized thickness in terms of incident wave length, it suggested that for porous acoustic material, the efficient acoustic insulation can be achieved at thickness of material about one tenth of the incident wavelength (Coates & Kierzkowski, 2002).

3.2.4. Compression

There has not been much research on the effects of compression on the acoustical property of textile material. The fabric compression causes decrease in the thickness of the fabric by bringing all fibers in the structure nearer to one another without effecting number of fibers, thus compression also cause increase in the fabric density, tortuosity, air flow resistivity. The effect of compression on acoustical property of textile may be interesting area to study the acoustic property of carpets, rugs and mats. The change in thickness occurred by compression brings significant changes in the sound absorption coefficient of fibrous material (Castagnede, Aknine, Brouard, & Tarnow, 2000).

3.2.5. Porosity and perforation

The number of pores, their sizes and types are important to be considered while analyzing sound absorption property of textile material. Change in the porosity of lightly needled estabragh nonwovens caused changes in the sound absorption of the fabrics (Hassanzadeh, Zarrebini, et al., 2014). By numerical calculations of several intrinsic parameters of nonwoven fiber-webs maximum sound absorption coefficient in the perceptible frequency range for noise propagation through porous flexible medium made of textile assemblies have been determined (Yakir Shoshani & Yakubov, 2000). Absorption coefficients of open woven textile made up of glass fiber and micro-perforated membranes mounted at 100 mm from a rigid wall have been determined both theoretically and experimentally exceeding 0.4 over 3-4 octaves, moreover, if the layer is doubled this result can be enlarged to 4-5 octaves (J. Kang & Fuchs, 1999). Acoustical description of perforated facings have been studied by an experimental method, showing the good understanding between practical and predicted values (Jaouen & Be´cot, 2011). Perforation of the cork layer were in direct relation with sound absorption coefficient particularly at frequencies higher than 1200 Hz (Tiuc et al., 2013).

Despite of this literature, Porosity and perforation are mystifying their consequences on acoustical property. In one study on noise insulation of plain knitted structures, it was found that sound absorbency of fabrics were higher when they had low pore size (Dias & Monaragala, 2006). Likewise, Porosity had negative effect on sound absorption property of spacer knitted fabric (Ozturk et al., 2010). Contrary, one research depicts that in the correctly manufactured nonwovens, the propagation of sound wave is in the direct relation to porosity (Y. Shoshani & Yakubov, 2001). Moreover, it should also be considered as significant that the porosity affects the height and width of the peaks in the curve of sound absorption plotted against frequency (Horoshenkov & Swift, 2001). The dissipation of the sound occurs at the structure of textile material, thus the effective number of pores are essential in textile material so that sound wave may enter in to the textile structure.

3.2.6. Air permeability and flow resistivity

For porous acoustic textiles, the acoustical property is mainly depended on the impedance and propagation constant, both depends on flow resistance of the porous material (Ren & Jacobsen, 1993). In one study, the amplitude of sound wave was decreased by hindrance of these interlocking offering more tortuous passages resulting the conversion of acoustic energy into heat (Hemond, 1983). In another study, negative relation was found between air permeability and GSM of nonwovens, resulting negative relation between air permeability and sound reduction (Mankodi & Mistry, 2014). Moreover, the collective air permeability of the woven and nonwoven fabric was lowered than only same nonwoven fabric, thus it may yield better sound reduction (Mankodi & Mistry, 2014).

Some researchers have considered flow resistivity an important parameter rather than air permeability. In one research flow resistivity affect the height and width of the peaks in the curve of sound absorption plotted against frequency (Horoshenkov & Swift, 2001). One other study maintain that higher airflow resistance showed better sound absorption values till certain value, late the sound absorption became lesser because sound wave might suffer difficulty in movement through the material (Hoda S. Seddeq, 2009). Oblique incidence sound absorption coefficient of thin woven fabrics backed by an air cavity and of thin woven fabrics used for curtains have been critically analyzed where specific airflow resistance is considered as the significant factors for the acoustical property (Pieren, 2012a, 2012b). The value of sound absorption of composite made up of poplar wood fiber and polyester was inversely related to the airflow resistance values (Peng et al.).

3.2.7. Tortuosity

In very simple words tortuosity may be defined as the ratio of arc or curve length and the space in between two end points of that arc or curve. For the study of acoustic textiles, it may be used to describe the diffusion in porous acoustic textiles which depends on the internal structure of textile material. Tortuosity influences the acoustical property of any material (Knapen, Lanoye, Vermeir, & Gemert, 2003). The tortuosity for acoustic textiles may also be defined as the deviation of pores from the normal. The value of tortuosity decides the performance of noise insulating absorbent materials at high frequency and it determines the position of the quarter-wavelength peaks and high frequency performance of sound insulating porous materials (Horoshenkov & Swift, 2001).

3.2.8. Surface

The surface of the acoustic textile also affect significantly on the acoustical property. In one research it has been determined that plain surfaced fabrics possess the better sound insulation than velour surfaced fabrics followed by cord surfaced fabrics (Shahani et al., 2014). In one other research, it was depicted that the sound absorption ability of nonwovens depends primarily on the surface characteristics of the fabric (Y. E. Lee & Joo, 2004).

3.3. Selection of appropriate processing parameters

Same textile fiber exhibits different acoustical properties if it is produced by different processing parameters. Acoustic home Textile products are made up of weaving, knitting, nonwoven, composites or panels. Each processing method has its own significance and its own parameters. The processing parameters to make the acoustic textile products varies from product to products, such as the processing parameters of nonwovens differs from processing parameters of woven fabrics, and processing parameters of woven fabrics varies from processing parameters of knitted good. Thus here the processing parameters of each type fabric are mentioned one by one.

3.3.1. Process parameters of nonwovens

The processing parameters of nonwovens have the significant affect the acoustical property of acoustic textiles. There are two main steps in the formation of nonwovens i.e. web formation and web bonding. Thus the consequences of each step are mentioned separately. In one research, it was found that the sound insulation property of nonwoven fabrics strongly depends on its composition and structure (Carvalho et al., 2012). The detailed description of both steps of nonwoven manufacturing is presented here.

a. Web formation

There are three types of web-formation i.e. dry laid, wet laid, polymer laid. Webs for dry laid nonwovens are formed by two methods namely carding or air-laying both creates uniform weight per square meter of the fabric. In one study the analysis of the acoustical property of both the methods of dry laid process have been done (Jayaraman, 2005). Wet-laid nonwoven are of natural fiber with different thermoplastic binding fibers have been assessed to determine their acoustic properties (Fages et al., 2013). In the polymer laid web-formation process the polymers is extruded by spinning processes and the filaments are directly collected in order to form a web by two different process, either by Spun bonding or by melt blowing. The acoustical property of spun-bonded nonwovens containing bi-component as islands-in-the-sea filaments have been investigated (Suvari, Ulcay, Maze, & Pourdeyhimi, 2013). There has been research on assessing the acoustical property of nonwoven textiles made by these three types of web formation. The literature survey depicts that the web formation plays a significant role on the final acoustical property of nonwoven acoustic textile. There is one important factor that affect the sound absorption property of the nonwoven acoustic textile made by dry laid web formation i.e. web orientation. Also one factor affecting the acoustical property of spun-bonded nonwovens has been investigated i.e. Number of islands. In the formation of web, the web orientation is key factor affecting the acoustical property of nonwoven textiles. In one research, three different orientation of webs and one woven fabric was compared, the results yielded that sound reduction of random laid nonwoven, cross laid nonwoven, parallel laid nonwoven and woven fabric made up of Jute (100%) of needle punched nonwovens follows the order of their respective names (Sengupta, 2010b). Moreover, in one another research it has been determined that anisotropic webs in their structure of nonwovens offers marginally higher noise absorption coefficient than isotropic webs in their structure of nonwovens (Y. Lee & Joo, 2003). In one research, the acoustical property of spun-bonded nonwovens that contain bi-component as islands-in-the-sea filaments in which Nylon 6 (PA6) as the islands and polyethylene as the sea polymers was determined. In this research it was concluded that sound absorption increased with an increase in the number of islands (Suvari et al., 2013).

b. Web bonding

There are three major types of the web bonding process i.e. mechanical bonding, thermal bonding and chemical bonding. The mechanical bonding process includes needle punching, stitch bonding and hydrogen tangling. Punch density and needling depth are two important parameters affecting the acoustical property of needle punched nonwovens. In the thermal bonding nonwovens, the type of fiber and type of binding fiber are very important parameter affecting the acoustical property of thermal bonded nonwovens. Where as in the chemical bonding process the chemical itself varies the final acoustical performance of chemical bonded nonwovens. In one research, multi layered needle punched nonwoven and multi layered thermal bonded nonwoven were analyzed, suggesting better mechanical properties of multi layered needle-punched nonwoven but not any significant difference in the sound absorption performance (Tai et al., 2010). There has been lot of research on assessing the acoustical property of nonwoven textiles made by these three types of web bonding methods. The literature survey illustrates that the web bonding also plays a significant role on the final acoustical property of nonwoven acoustic textile. Increase in punch density makes larger flow resistivity increasing tortuosity due to higher number of tiny pores and larger fiber to fiber areas of contact. For nonwoven having lower to medium areal density, punch density affects the sound insulation property of fabrics marginally whereas for nonwoven having higher areal density, rise in punch density likewise raises fabric compactness and density making nonwovens better sound absorbers (Shahani et al., 2014). The higher punch density results more interlocking. The sound wave considers fibers interlocking in nonwovens as the resisting element as it provides hindrance to sound waves on entering into the structure (Hemond, 1983). Interestingly, the sound absorption coefficient of webs were better than needle punched nonwovens (Ogunbowale, Banks-lee, Bello, Maiwada, & Kolawole, 2012). Punch density effects on sound transmission loss of jute fibers, minimum sound transmission loss was obtained at punch density of 180 punches/cm^2 for nonwovens made of jute fiber (Sengupta, 2010a). The effect of punch density on lightly needled estabragh nonwovens was found to be insignificant for the sound absorption since of the structure of lightly needled samples is less dense (Hassanzadeh, Zarrebini, et al., 2014).

The needling depth is also one of the important processing parameters to be considered while making better acoustical textile product. The needling depth also effects on sound transmission loss (STL) of jute fibers, maximum sound transmission loss was obtained at needling depth of 15 mm for nonwovens made of jute fiber (Sengupta, 2010a). As the needling depth will be larger, consequently fiber entanglement with in nonwoven increasing, it results more sounds transmission loss (Ghorbani et al., 2014). One research signified that the nonwoven composite made by thermal bonding of polyester and cotton mixture of fibers results in outstanding sound absorption properties much superior to the wool and bi-component polyester composite (Kucuk & Korkmaz, 2012). Moreover, one another research maintained that Wet-laid nonwoven of flax with thermoplastic binding fibers of PVA showed better acoustic properties than wet-laid nonwoven of flax with thermoplastic binding fibers of PA6/CoPA (Fages et al., 2013). In the chemical bonding the webs are combined by using some chemicals or additives. These chemical becomes the part of nonwovens, and thus affects significantly on the acoustical performance of nonwovens. In one research it was found that the chemical bonding using SBR latex contributed negatively to the sound insulation property of nonwoven fabric (Shahani et al., 2014).

3.3.2. Process parameters of woven

There are various factors that can be altered in weaving to assess their effects on the final acoustical properties. Weave type, fabric density, pile height and pile density are the factors affecting the final acoustical property of the woven fabrics. There is large variety of type of weaves available today. Type of weave not only affects the aesthetic and physical properties of the fabric but it also affects the acoustical property of the fabric. In one research, the consequence of weave type on noise reduction coefficient was studied of plain, 2/1 twill, 3/1 twill, 2/2 twill, rips and satin woven fabrics on same warp and weft density of yarns possessing same linear density and tpm, the noise reduction coefficient decreased in the respective order (Soltani & Zerrebini, 2012). The different structures of woven fabrics used for curtains has been analyzed, and it has been found that plain woven/open structure holds lowest sound reduction and one side laminated holds highest sound reduction. The air permeability is considered as the main factor affecting the sound reduction negatively (Mankodi & Mistry, 2014). This suggests that weave type or fabric structure affects the sound insulation property of the fabric

The number of warp yarns per unit width of the fabric is termed as the warp density, and the number of weft yarns per unit length of the fabric is termed as weft density. This both in general termed as fabric density. While changing other properties of the fabric, the fabric density also changes the acoustical properties of the fabric. In one study the consequence of weft density was determined, and it was maintained that incremental in noise reduction coefficient of layered fabrics was larger for the fabrics woven at lower weft densities (Soltani & Zarrebini, 2013). Pile is the yarn that is deliberately inserted to be extended outward from the axis of the fabric. The piles are inserted in towel and carpets mostly. The length that is extended outward from the axis of the fabric is known as pile height and the number of piles per unit space in known as pile density. This pile also affects the acoustical property of the fabric. In one study two parameters of pile i.e. pile height and pile density were analyzed in terms of their effects on the acoustical property of the fabric, it was finalized that pile height does not affect noise absorption coefficient significantly, yet pile density affects positively on the noise absorption coefficient of tufted carpet, regardless of the fiber being used (Y. Z. Shoshani & Wilding, 1991). In one of our research the effect of fabric parameters i.e. air permeability, fabric thickness and fabric GSM on the acoustical properties have been analyzed (Memon, Naeem, et al., 2015).

3.3.3. Process parameters of knitting

The Knitted fabrics are preferred as acoustic textiles over other types of fabric particularly in automotive industry due to their better-quality draping properties (Ozturk et al., 2010). The basic unit of any plain knitted structure is the stitch that is produced by intermeshing the loops of yarn. Knitting type and stitch size are the important process parameters of knitting affecting the acoustical property of knitted fabrics. The type of knitting is important factor affecting the acoustical property of knitted fabrics. In one research it was determined that noise absorption coefficient values were higher for mini-jacquard knit fabrics than plain knit structure because of thicker face layer as a result thicker spacer fabric (Ozturk et al., 2010). In one another study, it has been found that interlock fabrics possess lesser resonance frequency than rib fabrics (Dias, Monaragala,

& Soleimani, 2007). Moreover, the simulation analysis for spacer fabric as a micro perforated panel for sound absorption was done, suggesting that spacer fabric are far better than conventional knitted fabrics (Dias, Monaragala, & Lay, 2007). In a study on noise insulation of plain knitted structures, was found that sound absorbency of fabrics was higher when they had smaller stitch size (Dias & Monaragala, 2006). It should be understood that smaller stitch size reduces pore size and porosity by allowing more yarn in a unit area and makes the fabric becomes denser.

3.3.4. Acoustic textile composite

The textile composites are widely being used nowadays. The use of textile composite is in many fields. The textile composite is compose of two components i.e. matrix and reinforcement. The textile fibers are generally used as the reinforcement component and the polymers are used as the matrix component. Thus, these two components are supposed to have consequences on the acoustical properties of the composites. The effect of Fiber contents and binder concentration on the acoustic performance of the textile composite has been described here. The change in the acoustical properties by changing the fiber contents is the obvious. In one research, it was observed that the change in the fiber content can cause changes in sound absorption coefficients of composites, as the higher fiber contents produced higher sound absorption coefficients (Jayamani et al., 2014). In order to make better acoustical product, it is necessary to optimize the binder concentration, as the binder may cause worse effects on the acoustical property of the acoustic textile product. Likewise in one research the consequence of the binder concentration on the final acoustical properties were analyzed, the research maintained that the changes in binder concentration can also cause changes in sound absorption coefficients of composites, as the lower binder concentrations produced higher sound absorption coefficients (Jayamani et al., 2014).

3.3.5. Sponges and foams

Sponges and foams are also used to make better acoustical textile product. Researchers have been analyzed the use of sponges into acoustical textile product. The detailed applications of sponges and foams are in the field of acoustic material rather than acoustical home textiles, thus it has not been described in detail. In one research it was maintained that structures matter a lot, such as sponges can decrease the noise generated at low and high frequencies; the merged sponges can reduce the noise from the wheels and transmission system (Yan Liu et al., 2013). In another research it was found that acoustical properties are increased by increasing the concentration of polymethacrylate membrane-forming agent (F. Chen, Zhu, & Guo, 2013).

3.4. Layering acoustical textile

Often different layers of fabrics are combined together to make the acoustical textiles. The number of layers may be woven, knitted or nonwovens. The type of backing and number of layers are important factors affecting the acoustical property of final acoustical textile.

3.4.1. Type of backing

The acoustical properties of acoustical products are changes by changing the type of backing used during the manufacturing of any acoustical textile product. There are three main type of backings that have been analyzed by different researchers i.e. Fabric backing, lamination and resistive layer. Mostly, the fabric backing is done in the manufacturing of acoustical textile product. Even in the commercial products of acoustic home textile the fabric backing is available and preferred over other types of backing. The curtains often have interlining made up of nonwoven or woven material that assists the acoustical property of the curtain. Similarly, the underlay behind the carpet is placed to enhance its acoustical property. In one research it was found that nonwoven backings affected noise absorption capacity positively of tufted carpets (Yakir Z. Shoshani, 1990). Moreover, the sound absorption was improved for nearly all samples when they were provided the backing on 3mm needle punched nonwoven layer and it was further improved when the backing was 4mm (Paola Ricciardi & Lenti, 2010). The lamination is the process to apply backing onto the acoustical product. Lamination of any other material such as aluminum foil progressed positively for the sound insulation property of thermo-bonded nonwoven fabrics significantly. Thus, the thermo bonded aluminum foil laminated nonwoven fabric provided the better sound insulation performance and better sound reduction efficiency than the other nonwoven produced from mineral wool in the audible frequency range of ear (Carvalho et al., 2012). The resistive layer may be any panel or plate with or without perforations. The acoustical property of acoustical product at varies by changing the type of resistive layer placed in the acoustical product. In one other study, the adding up of an upstream resistive layer (perforated plate) allow to increase sound absorption at low frequency of a fine sound absorber as glass wool but this resistive layer simultaneously decreases sound absorption at high frequency (Chevillotte, 2012).

3.4.2. Number of layers

Several researches have been done to assess the final acoustical properties of the acoustical product after combing various layers of textile material. One research maintained that the best design for the sound barrier is honeycomb structure, while a zigzag pattern prepared by combining numerous nonwoven webs with one cover of woven textile facing the sound supply is an suitable design for an sound insulating ceiling (Y. Z. Shoshani, 1993). In one another similar research, it was found that the noise insulating panel was made of numerous layers of nonwoven fiber webs and one layer of woven fabric, for many frequencies 70 degree yielded highest noise insulation (Y. Shoshani & Rosenhouse, 1992). One other research revealed that by increasing number of layers affected marginally on sound reduction of the acoustical textile product (Sengupta, 2010b). Six layered samples, woven with finer yarn exhibited higher NRC than six layered samples, woven with coarser yarn whereas three layered samples, woven with finer yarn exhibited lower NRC than three layered samples, woven with coarser yarn (Soltani & Zerrebini, 2012). needle-punched nonwoven having many layers and thermal bonded nonwoven also having many layers were analyzed, the study finalized that there is not any significant difference in the acoustical performance (Tai et al., 2010). It has been exposed that by adding number of layers the final acoustical product becomes thicker, the thicker the product the higher the sound absorption coefficient (α) at low frequency level (Rus et al., 2013). Increasing number of layers yielded increase in NAC, till four layers for weft knitted and so on for warp knitted. Combining both can considerably improve acoustic property but depending on their arrangement sequence. Multilayered warp-spacer-knits can substitute air-back cavity to achieve high NACs at lower and middle frequencies (Yanping Liu & Hu, 2010). The single layered STF treated fabric yielded sound insulation index about 0.8–1.6 dB while double layered STF treated fabric yielded sound insulation index about 10.25–13.84 dB (Wang, Zhu, Fu, & Fu, 2014). In one other study, it was revealed that three layered fabric coated with STF yielded the highest sound absorption coefficient about 13 dB (S. Li, Wang, Ding, Wu, & Fu, 2014). Effect of number of layers on the sound insulation property have been discussed finding α = 0.848 at 4000 Hz for 3-layer un-thermo-bonded fabrics (J. H. Lin, Li, Lin, Lin, & Lou, 2013). Improvement in sound transmission loss was found by increasing the number of nanofiber layers (Rabbi et al., 2013).

3.5. Chemical finishing

Some chemical finishes are applied to get enhancement into the properties other than acoustic properties of textiles; such as antimicrobial or UV radiation protection (Abidi, Hequet, Tarimala, & Dai, 2007; Mahltig, Böttcher, et al., 2005; Mahltig, Fiedler, & Böttcher, 2004; Mahltig, Haufe, &

Böttcher, 2005; Xing, Yang, & Dai, 2007), dye fastness (Cireli & Onar, 2008), anti-wrinkle finishing (K. S. Huang, Nien, Hsiao, & Chang, 2006), super-hydrophobicity (Mahltig & Böttcher, 2003; Xue, Ji, Chen, & Wang, 2008), bimolecular immobilization (F. Y. Li, Xing, Ding, & Zu, 2007), flame retardant and photo catalytic properties (Colleoni, Massafra, & Rosace, 2012; Moafi, Shojaie, & Zanjanchi, 2011) and sensor characteristics (Schueren et al., 2012). Those chemical modifications whose effect on the acoustical properties have been assessed are presented here in this paper, these includes doping, coating and oil painting. In one of our previous research, the sound insertion loss before and after coating of polyester woven fabrics were analyzed (Memon, Khoso, et al., 2015).The sound absorption coefficient as high as 0.999 was achieved at the frequency of 4 KHz from the 60% doped TiO_2 flexible polymer foam before UV irradiation, later after irradiating with UV the highest peak was achieved by 100% doped TiO2 flexible polymer foam (Atan, 2014). In one study, related to sound insulation in terms of coating on to woven and nonwoven fabrics, it was found that noise insulation properties of multilayer surfaces were improved by increasing the concentration of pumice stone powder and by decreasing particle size of pumice stone (Canbolat, Kut, & Dayioglu, 2015). In one another study, better acoustical properties were obtained using tetra pod ZnO whisker (TW-ZnO)/SiO_2-compounded shear thickening fluid (STF) (Wang et al., 2014). Particularly among the acoustic home textiles; the curtains are preferred to have some paintings on it. Paintings not enhance the beauty of the curtains but also they are helpful in getting modifications in the acoustical properties. Oil paintings with the gypsum base treatment let the canvas fabric behave as an resistant membrane towards sound, this improved sound absorption at low frequency performance but make it worse for sound absorption at high frequency (Martellotta & Castiglione, 2011).

3.6. Consider incident sound parameters

The incident sound parameters should also be kept in mind, while making the acoustic textiles. It should be noted that various sound frequencies and sound intensities affects differently on the acoustical performance of the acoustic textile. These two parameters of the incident sound are described in brief here. It has mostly been found that better acoustical properties are obtained at the higher frequencies as compare to lower frequency, the possible reason in front of the author is shorter wavelength of high frequency sound wave; this shorter wave length can easily be absorbed into the thickness of acoustic textile product, on contrary when this frequency is higher, it means the wave length is lower; thus it make it complicated to be absorbed into the structure of acoustic textile product of shorter thickness. One study found that the absorption coefficient of a cover made of woven fabric was much higher at higher frequencies (Y. Shoshani & Rosenhouse, 1990). likewise, higher sound transmission loss was found by nonwovens at higher frequency (Ghorbani et al., 2014). In one other research supporting these results it was found that for both fabrics, the NAC was directly related to the frequency, both backed with the air-back cavity showed frequency-selected noise absorption by means of resonance form. At higher and lower frequencies, the NACs of the warp-spacer-knits backed with weft-knits are much higher and lower than those of the weft-spacer-knits backed with warp-knits respectively (Yanping Liu & Hu, 2010). It is the easily understandable that if the incident sound would have higher intensity, then it is supposed to get larger noise at the receiver. Moreover, it should be noted that the higher sound intensity of the incident sound wave not only make it promote to have larger noise at the receiver, but also most of the acoustical home textiles performs worse when they are subjected to higher intense incident sound wave. In one research, higher the incident decibel, lower the sound reduction has been proved for needle punched nonwovens of Jute (Sengupta, 2010b).

3.7. Placement of acoustic textiles

Placing the acoustic textile product in dispersed area not in continuous area efficiently increase the noise absorption because it enhances the diffusion; moreover, it is better to place acoustic textile product in such a way so that all three axis of the space are being covered (Everest & Pohlmann, 2009). The sound reduction rises as the distance between the sound source and fabric increases for woven, nonwoven and the combination of woven and nonwovens (Mankodi & Mistry, 2014), thus the acoustical textile product should be placed at a certain distance. Moreover, there should be gap in between wall and acoustic textile products to get better efficiency of this acoustic home textile. In one study, it has been found that the air gap work optimum only, results suggests that when there was air gap, absorption coefficient was higher; but this makes insignificant effect in between air gap of 5 mm and 10 mm (Hoda S. Seddeq, 2009). Similarly, might not be compulsory, yet the minimum value of noise reduction coefficient occurred at lower frequencies for increasing the air space beyond fabric (Soltani & Zerrebini, 2012). In addition to, one another study also revealed that increasing air space from 0 mm to 25 mm and then 25 mm to 50 mm yielded increment in sound absorption for lower frequencies only whereas increasing of air space showed different peaks at different range in medium to higher frequencies for bamboo wool composite (Tsujiuchi et al., 2005).

In the auditorium hall, acoustic textile product efficient at higher frequencies should be used till the height of the heads; the acoustical properties are depicted twice when these acoustic textile products are used at the lower portions of high walls (Everest & Pohlmann, 2009). One study reveals that sound reduction is directly related to the distance between fabric and sound source and remained negligible changed by changing distance between fabric and receiver; moreover, as areal density increases, this effect further increases (Sengupta, 2010b). In the rectangular space, it is mainly preferred to place acoustic textile product close to corners and beside room surface boundaries (Everest & Pohlmann, 2009). If the cavity is placed behind sound absorbing material, the maximum sound absorbing value shifted to lower frequencies and on increasing the thickness of the cavities, maximum value of sound absorption coefficient in the lower frequencies is not clear (Peng et al.). Moreover, it should be noted that untreated surfaces should never face each other (Everest & Pohlmann, 2009).

4. Conclusion

This review suggests that there have been lot of researches in the area of acoustic textiles. Following summary statements could be made from this extensive literature review. The research in the field of acoustic textiles covers large variety of textile materials including natural fibers i.e. cotton, jute, flax, sisal, kapok, kenaf, ramie, coir (coconut fibers), pina (pineapple fiber), banana fibers, estabragh fibers, luffa cylindrica fiber, date palm fibers, self-facing date palm fibers, oil palm fibers, acai fibers, tea-leaf-fiber, paddy waste fibers, poplar wood fiber, stubble fibers, sunflower stalk, cashmere, wool, goose down and saw dusts of fir, rice hull and pine. acrylic fiber; waste material i.e. cotton waste, textile waste , elastomeric waste residue obtained from tire and carpet, waste paper, fibers of end of life tires, textile powder remainders, recycled polyester, recycled polypropylene, recycled foam, recycled polymers, recycled Kevlar, recycled PVC, recycled carpet waste; synthetic fibers i.e. micro-fiber of polyester and nylon, PET in different shapes (round, hollow, trilobal and 4DG), high performance all polyester, nanofiber, bamboo, bamboo wool, polyamide, polypropylene, polypropylene (PP) with surface layer of activated carbon fiber (ACF) and glass fiber.

Every fiber has its own significance in the field of acoustic textiles to be used in different acoustical environments. In general, the bulkier, finer, lighter and larger surface area of the fiber, the better the acoustical properties; and in case of fiber blending the better acoustical properties are dependent on the amount of the respective fibers. Yarn linear density, yarn twist and yarn texture affects marginal, negative and positive respectively on the sound absorption of the acoustic textiles. Open end yarn spinning system is better and compact yarn spinning system is worse than ring spinning system in terms of their consequence on sound absorption of acoustic textiles.

In general, heavier, thicker, uncompressed and tortuous acoustic textiles absorbs more sound, yet the effect of density, porosity, perforation, air permeability and flow resistivity is insignificant. Plain surfaced, velour surfaced and cord surfaced fabrics possess the sound absorbing ability in the order of their respective names. In general, the more random orientation of fibers in the web, the better the sound absorbing performance. Likewise, the more the numbers of islands in islands in the sea spun-bonded nonwovens better the acoustical performance. Punch density has negative whereas needling depth has positive effect on the acoustical property of needle-punched nonwovens. The sound insulation property of thermal bonded nonwoven is dependent on the sound insulation property of thermoplastic binding fibers; similarly, the sound insulation property of chemical bonded nonwoven is dependent on the sound insulation property of chemical. In brief, more interlacement of yarns (close structure) may cause better sound insulation. Interestingly, fabric density affects negatively but pile density affect positively on the sound insulation, whereas there is not much consequence of pile height. Spacer knitted and jacquard knitted fabrics have shown better acoustical performance than conventional and plain knitted fabrics. Knitted fabrics with smaller stitch size (denser fabric) possess better acoustical performance.

Higher fiber contents and lower binder concentrations produce higher sound absorption coefficients of acoustic composites. Moreover, higher concentrations of membrane-forming agent causes higher sound absorption coefficients of sponges. Porous and thicker fabric backing results better acoustical performance. Perforated plate may be better choice of backing to resist lower sound frequency. Moreover, lamination develops sound insulation property positively than the nonwovens. Initially, increasing number of layers causes increase in sound absorption but later it becomes insignificant when more numbers of layers are added. Coating increases sound insulation performance. Doping with 60% TiO_2 resulted sound absorption coefficient equals to 0.999 at the frequency of 4 KHz before UV irradiation, and doping with 100% TiO_2 resulted highest sound absorption coefficient after UV irradiation. Raising the concentration of pumice stone powder and diminishing particle size of pumice stone resulted better acoustical performance. Oil paintings enhanced sound absorption at lower frequency but decreased sound absorption at higher frequency.

Higher the frequency of incident sound wave and lower the intensity of incident sound wave better the sound absorption of acoustic textiles. For better acoustical performance, the acoustical textiles should be placed detached, unaligned, three axial, far from sound source, slightly away from wall, in the lower portion of hall, close to corners, beside walls, and back to back if having untreated surfaces.

References

(Tiuc), A. B., Rusu, T., Ionescu, S., Cretu, M., & Ionescu, A. (2011). Acoustical Materials – Sound Absorbing Materials Made of Pine Sawdust. *RJAV, VIII*(2), 4.

Abidi, N., Hequet, E., Tarimala, S., & Dai, L. L. (2007). Cotton fabric surface modification for improved UV radiation protection using sol-gel process. *J Appl Polym Sci, 104*(1).

ALRahman, L. A., Raja, R. I., Rahman, R. A., & Ibrahim, Z. (2014). Comparison of Acoustic Characteristics of Date Palm Fibre and Oil Palm Fibre. *Research Journal of Applied Sciences, Engineering and Technology 7(8): 1656-1661, 2014, 7*(8), 6.

Arenas, J. P., & Crocker, M. J. (2010). Recent Trends in Porous Sound-Absorbing Materials. *Materials Reference Issue*.

Asdrubali, F., D'Alessandro, F., Schiavoni, S., & Baldinelli, G. (2011, 27 June 2011 - 1. July 2011). *Lightweight screeds made of concrete and recycled polymers: acoustic, thermal, mechanical and chemical characterization* Paper presented at the FORUM ACUSTICUM 2011, Aalborg, Denmark.

Atan, B. A. B. M. (2014). *Influence of UV Irradiated on High Doping* TiO_2 *of Polymer Foam for Acoustic Study-Masters Thesis.* (Master of Mechanical Engineering), Universiti Tun Hussein Onn Malaysia, Universiti Tun Hussein Onn Malaysia.

Aybek, A., Kamer, H. A., & Arslan, S. (2010). Personal noise exposures of operators of agricultural tractors. *Applied Ergonomics, 41*(2010), 8. doi:10.1016/j.apergo.2009.07.006

Bastos, L. P., Vieira de Melo, G. d. S., & Soeiro, N. S. (2012). Panels Manufactured from Vegetable Fibers: An Alternative Approach for Controlling Noises in Indoor Environments. *Advances in Acoustics & Vibration, 2012*.

Benkreira, H., Khan, A., & Horoshenkov, K. V. (2011). Sustainable acoustic and thermal insulation materials from elastomeric waste residues. *Chemical Engineering Science, 66*(2011), 15. doi:10.1016/j.ces.2011.05.047

Berto, L., Rey, R. D., Alba, J., & Sanchis, V. (2012, 23-27 April 2012). *Reuse of textile powder remainders for acoustic applications using the Wet-Laid technology.* Paper presented at the Acoustics 2012, Nantes, France.

Binici, H., Eken, M., Dolaz, M., Aksogan, O., & Kara, M. (2014). An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres. *Construction and Building Materials, 51*(2014).

Binici, H., Gemcib, R., Kucukonder, A., & Solak, H. H. (2012). Investigating sound insulation, thermal conductivity and radioactivity of chipboards produced with cotton waste, fly ash and barite. *Construction and Building Materials, 30*(2012). doi:10.1016/j.conbuildmat.2011.12.064

Bravo, A., Toubal, L., Koffi, D., & Erchiqui, F. (2014). Development of novel green and biocomposite materials: Tensile and flexural properties and damage analysis using acoustic emission. *Materials and Design*, 13. Retrieved from http://dx.doi.org/10.1016/j.matdes.2014.10.026

Canbolat, S., Kut, D., & Dayioglu, H. (2015). Investigation of pumice stone powder coating of multilayer surfaces in relation to acoustic and thermal insulation. *Journal of Industrial Textiles, 44*(4), 23. doi:10.1177/1528083713516665

Carvalho, R., Rana, S., Fangueiro, R., & Soutinho, F. (2012). *Noise Reduction Performance of Thermobonded Nonwovens*. Paper presented at the 12th World Textile Conference AUTEX, Zadar, Croatia.

Castagnede, B., Aknine, A., Brouard, B., & Tarnow, V. (2000). Effects of compression on the sound absorption of fibrous materials. *Applied Acoustics, 61*(2000), 10.

Chen, F., Zhu, H.-L., & Guo, Y.-H. (2013). Study on Waterproof Textile Materials Used for Earphone Membrane of Phone. *Journal of Zhejiang Sci-Tech University, 30*(2).

Chen, J. Y., Müller, D. H., König, C., Nießen, K., & Müssig, J. (2010). Spunlaced Flax/Polypropylene Nonwoven as Auto Interior Material: Acoustical and Fogging Performance. *Journal of Biobased Materials and Bioenergy*, *4*(4), 8.

Chen, Y., & Jiang, N. (2007). Carbonized and Activated Non-wovens as High-Performance Acoustic Materials: Part I Noise Absorption. *Textile Research Journal, 77*(10). doi:10.1177/0040517507080691

Chevillotte, F. (2012). Controlling sound absorption by an upstream resistive layer. *Applied Acoustics*, *73*(2012), 5.

Cireli, A., & Onar, N. (2008). Leaching and fastness behavior of cotton fabrics dyed with different type of dyes using sol-gel process. *J Appl Polym Sci*, *109*(1), 8.

Coates, M., & Kierzkowski, M. (2002). Acoustic textiles-lighter, thinner and more sound-absorbent. *Technical-Textiles-International*. http://www.highbeam.com/ Retrieved from http://www.highbeam.com/

Colleoni, C., Massafra, M. R., & Rosace, G. (2012). Photocatalytic properties and optical characterization of cotton fabric coated via sol-gel with non-crystalline TiO_2 modified with poly (ethylene glycol). *Surf Coat Technol*, *207*(August).

Colom, X., Cañavate, J., Carrillo, F., & Lis, M. J. (2014). Acoustic and mechanical properties of recycled polyvinyl chloride/ground tyre rubber composites. *Journal of Composite Materials*, *48*(9).

Dias, T., & Monaragala, R. (2006). Sound absorbtion in knitted structures for interior noise reduction in automobiles. *Measurement Science and Technology*, *17*(9).

Dias, T., Monaragala, R., & Lay, E. (2007). Analysis of thick spacer fabrics to reduce automobile interior noise. *Measurement Science and Technology*, *18*(2007).

Dias, T., Monaragala, R., Needham, P., & Lay, E. (2007). Analysis of sound absorption of tuck spacer fabrics to reduce automotive noise. *Measurement Science and Technology, 18*(8). doi:10.1088/0957-0233/18/8/042

Dias, T., Monaragala, R., & Soleimani, M. (2007). Acoustic response of a curved active PVDF-paper/fabric speaker for active noise control of automotive interior noise. *Measurement Science and Technology*, *18*(2007).

Ekici, B., Kentli, A., & Kucuk, H. (2013). Improving Sound Absorption Property of Polyurethane Foams by Adding Tea-Leaf Fibers. *Archives of Acoustics, 37*(4).

Ersoy, S., & Kucuk, H. (2009). Investigation of industrial tea-leaf-fibre waste material for its sound absorption properties. *Applied Acoustics, 70*(2009), 6.

Everest, F. A., & Pohlmann, K. C. (2009). *Master Handbook of Acoustics* (Fifth Edition ed.). New York: Mc Graw Hill.

Fadzlita, M. T., Yeo, K. B., Choong, W. H., & Melvin, M. (2014). Absorption Coefficient of Acoustic Coir Fibre Panel and Effects of Varying Percentage of Perforated Plates. *Journal of Applied Sciences*, *14*.

Fages, E., Cano, M. A., Girones, S., Boronat, T., Fenollar, O., & Balart, R. (2013). The use of wet-laid techniques to obtain flax nonwovens with different thermoplastic binding fibers for technical insulation applications. *Textile Research Journal, 83*(4), 12.

Fatma, T., & Goel, A. (2013). Nonwoven acoustic textiles. *Asian Textile Journal,, 22*(2), 6.

Fernández, J. A., Soriano, J. R., Sanchis, E. J., & Silla, E. E. (2007). Empirical equations for sound propagation in different sound absorbent materials. *Noise & Vibration Worldwide, 38*(3), 10.

Fung, W., & Hardcastle, M. (2001). *Textiles in Automotive Engineering*. Cambridge, UK: Woodhead Publishing.

Ghorbani, K., Zarrebini, M., Hasani, H., & Saghafi, R. (2014). *Sound Transmission Loss of Needled Nonwovens in Relation to Layer Weight and Needling Parameters*. Paper presented at the International Conference on Technical Textiles and Nonwovens 2014, Indian Institute of Technology Delhi, India.

Hao, A., Zhao, H., & Chen, J. Y. (2013). Kenaf/polypropylene nonwoven composites: The influence of manufacturing conditions on mechanical, thermal, and acoustical performance *Composites: Part B, 54*(2013), 8.

Hassanzadeh, S., Hasani, H., & Zarrebini, M. (2014). Analysis and prediction of the noise reduction coefficient of lightly-needled Estabragh/polypropylene nonwovens using simplex lattice design. *The Journal of The Textile Institute, 105*(3). doi:10.1080/00405000.2013.835903

Hassanzadeh, S., Zarrebini, M., & Hasani, H. (2014). An Investigation into Acoustic Properties of Lightly Needled Estabragh Nonwovens Using the Taguchi Method *Journal of Engineered Fibers and Fabrics, 9*(3), 9.

Hemond, C. J. (1983). *Engineering Acoustics and Noise Control*: Prentice Hall.

Hirabayashi, T., McCaa, D. J., Rebandt, R. G., Rusch, P., & Saha, P. (1999). Automotive Noise and Vibration Control Treatments. *Sound and Vibration, 33*(4).

Horoshenkov, K. V., & Swift, M. J. (2001). The effect of conolidation on the accoustic properties of loose rubber granulates. *Applied Acoustics, 62*(2001).

Huang, C.-H., Lin, J.-H., & Chuang, Y.-C. (2014). Manufacturing process and property evaluation of sound-absorbing and thermal-insulating polyester fiber/polypropylene/ thermoplastic polyurethane composite board. *Journal of Industrial Textiles, 43*(4), 14. doi:10.1177/1528083712471697

Huang, K. S., Nien, Y. H., Hsiao, K. C., & Chang, Y. S. (2006). Application of DMEU/SiO2 gel solution in the ant wrinkle finishing of cotton fabrics. *J Appl Polym Sci, 102*(5).

Ibrahim, L. L., & Melik, R. W. (1978). *Physical Parameters Affecting Acoustic Absorption Characteristics of Fibrous Materials*, Egypt.

Jaouen, L., & Be´cot, F.-X. (2011). Acoustical characterization of perforated facings. *Journal of Acoustical Society of America, 129*(3), 7.

Jayamani, E., & Hamdan, S. (2013). Sound Absorption Coefficients Natural Fibre Reinforced Composites. *Advanced Materials Research, 701*(2013), 6. doi:10.4028/www.scientific.net/AMR.701.53

Jayamani, E., Hamdan, S., Rahman, M. R., Heng, S. K., & Bakri, M. K. B. (2014). Processing and Characterization of Epoxy/Luffa Composites: Investigation on Chemical Treatment of Fibers on Mechanical and Acoustical Properties. *Accoustic Absorbers, 9*(3), 15.

Jayaraman, K. A. (2005). *Acoustical Absorptive Properties of Nonwovens.* (M.Sc. in Textile Management and Technology), North Carolina State University, Raleigh, U.S.A.

Ji, C., He, D., Shen, L., Zhang, X., Wang, Y., Gupta, A., . . . Bao, N. (2014). A facile green chemistry route to porous silica foams. *Materials Letters, 119*(2014), 4.

Jiang, N. (2008). *Fabrication and Evaluation of Specialty Nonwoven Materials.* (Doctor of Philosophy in Textile Science), Louisiana State University, Louisiana State University, Baton Rouge, LA 70803.

Jiang, N., Chen, J. Y., & Parikh, D. V. (2009). Acoustical evaluation of carbonized and activated cotton nonwovens. *Bioresource Technology, 100*(2009), 4.

Kang, C.-W., Oh, S.-W., Lee, T.-B., Kang, W., & Matsumura, J. (2012). Sound absorption capability and mechanical properties of a composite rice hull and sawdust board. *Journal of Wood Science, 58*(3).

Kang, J., & Fuchs, H. V. (1999). Predicting the absorption of open weave textiles and micro-perforated membranes backed by an air space. *Journal of Sound and Vibration, 220*(5), 16.

Khidir, E. A., Nik Mohamed, N. A., Mohd Nor, M. J., Mat Tahir, M. F., & Zulkifli, R. (2014). A Preliminary Study on the Sound Absorption of Date Palm Fibers. *Applied Mechanics & Materials, 663*.

Khidir, E. A., Nikabdullah, N., Nor, M. J. M., Tahir, M. F. M., & Nuawi, M. Z. (2014). A Preliminary Study on the Sound Absorption of Self-Facing Date Palm Fibers. *Applied Mechanics and Materials, 565*, 25.

Knapen, E., Lanoye, R., Vermeir, G., & Gemert, D. V. (2003). *Sound Absorption By Polymer-Modified Porous Cement Mortars.* Paper presented at the 6th International Conference on Materials Science and Restoration.

Koizumi, T., Tsujiuchi, N., & Adachi, A. (2002). The Development Of Sound Absorbing Materials Using Natural Bamboo Fibers. *High performance Structure and Composites, 59*, 10. doi:10.2495/HPS020161

Kucuk, M., & Korkmaz, Y. (2012). The effect of physical parameters on sound absorption properties of natural fiber mixed nonwoven composites. *Textile Research Journal, 82*(20). doi:10.1177/0040517512441987

Lee, Y., & Joo, C. (2003). Sound Absorption Properties of Recycled Polyester Fibrous Assembly Absorbers. *AUTEX Research Journal, 3*(2), 7.

Lee, Y. E., & Joo, C. W. (2004). Sound absorption properties of thermally bonded nonwovens based on composing fibers and production parameters. *Journal of Applied Polymer Science, 92*(4).

Li, F. Y., Xing, Y. J., Ding, X., & Zu, Y. (2007). Immobilization of papain on cotton fabric by sol-gel method. *Enzyme Microb Technol, 40*(7).

Li, S., Wang, Y., Ding, J., Wu, H., & Fu, Y. (2014). Effect of shear thickening fluid on the sound insulation property of textiles. *Textile Research Journal, 84*(9).

Li, T.-T., Wang, R., Lou, C.-W., & Lin, J.-H. (2012). Acoustic absorption evaluation of high-modulus puncture resistance composites made by recycled selvages. *Textile Research Journal, 82*(15).

Lin, J.-H., Li, T.-T., & Lou, C.-W. (2014). Puncture-resisting, sound-absorbing and thermal-insulating properties of polypropylene-selvages reinforced composite nonwovens. *Journal of Industrial Textiles, 0*(00), 13.

Lin, J. H., Huang, C. H., Chuang, Y. C., Shih, Y. H., Lin, C. W., & Lou, C. W. (2012). Property Evaluation of Sound-Absorbent Nonwoven Fabrics Made of Polypropylene Nonwoven Selvages. *Advanced Materials Research, 627*(2013).

Lin, J. H., Li, T. T., Lin, J. Y., Lin, M. C., & Lou, C. W. (2013). Comparative Sound Absorption and Thermal Insulation Properties of Compound Fabrics. *Applied Mechanics and Materials*, *365-366*. doi:10.4028/www.scientific.net/AMM.365-366.1066

Lindström, K. (2014). *Bicomponent Fiber in Sound Absorbent Production - Investigation of using bicomponent fiber as adhesive between woven and nonwoven textile and how it affects the sound absorption.* (Master in Science (One Year) with a major in Textile Engineering), University of Boras, Skaraborgsvägen, Boras, Gothenburg. (2014.5.02)

Liu, Y., & Hu, H. (2010). Sound Absorption Behavior of Knitted Spacer Fabrics. *Textile Research Journal, 80*(18). doi:10.1177/0040517510373639

Liu, Y., Zhang, X. J., & Liu, Z. C. (2013). Car's Materials Acoustic Properties Test and Analysis. *Advanced Materials Research, 785-786*. doi:10.4028/www.scientific.net/AMR.785-786.1244

Lou, C.-W., Lin, J.-H., & Su, K.-H. (2005). Recycling Polyester and Polypropylene Nonwoven Selvages to Produce Functional Sound Absorption Composites. *Textile Research Journal, 75*(5).

Maderuelo-Sanz, R., Nadal-Gisbert, A. V., Crespo-Amorós, J. E., & Parres-García, F. (2012). A novel sound absorber with recycled fibers coming from end of life tires (ELTs). *Applied Acoustics, 73*(2012).

Mahltig, B., & Böttcher, H. (2003). Modified silica sol coatings for water-repellent textiles. *J Sol-Gel Sci Technol, 27*(1).

Mahltig, B., Böttcher, H., Rauch, H., Dieckman, U., Nitsche, R., & Fritz, T. (2005). Optimized UV protecting coatings by combination of organic and inorganic UV absorbers. *Thin Solid Films, 485*(1-2).

Mahltig, B., Fiedler, D., & Böttcher, H. (2004). Antimicrobial sol-gel coatings. *J Sol-Gel Sci Technol, 32*(1-3).

Mahltig, B., Haufe, F., & Böttcher, H. (2005). Functionalization of textiles by inorganic sol-gel coatings. *J Mater Chem, 15*(41).

Mankodi, H. R., & Mistry, P. (2014). Woven Fabrics Combination for Acoustics of Building Interior. *International Journal of Industrial Engineering & Technology (IJIET), 4*(2), 8.

Martellotta, F., & Castiglione, M. L. (2011). *On the use of paintings and tapestries as sound absorbing materials*. Paper presented at the FORUM ACUSTICUM 2011, Aalborg, Denmark.

Memon, H., Khoso, N. A., Mushtaq, M., Khan, M. Q., Memon, S., & Halepoto, F. A. (2015). *The effect of coating on the acoustical property of coated fabric*. Paper presented at the 6th International Color & Coating Congress, Tehran, Iran.

Memon, H., Naeem, M. A., Abro, Z. A., Khoso, N. A., Khan, M. Q., & Memon, S. (2015). *The effect of fabric parameters on the acoustical property of coated fabric*. Paper presented at the 6th International Color & Coating Congress, Tehran, Iran.

Moafi, H. F., Shojaie, A. F., & Zanjanchi, M. A. (2011). Flame-retardancy and photo catalytic properties of cellulosic fabric coated by Nano-sized titanium dioxide. *J Therm Anal Calorim, 104*(2).

Mueller, D. H., & Krobjilowski, A. (2003). New Discovery in the Properties of Composites Reinforced with Natural Fibers. *Journal of Industrial Textiles, 33*(2), 20.

Na, Y. J., Lancaster, J., Casali, J., & Cho, G. (2007). Sound Absorption Coefficients of Micro-fiber Fabrics by Reverberation Room Method. *Textile Research Journal, 77*(5). doi:10.1177/0040517507078743

The naked truth about British carpets. (1999). *ICB: International Carpet Bulletin,* (308), 2-3.

Narang, P. P. (1995). Material Parameter Selection in Polyester Fibre Insulation for Sound Transmission and Absorption. *Applied Acoustics, 45*(1995), 24.

Netravali, A. (2002). Compostable composites. *Advanced Composites Bulletin,* (November), 2. Retrieved from http://www.highbeam.com website: http://www.highbeam.com/doc/1G1-93956458.html Retrieved from http://www.highbeam.com/doc/1G1-93956458.html

Nor, M. J. M., Ayub, M., Zulkifli, R., Amin, N., & Fouladi, M. H. (2010). Effect of Different Factors on the Acoustic Absorption of Coir Fiber. Journal of Applied Sciences, 10: 2887-2892. *Journal of Applied Sciences, 10*. doi:10.3923/jas.2010.2887.2892

Ogunbowale, W. O., Banks-lee, P., Bello, K. A., Maiwada, S., & Kolawole, E. G. (2012). Acoustical Absorptive Properties of Cotton, Polylactic Acid Batts and Fabrics. *American International Journal of Contemporary Research, 2*(11), 9.

Oh, K. W., Kim, D. K., & Kim, S. H. (2009). Ultra-porous Flexible PET/Aerogel Blanket for Sound Absorption and Thermal Insulation. *Fibers and Polymers, 10*(5), 7. doi:10.1007/s12221-010-0731-3

Ozturk, M. K., Nergis, B. U., & Candan, C. (2010). *A Study on the Influence of Fabric Structure on Sound Absorption Behavior of Spacer Knitted Structures*. Paper presented at the 7th International Conference - TEXSCI 2010, Liberec, Czech Republic.

Parikh, D. V., Chen, Y., & Sun, L. (2006). Reducing Automotive Interior Noise with Natural Fiber Nonwoven Floor Covering Systems. *Textile Research Journal, 76*(11). doi:10.1177/0040517506063393

Peng, L., Song, B., Wang, J., & Wang, D. Mechanic and acoustic properties of the sound-absorbing material made from natural fiber and polyester. *Advances in Materials Science and Engineering*, 10.

Pieren, R. (2012a). Sound absorption modeling of thin woven fabrics backed by an air cavity. *Textile Research Journal, 82*(9). doi:10.1177/0040517511429604

Pieren, R. (2012b). *Sound Absorption Modelling of Thin, Lightweight Curtains*. Paper presented at the Euronoise Prague 2012, Prague, Czech Republic.

Putra, A., Abdullah, Y., Efendy, H., Mohamad, W. M. F. W., & Salleh, N. L. (2013). Biomass from Paddy Waste Fibers as Sustainable Acoustic Material. *Advances in Acoustics & Vibration*.

Rabbi, A., Bahrambeygi, H., Shoushtari, A. M., & Nasouri, K. (2013). Incorporation of Nanofiber Layers in Nonwoven Materials for Improving Their Acoustic Properties. *Journal of Engineered Fibers and Fabrics, 8*(4), 6.

Rao, M. D. (2003). Recent applications of viscoelastic dampingfor noise control in automobiles and commercial airplanes. *Journal of Sound and Vibration, 262*(2003), 18. doi:10.1016/S0022-460X(03)00106-8

Ren, M., & Jacobsen, F. (1993). A method of measuring the dynamic flow resistance and reactance of porous materials. *Applied Acoustics, 39*(4).

Rey, R. d., Alba, J., Arenas, J. P., & Sanchis, V. J. (2012). An empirical modelling of porous sound absorbing materials made of recycled foam. *Applied Acoustics, 73*(2012), 6.

Ricciardi, P., Belloni, E., & Cotana, F. (2014). Innovative panels with recycled materials: Thermal and acoustic performance and Life Cycle Assessment. *Applied Energy, 134*, 12.

Ricciardi, P., & Lenti, M. (2010, 23-27 August 2010). *Sound absorption characterisation of woven materials. Case study: auditorium restoration.* Paper presented at the 20th International Congress on Acoustics, Sydney, Australia.

Rus, A. Z. M., Normunira, M. H. N., & Rahim, R. A. (2013). Influence of Multilayer Textile Biopolymer Foam Doped with Titanium Dioxide for Sound Absorption Materials. *Key Engineering Materials, 594-595*. doi:10.4028/www.scientific.net/KEM.594-595.750

Rushforth, I. M., Horoshenkov, K. V., Miraftab, M., & Swift, M. J. (2005). Impact sound insulation and viscoelastic properties of underlay manufactured from recycled carpet waste. *Applied Acoustics, 66*(2005), 19.

Saha, P. (2002). Application of Noise Control Materials to Trucks and Buses. *SAE Technical Paper*. doi:10.4271/2002-01-3063

Saha, P. (2011). Developing Vehicle Sound Packages. *Sound & Vibration, 2011*(October), 4. Retrieved from www.SandV.com

Schueren, L. V. d., Clerck, K. D., Brancatelli, G., Rosace, G., Damme, E. V., & Vos, W. D. (2012). Novel cellulose and polyamide halo chromic textile sensors based on the encapsulation of methyl red into a sol-gel matrix. *Sens Actuators B*, *162*(1).

Seddeq, H. S. (2009). Factors Influencing Acoustic Performance of Sound Absorptive Materials. *Australian Journal of Basic and Applied Sciences, 3*(4), 8.

Seddeq, H. S., Aly, N. M., A, A. M., & Elshakankery, M. H. (2012). Investigation on sound absorption properties for recycled fibrous materials. *Journal of Industrial Textiles, 43*(1), 18.

Sengupta, S. (2010a). Modeling on sound transmission loss of jute needle-punched nonwoven fabrics using central composite rotatable experimental design. *Indian Journal of Fibre & Textile Research, 35*(December).

Sengupta, S. (2010b). Sound reduction by needle-punched nonwoven fabrics. *Indian Journal of Fibre & Textile Research, 35*(September), 6.

Shahani, F., Soltani, P., & Zarrebini, M. (2014). The Analysis of Acoustic Characteristics and Sound Absorption Coefficient of Needle Punched Nonwoven Fabrics. *Journal of Engineered Fibers and Fabrics, 9*(2), 9.

Shoshani, Y., & Rosenhouse, G. (1990). Noise absorption by woven fabrics. *Applied Acoustics, 30*(4). doi:10.1016/0003-682X(90)90081-5

Shoshani, Y., & Rosenhouse, G. (1992). Noise-insulating blankets made of textile. *Applied Acoustics,, 35*(2).

Shoshani, Y., & Yakubov, Y. (2000). Numerical assessment of maximal absorption coefficients for nonwoven fiberwebs. *Applied Acoustics, 59*(2000).

Shoshani, Y., & Yakubov, Y. (2001). Use of Nonwovens of Variable Porosity as Noise Control Elements. *International Nonwovens Journal, 10*(4).

Shoshani, Y. Z. (1990). Effect of Nonwoven Backings on the Noise Absorption Capacity of Tufted Carpets. *Textile Research Journal,, 60*(8).

Shoshani, Y. Z. (1993). The feasibility of using textiles in noise abatement technology. *Israel Textile Journal, 132*(1993), 4.

Shoshani, Y. Z., & Wilding, M. A. (1991). Effect of Pile Parameters on the Noise Absorption Capacity of Tufted Carpets. *Textile Research Journal, 61*(12).

Soltani, P., & Zarrebini, M. (2013). Acoustic performance of woven fabrics in relation to structural parameters and air permeability. *The Journal of The Textile Institute, 104*(9). Retrieved from http://dx.doi.org/10.1080/00405000.2013.771427

Soltani, P., & Zerrebini, M. (2012). The analysis of acoustical characteristics and sound absorption coefficient of woven fabrics. *Textile Research Journal, 82*(9), 8. doi:10.1177/0040517511402121

Splain, C. W. (2008). Acoustical Banners for Reverberation Control in Sports Arenas. *Sound & Vibration, 42*(6), 6.

Sun, F., Banks-Lee, P., & Peng, H. (1993). Sound absorption in an anisotropic periodically layered fluid-saturated porous medium. *Applied Acoustics, 39*(1-2).

Suvari, F., Ulcay, Y., Maze, B., & Pourdeyhimi, B. (2013). Acoustical absorptive properties of spunbonded nonwovens made from islands-in-the-sea bicomponent filaments. *The Journal of The Textile Institute, 104*(4). doi:10.1080/00405000.2012.740330

Tai, K.-C., Chen, P., Lin, C.-W., Lou, C.-W., Tan, H. M., & Lin, J.-H. (2010). Evaluation on the Sound Absorption and Mechanical Property of the Multi-layer Needle-punching Nonwoven. *Advanced Materials Research, 123-125*(2010), 4.

Tascan, M., & Vaughn, E. A. (2008). Effects of Total Surface Area and Fabric Density on the Acoustical Behavior of Needlepunched Nonwoven Fabrics. *Textile Research Journal, 78*(4), 8. doi:10.1177/0040517507084283

Thilagavathi, G., Pradeep, E., Kannaian, T., & Sasikala, L. (2010). Development of Natural Fiber Nonwovens for Application as Car Interiors for Noise Control. *Journal of Industrial Textiles, 39*(3).

Tiuc, A. E., Rusu, T., & Vasile, O. (2013). The Influence of Perforations on the Surface of a Sound Absorbing Material on the Sound Absorption Coefficient. *RJAV, V*(1), 4.

Tsujiuchi, N., Koizumi, T., Ohshima, Y., & Kitagawa, T. (2005, 31 January - 3 February 2005). *An optimal design and application of sound-absorbing material made of exploded bamboo fibers.* Paper presented at the 2005 IMAC-XXIII: Conference & Exposition on Structural Dynamics, Orlando, Florida, USA.

Unifi unveils antimicrobial and hollow-fiber yarns. (2001). *International Fiber Journal, 16*(5), 44-45. http://www.just-style.com Retrieved from http://www.just-style.com

Wang, Y., Zhu, Y., Fu, X., & Fu, Y. (2014). Effect of TW-ZnO/SiO2-compounded shear thickening fluid on the sound insulation property of glass fiber fabric. *Textile Research Journal*, 7. doi:10.1177/0040517514561925

Warnock, A. C. C. Controlling the Transmission of Impact Sound through Floors. *Construction Technology Update, 35,* 6.

Watanabe, K., Minemura, Y., Nemoto, K., & Sugawara, H. (1999). Development of high-performance all-polyester sound-absorbing materials. *JSAE Review, 20*(3).

Xing, Y. J., Yang, X. J., & Dai, J. J. (2007). Antimicrobial finishing of cotton textile based on water glass by sol-gel method. *J Sol-Gel Sci Technol, 43*(2).

Xue, C. H., Ji, S. T., Chen, H. Z., & Wang, M. (2008). Super hydrophobic cotton fabrics prepared by sol-gel coating of TiO_2 and surface hydrophobization. *Sci Technol Adv Mater, 9*(3).

Yang, S., Yu, W., & Pan, N. (2011). Investigation of the sound-absorbing behavior of fiber assemblies *Textile Research Journal, 81*(7). doi:10.1177/0040517510385177

Yang, W. D., & Li, Y. (2012). Sound absorption performance of natural fibers and their composites. *Science China Technological Sciences, 55*(8).

Yilmaz, N. D. (2009). *Acoustic Properties of Biodegradable Nonwovens.* (PhD. Textile Technology Management), North Carolina State University, Raleigh, North Carolina.

Zafirova, K., & Uzunovich, R. (1998). Some Investigations of Sound Absorption Properties of Upholstery Textile Materials. *Tekstilna Industrija, 46*(1-2).

Zulkifli, R., Mohd Nor, M. J., Ismail, A. R., Nuawi, M. Z., & Mat Tahir, M. F. (2009). Effect of Perforated Size and Air Gap Thickness on Acoustic Properties of Coir Fibre Sound Absorption Panels. *European Journal of Scientific Research, 28*(2).