ACOUSTIC BEHAVIOR OF TEXTILE STRUCTURES

Abstract

Noise is a complicated, nonperiodic sound that affects humans and other species. The International Commission on Biological Effects of Noise states that the risks caused by noise are still "often underestimated" in fields ranging from governmental regulation to medical practice. Noise pollution contributes to hearing loss, tinnitus, and hypersensitivity. It can also worsen or cause cardiovascular disease, type 2 diabetes, sleep disorders, stress, memory and attention issues, children's learning delays, and low birth weight. Animal health and welfare are also impacted by noise pollution. Animals use sound for several purposes: navigating, locating food, luring mates, and fending off predators. They struggle to carry out these duties due to noise pollution, which impacts their survival capacity. Passive methods reduce noise by transforming the sound energy from noise into heat. One of the best examples of passive materials is porous materials that minimize sound energy by dispersing heat energy because of their void structure. At higher sound frequencies, passive noise suppression is more effective.

Textile structures are lightweight and porous, which makes them a decent choice for sound absorption, even though they are not particularly effective materials for sound barrier solutions. Although there has been much research on textiles for reducing noise pollution in the past, those studies still lack a systematic and comprehensive methodology. The difficulty is preserving or improving the audio environment while achieving the appropriate sound levels. Developing textile-based acoustic materials and structures needs to follow a scientific methodology. It is necessary to investigate acoustical materials' eco-friendly and economically advantageous qualities, such as cost-effectiveness, lightweight, and recyclability. Production of nonwoven fabrics is quicker and less expensive because it does not involve a stage of yarn manufacturing.

In the first chapter of this research, polyester staple fiber, flax comber noil, and jute caddies were used to examine the effect of fiber type, fiber fineness, fiber cross-sectional shape, and fabric areal density on the acoustic properties of needle-punched nonwoven fabrics. In this study, a comparison has been carried out between synthetic and natural fibers using the same process and machine settings. The noise reduction coefficient and the sound absorption coefficient of polyester staple fiber, flax comber noil, and jute caddies were determined, and the effect of different variables on acoustic characteristics was investigated using the impedance tube system. According to this investigation, the hollow conjugated cross-section of polyester fiber offers the greatest sound absorption characteristics. Nonwoven materials manufactured using recyclable and biodegradable jute caddies and flax comber noil are less expensive than polyester synthetic fiber and exhibit significant sound absorption behavior. Higher punch density increases the interlocking among the fibers. As a result, the fabric porosity decreases, causing a hindrance to the propagation of sound. The existence of an air layer gives layered nonwoven structures enhanced sound absorption characteristics.

The most suitable textile for acoustic purposes is nonwoven. Nevertheless, they lack aesthetic quality. The lack of structural integrity of the nonwoven fabrics is its intrinsic flaw. This flaw does not exist in woven fabrics. A three-dimensional weaving technique can develop a multilayer orthogonal structure using the third set of binder threads in addition to the traditional warp and weft. Textile structures in three dimensions are one of the least researched possibilities for acoustic insulation. Because no prior research has been done, it establishes a range of investigations on the acoustic behaviors of three-dimensional woven orthogonal fabrics. Therefore, in the second chapter of this research, the acoustic behavior of unidirectional (UD), two-directional (2D), and three-dimensional (3D) woven fabrics developed using glass, jute, and flax yarns were investigated. The effect of weave geometry, number of stuffer layers, and fiber type on the acoustic behavior of three-dimensional orthogonal woven fabrics was also determined. Natural fibers such as jute and flax yarns were preferred because of their biodegradability and superior sound-absorbing qualities. 3D hybrid orthogonal structures were developed to utilize the properties of both glass and natural fibers (jute, recycled shoddy) together. Jute and flax orthogonal fabrics exhibited better acoustic behavior than glass fabrics. This study implies that three-dimensional orthogonal fabrics can be used to avoid the naturally low sound absorption characteristics of two-dimensional materials. Compared to jute or recycled denim waste yarn, hybrid fabrics made with glass exhibited less sound absorption due to their solid circular cross-section.

It has been observed that the acoustic performance of woven and nonwoven structures is mainly dependent on the structure's bulk density/porosity/air space. All these parameters influence the air flow resistivity of the fabrics. Static air flow resistivity is one of the well-known characteristics used to describe the acoustical behavior of porous materials. The visco-inertial effects at low frequencies are characterized by static airflow resistance. Consequently, the investigation of the airflow resistance of the fabrics and its correlation with the sound absorption coefficient becomes an important part of this study. Therefore, in the third chapter of this research, an instrument based on ISO 9053 standard was fabricated to measure airflow resistivity. It was observed that as areal density increases, the airflow resistance also increases. The airflow resistance increases with increase in mass density and decrease in porosity. With an increase in punch density, observable variations in airflow resistance were seen. Low porosity accounts for low airflow resistivity of 3D orthogonal fabrics manufactured from glass roving due to the round and solid structure of glass fiber. Plain orthogonal fabrics show maximum airflow resistivity due to maximum number of interlacements. Three-dimensional orthogonal woven fabrics made of jute and flax yarn shows improved airflow resistivity due to multiscale micromorphology. It was observed that the sound absorption coefficient and airflow resistance were directly proportional to each other for different type of fabrics (woven, nonwoven etc.) and different variations (fiber type, weave type, stuffer layers etc.) considered.

Acoustic materials can work in two broad principles: sound absorption and sound insulation. While fibrous structures are considered suitable for sound absorption, the fiber-reinforced composite materials can be used as a barrier to sound transmission. In addition, fiber-reinforced composite materials are well known for their load-bearing properties. Therefore, the acoustic properties of composites are significantly important when used in buildings and civil structures as they must effectively insulate against noise and heat along with high strength to weight ratio. Composites possess excellent properties such as low weight, high strength and stiffness, and impact resistance, enabling them to be used in automobiles as acoustic and load-bearing components. The sound transmission loss and sound absorption can be enhanced if the composites are used in conjunction with other sound barrier fillers. Using textile structural composites with reinforcements such as nonwoven, 3D woven, and hybrid structures can fulfil dual load bearing and sound insulation purposes.

Therefore, in the fourth chapter of this research, the acoustic performance of fiber-reinforced composites pertaining to different type of textile structures, fiber volume fraction, and orientation of fibers were explored. The two-dimensional and three-dimensional orthogonal fabrics developed using glass, jute, and flax woven fabrics were used as reinforcement to develop composites using a vacuum-assisted resin infusion technique. The acoustic behavior of the developed composites was thoroughly investigated. The sound absorption coefficient of neat epoxy resin is lower than fibers. It was observed that sound absorption coefficient of composites was less than the three-dimensional orthogonal woven fabrics used as reinforcement. Composites with different types of fibers, varying weave geometry, and the number of stuffer layers show similar sound absorption coefficients. This behavior is due to the infusion of epoxy resin. Compared to other composite forming manufacturing techniques, compression molding is a simpler technique. The nonwoven composites were developed using compression molding. It was observed that compression-molded composites made of jute nonwoven have the potential to be used as better sound-absorbing materials. Therefore, it can be stated that the selection of reinforcement for the development of composite material for acoustic application should be made purely based on end-use applications because composites prepared from identical fiber volume fraction using different fibers have no significant difference in their sound insulation value.

The sound absorption properties of composite materials can be improved by incorporating nanofillers, allowing these composites to be used as both sound-insulating and sound-absorbing materials. Investigation of incorporating nanofillers such as graphene, silica, and other metal oxides into textile structural composites to boost their sound absorption properties is reportedly a grey area. Nanomaterials/nanofillers are good at absorbing acoustic energy due to their large surface area and effective airflow resistance. Though some research is performed using silica, iron nanoparticles, and graphene to modify the sound absorption properties of polyurethane, silica, and melamine foam, a scant amount of research has been done on the acoustic behavior of nanoparticle-filled epoxy resin composites. Therefore, in the fourth chapter of this research, an effort has been made to investigate acoustic behavior of composites incorporating nanoparticles. Graphene is among the most promising nanomaterials due to its special qualities, such as being thin, robust, and having superior heat conductivity to other materials. Other nanofillers used were copper oxide, iron oxide, and silicon dioxide nanoparticles. It was observed that adding nanoparticles can greatly improve the acoustic behavior of composite materials in the higher frequency ranges due to the damping characteristics of nanofillers.

Thus, systematic research has been done on the acoustic performance of nonwovens, unidirectional textile structures, two-dimensional structures, and three-dimensional structures. Hybrid orthogonal woven structures, spacer fabrics, and honeycomb structures were also characterised for their acoustic properties. The natural fiber wastes that are widely available and would otherwise be thrown out such as flax comber noil, and jute caddies, are efficient and beneficial value-added textile materials can be used in acoustic applications. In this study, sustainable recycled textile-based sound-absorbing materials were developed, and these materials were found suitable for acoustic applications as composite reinforcement and porous fibrous material form.