Biocomposite Materials and Its Applications in Acoustical Comfort and Noise Control

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Abstract In this chapter, an overview of various composite materials for sound absorption applications were reported and discussed in details. This includes composites made of polymer matrix reinforced with synthetic fibers and with natural fibers. This chapter also deals with composites made of recycled materials, bio-based matrix and bio-based fiber materials, hybrid biodegradable materials and surface treatment fiber composites for sound absorption applications. New developments dealing with composite materials made of lignocellulosic fiber and the pros and cons of synthetic fibers and natural fibers were also studied. This chapter also examines the critical issues regarding on composite materials and the scientific challenges faces by researchers and industries that require further research and development of composite materials made from polymer composites for their increased acceptance in the modern world for sound absorption purpose.

Keywords Materials science · Polymer · Plastics · Natural fiber · Synthetic fiber · Sound absorption

1 Introduction

It is noticeable that time elapses before the noise becomes inaudible when a source of sound in a living room is turned off. Less sound absorbing materials in a room, causes the sound to take longer time to fade away. The reverberation time, usually

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M. Jawaid et al. (eds.), *Green Biocomposites*,
Green Energy and Technology, DOI 10.1007/978-3-319-49382-4_11

defined as the time required for sound to decay in seconds, as it decreases in level less by 60 dB of its original intensity. The sound absorption in the room depends on the frequency of the sounds being considered, it is the same concept as reverberation time (Warnock 1980). For a given noise source, the noise levels it produces within a room and the behavior of the sound it emits are largely determined by the sound absorbing properties of the materials in the room. The sound absorption coefficient of a material is the fraction or percentage of incident sound energy that is absorbed by the material. It is known that the sound absorption coefficient is usually depends on the sound frequency and the values, which are provided in certain literature at the standard frequencies of 125, 250, 500, 1000, 2000 and 4000 Hz. Meanwhile, the noise reduction coefficient (NRC) is the average of the values from 250 to 2000 Hz, inclusive, rounded to the nearest 0.05. The sound absorption coefficient is also used to characterize and rank sound absorbing materials, especially which involve in reduction of noise.

Recently, sound absorption coefficients are also expressed as percentages. A lot of researches and studies have been carried out in this field to find new ways or findings. Thus, many new ways or findings were uncovered, which leads to the potential use of new materials for sound absorption applications. Sound absorbing material is used in a variety of locations, either by making it close to the sources of sound or noise, various in the pathway, or close to the receivers (Ver and Beranek 2006). A wide range of sound absorbing materials that exists which provides varieties of sound absorption properties dependent upon the frequency, thickness, composition, method of mounting, and surface finish. However, most of the materials that have a high value of sound absorption coefficient are usually porous.

A porous absorbing material is a solid material that contains channels, cavities, or interstices that enable sound waves to enter through them. The function of absorptive materials is to transform or impinging the acoustic energy into heat energy. Generally, sound absorptive materials are used to counteract the undesirable effects of sound reflection due to the rigid and hard interior surfaces, which usually help to reduce the reverberant noise levels (Jayaraman 2005). Other than that, sound absorbing materials can also be used either by combination with barriers or inside enclosures to improve its effectiveness (Arenas and Crocker 2010). This chapter addresses the overview of various composite materials used for sound absorption purposes and also addresses various recent researches have already done on composite materials for sound absorption. The following sections present the details of various researches done in the field of polymer matrix composite materials for sound absorption applications.

2 Sound Absorbing Materials

Sound absorbing materials are materials that reduce the acoustic energy of a sound wave as the wave passes through it by the phenomenon of absorption. Sound absorbing materials are commonly used to soften the acoustic environment of a closed volume by reducing the amplitude of the reflected waves. Absorptive materials are generally resistive in nature, either porous, fibrous, or reactive resonators in rather special cases (Bell 1994). Most sound absorbing materials absorbed the sound energy that strikes or projected on it or just reflect a very little amount of sound energy. Therefore, sound absorbing materials have been found to be very useful for noise control. By applying the basic theory on the fiber sound absorption, the kinetic energy of the sound is converted to heat energy when the sound strikes the fibers. Hence, the sound disappears after striking the material due to its conversion into heat. The main reasons for the acoustic energy losses when sound passes through the sound absorbing materials are due to the momentum losses, frictional losses, and temperature fluctuations.

It is known that there are several parameters that may influence the sound losses, especially in sound energy of fibrous materials. It is either caused by the size, number, and type of pores, which are the important factors that affect the sound absorption. To allow sound dissipation by friction, the sound wave has to enter the porous material. This shows that there should be enough pore structures on the surface of the material for the sound to pass through and get dampened (Krcma 1971). To define the normal incidence sound absorption, three parameters (plus the sample thickness) such as tortuosity, airflow resistivity, and porosity are sufficient to be used (Wassilieff 1996). One method to increase the flow resistivity is by creating a flow resistant either by scrim or film layer. Scrim means a fibrous cover layer with finite flow resistivity and film means a plastic cover layer with an infinite flow resistivity (Zent and Long 2007).

To further improve the acoustic characteristic, a perforated plate design can be used in the construction of the panels. The perforated panel porosity and porous material density will significantly change the absorption and coefficient acoustic impedance of the acoustic absorber (Davern 1977; Ver and Beranek 2006). The expression indicated that the influence factor may include the thickness, pitch and radius of the hole, and porosity of the perforated plates and the air contained in the holes. According to Delany and Bazley (1970), for porous material, the characteristic impedance and complex wave propagation constant can be expressed in terms of the wave number, air density, flow resistivity, and sound frequency. Characteristic of sound absorption for porous material is not just a function of type of material, but covered the airflow resistivity and how well material construction can be executed to achieve desirable properties for sound absorbers (Lee and Chen 2001). Thus this showed that all materials have some of its own sound absorbing properties. The incident sound energy which is not absorbed are most probably be reflected, transmitted or dissipated.

Sound absorbing material properties can be described as a sound absorption coefficient in a particular frequency range. The absorption coefficients of the many types of sound absorbing materials available are influenced by a number of factors. In general the greater is the porosity of a given volume of material, the greater its sound absorbing capability. Particularly, the performance of sound absorbing materials is evaluated by the sound absorption coefficient (Horoshenkov and Swift 2010; Bell 1994). The absorption coefficient is a useful concept when using geometrical acoustic theory, especially to evaluate the decay and growth of sound energy in a room. However, when sound is considered as a wave motion, it is necessary to use the concept of acoustic impedance.

Sound absorption coefficient or alpha (α) is defined as the measurement upon incidence of the acoustical energy absorbed by the material and is commonly expressed as a decimal varying between 0 and 1. If 50% of the incident sound energy projected is absorbed, the material sound absorption coefficient is said to be 0.50. A material that absorbs all incident sound waves will have a sound absorption coefficient of 1. Sound absorbing materials are generally used to counteract the sound reflection of undesirable effects created due to the hard and rigid interior surfaces which also help to reduce the reverberant noise levels (Beranek 1960). They are used as interior lining for apartments, automobiles, aircrafts, and ducts, enclosures for insulations and noise equipment's for appliances (Knapen et al. 2003). Sound absorbing materials may also be used to control the artistic performance response of the transient and steady sound sources, thereby affecting the intelligibility of unreinforced speech, the character of the aural environment, and the quality of unreinforced musical sound (Fahy 2001).

2.1 Synthetic Fibers

Glass or mineral fiber materials are the most practical sound absorbing products used in the building construction industry. Sound absorption characteristic values of rock wool were measured and found to be similar to those available commercial sound absorption materials for acoustic treatment, which includes of glass or mineral fiber material (Takahashi and Tomiku 2005). A composite structure with a combination of perforated panel, porous material, polyurethane (PU) foam, rubber particle, and glass wool were also found to demonstrate significant sound attenuation (Wang and Torng 2001). Generally, an industrial application of sound insulation includes the use of materials such as glass wool, foam, mineral fibers and its composites. Although these materials possess good thermal heat and acoustical insulating properties, it may cause environmental pollution and poses a threat and danger to human health.

A very high sound absorption property exhibits by a porous laminated composite material manufactured by premix, lamination, preheating, and molding technique in the frequency range from 500 to 2000 Hz (Hong et al. 2007). Two-stage compression molding of polyolefin-based packaging wastes along with plastic coated aluminum foils, expanded polystyrene and coir pith yields sound absorption properties are comparable to those glass wool (Yang et al. 2003). The combination of non-woven fabric and para-aramid paper was studied and a sound absorption performance at over 2000 Hz was found to be better than that of glass wool (Murugan et al. 2006). Sintered aluminum fiber of 10 mm thickness and 0.6 relative densities demonstrates a high sound absorption coefficient of 0.70 for the frequency range of 800–2000 Hz. Similarly, metal foam yields good sound absorption rate at

2000–4000 Hz (Kosuge et al. 2005). However, when reviewing the issue of safety and health, these fibers can interference human health mainly lungs and eyes when exposed to human. These issues exploration of an opportunity to find alternative materials made from organic fibers to be developed as noise absorption materials.

Using organic fibers as basic material for absorber materials has several benefits. It is renewable, abundance, non-abrasive, cheaper, and safer and less potential health risks concern during handling and processing. Several researchers (Bozkurt et al. 2007) have succeeded in developing particle composite boards using agricultural wastes. Rice straw-wood particle composite boards have properties that tend to absorb noise, preserve the temperature of indoor living spaces and to be able to completely or partially substitute for wood particleboard and insulation board in wooden construction (Khedari et al. 2003). Natural fibers have many remarkable advantages over synthetic fibers. Nowadays, various types of natural fibers (Mohd Yuhazri et al. 2010) have been investigated for use in composites including flax, hemp, wheat, jute straw, rice husk, wood, barley, oats, rye, (sugar and bamboo) cane, grass, reeds, kenaf, ramie, sisal, coir, oil palm, water hyacinth, penny-wort, pineapple leaf fiber, kapok, banana fiber, paper mulberry, and papyrus.

Natural fibers show a lot of advantages in its properties as reinforcement for composites (Sabeel Ahmed and Vijayarangan 2008). Some of the natural fibers have low-density materials that can yield relatively high specific properties with lightweight properties. Natural fibers also offer significant benefits and cost advantages associated with the processing process, as compared to synthetic fibers such as glass, nylon, carbon, etc. Unfortunately, the mechanical properties of the natural fiber composites are much lower than those of synthetic fiber composites. Another drawback of natural fiber composites that make it less attractive is the poor resistance to moisture absorption (Brahmakumar et al. 2005). Hence, the use of standalone natural fiber in polymer matrix is inadequate to satisfy all the technical needed for a fiber to be reinforced with composite. Thus, to develop a superior, but economical composite, a synthetic fiber can be combined with a natural fiber in the same matrix material so as to take the best advantage of the properties of both fibers (D'Arcy 1986).

2.2 Natural Fibers

Due to noise pollution in our surroundings, there are need and demand to find alternative materials that are capable to reduce the noise level at various frequency ranges. The common acoustic panels are those made from synthetic fibers, which poses hazardous substances to the environment and human health and sometimes very expensive for small need. Researches on natural fibers and composite materials were done on acoustical panels. From the view of environmental protection, natural bamboo fibers were alternative materials that can use for sound absorbing purposes. By using impedance tube measurement, the bamboo fiber samples show similar properties to those of glass wool. Enclosing the surface of the bamboo material fiberboard yields a superior sound absorption property when compared to plywood material of similar density (Koizumi et al. 2002). Composite boards of random cut rice straws and wood particles were found to demonstrate higher sound absorption properties than particleboard, fiberboard and plywood in 500–8000 Hz frequency range (Mehta and Parsania 2006). Composite materials made from plant fibers are receiving a great deal of today attention since they are considered environmentally friendly options.

Among all the reinforced fibers, natural fibers have gained its importance, especially for load bearing applications. Natural fiber reinforced polymer composites have a superior properties than those synthetic fiber reinforced composites with certain properties, such as enhanced lightweight, biodegradability, combustibility, ease of recyclability, and etc. These advantages place the natural fiber composites, among those high performance composites that having good physical properties, while maintaining the economic and environmental advantages (Avella et al. 2000). Thus, the interest arises toward polymer composites filled with natural organic fillers. In recent years there has been an increasing interest in the use of fiber-reinforced polymers (FRP) in the sound absorption measurement field. In recent years, bio-composite materials based on natural fibers as reinforcements and biodegradable polymer matrices have received a significant scientific attention (Maldas and Kokta 1989).

A lot of researchers have redirected their research work towards the use of numerous combinations of natural fibers and biodegradable matrix polymer in order to create new types of biodegradable composites with improved mechanical properties with lower cost production. Among the research investigated, especially those natural fibers within its own area, different fillers have its own significant importance. For instance, the development of wood flour composites has been actively pursued (Lee et al. 2004). With the increasing usage of wood-based raw materials, its substitutions are inevitably needed. Recently, usage of agricultural waste as a substitute for wood-based raw materials is fast growing in interest. Among the various agricultural waste, rice straw could be very interesting material to be used as filler in biodegradable polymers due to its high thermal stability compared to other agricultural waste. Mainly, the rice straw is comprised of carbohydrate constituents such as cellulose, hemicellulose, and lignin (Pan et al. 1999).

The content of carbohydrate may vary, as well as other components, such as ash and silica. The character of the rice straw that is hydrophilic is one of the reasons for relatively high moisture content, which is approximately 60% is wet base, or/and 10–12% is dry base. The ash may contents as high up to 22% and low protein content may result in readily material decomposing which is not the same with other type of straws (Yang et al. 2004). In composite materials for building, the rice straws have an advantage and suitable resistance to bacterial decomposition, which makes it a good material to be used as fillers. On the other hand, high content of silica up to 20% represents an additional potential benefit posed for flame retardant usage when used in building industry. From this point of view, various studies showed that the rice straw has a potential as filler in various thermoplastic matrices. Recently, a report of the World Commission on Environment and Development prepared by the United Nations, has examined the potential used of polypropylene filled rice straw composites (Khedari et al. 2003). They reported improved mechanical properties, such as increased tensile modulus of the PP/rice straw composites with the increase of filler content.

In the late 1987, the World Commission on Environment and Development developed a definition of sustainability which became widely known as the Brundtland Report (United Nations 1987). It stated that sustainable development needs to meets the present without compromising the ability to meet future generation's needs. Green technology is widely used to manufacture materials from agricultural based, either as a substitute to synthetic fibers and wood-based materials for acoustics absorption purposes. For example, Malaysia has plenty of agricultural waste such as coconut coir (*Cocos nucifera*), rice husk (*Oryza sativa*) and oil palm frond (*Elaeis guinnesis*) fiber which are anticipated to increase in the future. Coconut coir fiber has good sound absorption at higher frequencies, but then, less for the lower frequencies, which is the same with oil palm fiber. Higher noise absorption of oil palm is due to its higher density (Zulkifli et al. 2009).

Agricultural lignocellulose fibers such as wheat straw, rice straw, or oil palm frond can be easily crushed into chips or particle size. It is almost similar to wood fiber or particle, and may be used as substitutes for wood-based raw materials (Nick et al. 2002). Besides, kenaf can be properly seen as an alternative, especially for thermo-acoustic applications and sound barriers. This shows that natural fibers have high potential to be applied as raw material of sound absorbing materials. Amongst the advantages of these fibers are renewable, non-abrasive, cheaper, abundance, less effect on health problem and safer while handling and processing. Therefore, it is important to increase research on materials acoustical based on the renewable resources that can lead to viable alternatives to conventional materials for current and future applications (Saheb and Jog 1999). Recently human hygiene and environmental protection have turned into another major requirement, which resulting in more environmentally benign, natural materials to be used in certain applications. Among the technologists and scientist, natural fibers have gained much interest for applications in civil, industrial, spacecraft, military, and biomedical sectors (Taj et al. 2007).

In the late 1970s, a series of events that related to the public health concerns made sound-absorbing materials makers to change their main components of their products which have contained of asbestos-based materials to new synthetic fibers. These new fibers are much safer and posed fewer problems to human health. As developed into new industrial ages, the issues related to global warming caused by the emission of greenhouse gases into the atmosphere produced by the materials and manufacture industry may give a lot of impact in the change of course in the acoustical materials market. Therefore, the research on acoustical materials is important and need to be increased, especially those based on renewable resources that can lead to viable alternatives than the conventional materials for future and current applications. These advances include the use of natural fibers, recycled and bio-based polymers, porous metals, surplus materials, new composites, and smart materials.

2.3 Recycled Materials

Great interests were showed by some researchers by trying to make an alternative sound absorber from recycled materials (Mediastika 2008). Use of recycled rubber material results comparable sound absorption properties. Composite material of recycled rubber particles and perforated polymer panel exhibits a sound absorption property dominated by rubber particles when the particle size is too small and where polymer porous material is dominant when the recycled rubber particle size is larger. However the continuing increase and environmental considerations strives the need to develop alternative materials for sound attenuation purposes. Several researchers have succeeded in developing particle composite boards using agricultural wastes. Rice straw wood particle composite boards have properties that tend to absorb noise, preserve the temperature of indoor living spaces and able to partially or completely substitute for wood particleboard and insulation board in wooden construction.

Many studies focused on developing natural fibers, such as palm, kenaf, coconut, coir and many other fibers that have potential to be used as raw or waste material for sound absorption and sound insulation applications (Ersoy and Kucuk 2009). The effect of perforated size and air gap thickness on acoustic properties of coir fiber on sound absorption was investigated and reported suitable for acoustic panel because of its high elasticity and hollow space (Zulkifli et al. 2009). Porous materials used for sound absorption may be fibrous or cellular. Fibrous materials may be in the form of mats, board or preformed elements manufactured of glass, mineral or organic fiber (natural or man-made) and include felts and felted textile (Conrad 1983). Using bio-fibers can address the ecological and economical concerns of the industrial materials (Stahl and Ramadan 2007).

Cotton and jute are very important fibers. Wool also is one of the most widely used textile fibers that are often blended with less-expensive fibers to reduce the cost of the fabric or to extend its use. Synthetic fibers such as polyester and polypropylene have great uses in the industry. Their staple forms can be blended with many other fibers contributing desirable properties to the blend without destroying those of the other fibers (El-Sayed and El-Sammi 2006). Lignocellulosic fibers from agriculture wastes such as rice straw and wood fibers have also great uses in the industry which help in reducing the negative impacts on the environment. In many parts of the country after harvest of the rice crops, the fields must be cleaned and prepared for the next winter cultivation. The rice straw is usually burned soon after threshing. The uncontrolled burning of huge amounts of rice straw causes severe air pollution and leads to the formation of the "Black Cloud".

Wood fiber wastes such as sawdust are mostly used in the thermoplastics industry. The scrap wood sourced for species certain purity and usually it is grounded to certain specific particle size distributions. The specific but broad particle size distribution in commercial sawdust varies among manufacturers (Stark and Rowlands 2003). Non-woven fabric technology is the most modern branch of the textile industry and it embodies both old and very new processing techniques and materials (Turbak 1993). Since 1970, the non-woven industry has observed a phenomenal growth mainly because of a close alliance among non-woven producers, fiber producers, binder producers and machinery manufacturers. There are many non-woven manufacturing processes and products that have been developed and commercialized in recent years (Turbak 1993). Non-woven is used in a variety of purposes due to their advantages, such as versatility, light weight, flexibility, efficiency in sound, and easily tailored properties, recyclability, low process and materials costs (Balasubramanian 2009).

3 Recent Developments in Composites for Sound Absorption

For the study of the multi-layer acoustic absorber, three-layer assembly consisting airspace, perforated plate, and porous material are studied respectively. The results indicated that the density of the porous material and the porosity of the perforated plate have considerably changed the acoustic impedance and absorption coefficient of the acoustic absorber. Some researchers provided a simple but almost accurate analytical acoustic transmission analysis for evaluating the acoustic absorption of multi-layer acoustic absorber which utilized several sections including the layers of airspaces, perforated plates, and porous materials together but only for normal sound incidence. From the results demonstrations, it is reported that the acoustic absorption is generally more broadband and better for the assembly with three layers of perforated plate backed with airspaces than that with single layer of perforated plate backed with airspace (Randeberg 2000).

Micro perforated panels are increasingly used for reverberation control. Micro perforated panels are panels of arbitrary material with perforations of very small dimensions. The perforation diameter is typically less than a millimeter (Stankevicius et al. 2007). A study of acoustical characteristics and physical-mechanical properties of plaster with rubber waste additives was done (Poulain 2006). The sound absorbent material made from scrap tires with small grains showed better sound absorption (Mediastika 2008). A single layer acoustic panel made of paddy husk reinforced sodium silicate showed the optimum sound absorption coefficient at higher silicate content in high range frequencies (Sabri 2007). Then, industrial tea-leaf-fiber waste material also has sound absorption properties at high frequencies *Arenga pinnata* is one of the natural fibers that is abundantly available from the palm sugar tree. Since the last decade, it is widely used for many applications like roof, rope, water filter, and sound proof in the recording studio. Ceiling boards from agricultural wastes, such as rice husks and sawdust, and tested ceiling boards and commercial samples for moisture content, rate of water absorption, and tensile strength. Dimensional stability and mechanical properties of particleboards made from coir pith with average particle sizes of 0.4–2.1 mm, using phenol–formaldehyde and urea–formaldehyde (UF) resins were confirmed and water absorption and swelling were lesser and mechanical properties were best for boards made from the larger particles and phenol–formaldehyde resin (Ajiwe et al. 1998).

Particleboards made of waste tea leaves bonded with UF resin adhesives in three densities. As density increased, internal bonding strength and bending strength also increased (Yalinkilic et al. 1998). More recently, the use of active noise control has been combined with passive control to develop hybrid sound absorbers (Galland et al. 2005). The use of a piezoelectric actuator as a secondary source and wire meshes as porous material has allowed the design of thin active liners composed of several juxtaposed cells of absorbers to be used to reduce noise in flow ducts. Some research has been aimed at producing a broadband sound absorber known as smart foam, which is a hybrid active-passive sound-absorbing material. The absorber is made of melamine foam (made of melamine resin, a thermoset polymer) with Poly-vinyl-dene fluoride (PVDF) piezoelectric-film-embedded actuators (Leroy et al. 2008). Optimization of the sound absorption properties of the smart foam has been developed using three dimensional, finite-element techniques. So a light-weight, thin, efficient sound absorbing material can be produced.

Another approach involves combining active and passive control is using micro perforated panels. This has given promising results when applied in absorber systems (Allard 1993). Porous materials such as foams and fibers are used as sound absorbers. Viscous losses convert acoustic energy into heat as sound waves travel through the interconnected pores (or fibers) of the material. Recently, two very similar analytical formulations have been developed to describe the sound propagation of porous elastic materials. One theory is the Biot-Allard theory and the other is the Bolton-Shaiu theory (Bolton 1984). Though independently developed, these two theories are very similar and yield similar predictive results. The theories predict three types of propagating wave in a porous elastic material–the airborne wave, the structured-borne wave, and the shear wave (which is also structured-borne). The theories demonstrate how the participation of the different types of waves is a function of the boundary conditions (Nae-Ming 1991).

4 Conclusions

The uses of composites have rapidly evolved over the last decade primarily due to the issue of the shortage of commonly used sound absorbing material. This overview outlines the significance of the research and development that has been undertaken in the field of polymer matrix composite for sound absorption. The four general classifications of this material group includes the composites made of synthetic fibers, made of natural fibers, made of recycled materials, and made of bio based matrix and fibers. Due to various environmental concerns natural fiber reinforced with polymer matrix composites has been gaining special attention of technologist, engineers, industrial and manufacture for its enormous potential for application in sound absorption applications. Natural fibers are of basic interests since natural fibers have the ability to be manipulated and functionalized.

Furthermore, it also has advantages from the point of view of weight and fiber-matrix adhesion, specifically with polar matrix materials. Further, natural fiber composite is cost effective, renewable material, low density, environment friendly and reduces CO_2 evolution. In this respect, polymer composite materials are particularly attractive because of their easy of manufacturing, and properties comparable to those of other materials used for sound absorption. Innovations in the composite material design and fabrication processes are increasing the possibility of realizing composites for sound absorption applications. The future growth and sustainability of polymers and composites from renewable sources is reliant on continued research.

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