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Recent progress in acoustical materials and noise control approach

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Abstract

Millions of individuals experience negative effects from noise pollution , and it can cause stress and major health problems. With the development of technology, we move toward a faster and more pleasant way of life, but this has its negatives as well. Due to contemporary urbanization and industrial developments, noise occupies one of the important positions among them. Therefore, it becomes imperative to efficiently regulate noise levels across all fields. A significant field of study is now focused on creating sound-absorbing materials that are effective and affordable for noise reduction in large spaces, buildings, and vehicles. This review tries to follow the most recent advancements and potential acoustic materials, spanning from environmentally benign natural materials(NMs) to man-made structures. This analysis largely concentrates on the most recent developments in acoustic materials, such as natural fibres, recycled materials(RMs), and metamaterials. Additionally, thermoplastic foams, textile fabrics, composite materials, and micro-perforated panels are covered. While reviewing technical applications such as automobile to built environment, opportunities and barriers are discovered. All of these acoustic materials have received a lot of attention currently and also support directions for the future. Additionally, it is discussed how the use of additive technology advances the creation of specialized acoustic structure designs.

Keywords: Noise; renewable; ecofriendly; metamaterial; micro-perforated panel; Helmholtz Resonator.

1 Introduction

Controlling noise is becoming urgent as a result of global industrialization. The practice and research of sound absorption have drawn a lot of interest in recent years due to its significance in noise attenuation. As a type of mechanical wave, sound waves must travel through a medium made of materials. Continuous attenuation of sound intensity results from energy loss during sound transmission. As stated by the World Health Organization (WHO), people in developing nations are more likely to experience hearing issues [1]. Long-term or short-term exposure to noise can both cause hearing impairment [2]. Numerous health difficulties, including inability to relax, cognitive decline, sleep disturbances, cardiovascular problems, preeclampsia in women, restlessness, and hypertension, will result from the loud noises [3]. So, it's important to discover the way to minimize the noise that comes from many sources in daily life. Therefore, it's important to figure out how to reduce the noise that comes from many sources in daily life. There are three techniques to control noise: installing attenuation systems at the source, lining the paths with soundproofing materials, and utilizing protective gear at the receiving end[4]. Therefore, it is crucial for noise mitigation to develop efficient acoustic or sound absorption materials. Although the terms "sound insulation" and "sound absorption" are frequently used interchangeably in everyday speech, they are fundamentally distinct. By decreasing reversals and converting absorbed energy into heat, sound-absorbing materials (SAMs) are intended to enhance sound quality, avoid echoes, and minimize distasteful reverberation in the internal area. They don't muffle the noise. On the other hand, sound insulation or soundproofing materials serve as an acoustic barrier (ACBs) to the loudspeaker by preventing sound waves from getting in or exiting a place [5]. In this review, we discuss several acoustic materials from a structural arrangement and material standpoint, including NFs, RMs, metamaterials, micro-perforated panels (MPP), and advanced foams. Additionally, the potential of additive manufacturing technology is being considered for the construction of intricate structures like periodic, gradient-index, space-coiling, and perforated panels. Lastly, this review finishes with a few significant issues and prospective research plans for creating new sound-absorbing materials.

2 Acoustics materials(AMs)

The sound wave that returned after striking a surface is, in theory, what the human ear perceives as sound. As the impact occurs, the particles on the surface vibrate due to motion, which results in a difference in air pressure and the creation of a sound wave. The frequency of this wave, which is often longitudinal, is measured in Hertz. The sound that the human ear will hear is caused by a shift in pressure. The (SAC), (SPoL), (SPL), and (SIL) are three crucial unit values in acoustics (SIL). The percentage of absorbed energy over incident energy is familiar as (SAC). The best materials for soundproofing have higher absorption coefficients. Another crucial unit of measurement is called "transmission loss, TL" which is the percentage of sound waves that are transmitted over the incident wave [4]. Materials for noise reduction are better at transmitting and absorbing sound waves than at reflecting them. Different materials have varying sound absorption coefficients depending on their porosity (SAC).

2.1 NFs , textile waste and RMs

A porous structure and high acoustic performance are characteristics of NFs. Accidental sound wave exposure to porous material enables the air to vibrate and change into different energy forms within the pores [6]. The NFs are favourable to the environment. They are inexpensive, biodegradable, and don't have any negative side effects; therefore, referred to as green materials. The geometry of the fibre, such as diameter, and the acoustic performance are significantly influenced by length, cross-section form, and regularity. The impedance tube approach was used to characterise the sound absorption measurement. NFs, including kenaf, wood, hemp, coco-nut, cork, cane, mineralized wood, and cardboard, are studied for their acoustic properties. unaided by a binder [8]. The materials with the highest airflow resistivity are the mineralized wood and dense kenaf. A porous substance's ability to effectively absorb sound is indicated by its high airflow resistance rating. Corn husk that was air-dried without chemical alteration exhibited effective sound-absorbing properties[9]. Although increasing the rear cavity distance has an impact on the corn husk's acoustic absorption coefficient, the multilayer structure does not improve acoustic absorption. Better noise-absorbing properties can be achieved by using acoustic absorption panels comprised of dry coir fibres and an adhesive with a low citric acid solution concentration[10]. The acoustic qualities of bamboo fibres are comparable to those of synthetic glass wool[11]. Due to its fibrous nature, bagasse, a fibrous material made from sugarcane residue, has excellent acoustic attenuation properties[12]. The acoustic performance of fibrous material is remarkably affected by its thickness and air gap. Due to biobased nature, biogradability of (NFs) and positive interactions with other fibrous materials, (NFs) are arising as the closer descent of sustainable sound AMs[13-15]. Santoni et al.[16] investigated how the physical properties and SAC of hemp fibrous materials were affected by sweep, alkaline handling, wider age combing, and fine age combing. It demonstrated that while an alkaline treatment method had little influence, 2 stride joining operation had a remarkable effect on enhancing sound absorption performance. Additionally, a straightforward model that clearly benefits the optimization of design was created to examine the connection between sound absorption manner and various working factors like treatment, sample thickness, and density. TiO_2 nanoparticules were added by El-Shafei et al. [17] to enhance the flame retardancy and antibacterial qualities of natural cotton fabrics. For vehicle floor covering systems, Parikh et al.[18] created NFs-based nonwovens by blending waste cotton, jute, and kenaf with PP and PET textiles. Another area of interest stems from the repurposing of textile waste into absorption material as a result of rising ecological consciousness and the push for a circular economy. The sound absorbing qualities of (TLeF) (WMs) with and without woven support fabric were investigated by Ersoy et al. [19]. The SAC of (TLeF) [1 cm thick] WMs with backings was discovered to be comparable to 6 sheets of woven supporting fabric. By spraying natural rubber latex for compaction on new materials like fique (endemic agave species), non-woven textiles can be created[20].In a case study, Singh et al. [21] demonstrated how jute felt and waste cotton were used as sound absorbers in a prototype (HVAC) unit to reduce noise in automobiles. Materials that can be recycled have a high noise reduction coefficient. The straightforward recycled paper tested in the form of an egg carton.

2.2 Fabric and textile-based sound AMs

The emphasis of this part will be on the most recent advancements in textile-based sound absorbers, specifically the use of nanofillers in hierarchical textile materials, as well as the utilization of discarded textiles and natural fibers.

2.2.1. Layered architectures, nanofillers, and the utilization of nanofibers

Thinner nonwoven textiles with higher (SSA) and lower (FR) have greater sound absorption characteristics through a wider frequency domain. Using nanofibrous materials to reduce low frequency noise has been successful [24]. Using electro spun silica fibre nonwovens, Akasaka et al. [25] investigated the effect of diameter of fibers, which ranged from 0.7µm to 3.4 µm, on sound absorption manner. This study also demonstrated that as fibre diameter steadily decreased below 3µm, sound absorption performance altered to a collection of porous and panel kind. Zarrebini et al. [26] inserted Na silicate-based aerogel into electro-spun PET nanofibre and observed increased SAC throughout a frequency range of 250Hz - 4000 Hz utilising three-dimensional nanofibrous aerogels (NFA) Si et al. [27] made from electro-spun nanofibres and freeze-drying process. Additionally, it has been discovered that adding nanofillers and layered fibrous structures are useful ways to improve the SAC. 3 principle sheets—cotton, ramie, and polypropylene—and two surface sheets- (ACF) and glass fiber—were used in six nonwoven composites that were tested by Chen et al.[28] for their ability to absorb sound. They discovered that between 10 and 640 Hz, namely in the (LF) domain to 1600 Hz, it displayed higher sound absorption characteristics than composites with glass fibre (for automotive).

2.3 Thermoplastic foams

This section is primarily concerned with the employment of SCF-state blowing agents in acoustic microcellular thermoplastic foams. The advantage of thermoplastic foams over (PUF) and textile-based sound-AMs is their ease of recycling and superior mechanical qualities. Since then, interest in microcellular plastic foams with cell diameters between 0.1 and 100µm has grown. These materials were initially developed to be lighter and to shorten cycle times, which reduced holding times [29]. (LDTPE), (PEBA) foams can be made via mold-opening injection, according to Wang et al. [30]. Significant absorption characteristics of foams of 8 mm thick via a broad domain (1-4 kHz) were attained. Due to enhanced dampening from the skeletons, in addition to stronger compressive strengths and elasticity, foams with smaller cells (39 m) retained better SAC.

2.4 Micro-perforated panel (MPP)

MPP absorbers can be thought of as a unique type of porous material because of the sub-millimeter to milli-sized holes in the panel surface[31]. They typically consist of an MPP and a backing cavity[32-35]. They offer the benefit of superior humidity resistance, environmental kindness, and customized absorption for a specified frequency domain by modifying the parameters[36, 37] over traditional foam and fibre absorbers. The acoustic manner of the MPPs can be predicted using straightforward mathematical formulas like Maa's formula[33-37]or more complex formulas that take structure-fluid reactions into consideration like Kim's model[38]. The perforation and resonance [39-41] is the basis for the sound absorption mechanism of MPPs. The acoustic characteristics of the aforesaid PP foams with and without perforation were researched by Park et al. [42]. It demonstrates that while the foams' sound absorption frequency range was extended by perforation, their transmission loss was not improved. Lin et al. [43] estimated dependency of both the mechanical and acoustic parameters on (PR) and (PD) of PU plates. According to experimental findings, perforating stiff PU foam panels improved their capacity to withstand loads and their capability to absorb waves within med-high frequencies. In addition to design changes, honeycomb backing, and the two frequently used methods are to create panels in the backing air gap utilized strategies to enhance the acoustic properties of absorbers for MPP [44]. Both situations allow for the generation of a local one-dimensional sound field by each air gap subdivision, which results in normal incidence into the apertures, the most efficient sort of Helmholtz-type resonance(HR) absorption. [45]. Toyoda and Takahashi partitioned an air-back gap to reduce transmission loss and increase absorption coefficient at mid-frequencies [46]. By using changeable perforation baffles, Zhang et al. created a honeycomb-MPP construction utilizing specific sound-absorbing frequencies. Recently, it has been observed that the usage of micro-capillary plate sound absorbers micrometric pore sizes results in broadband (LF) sound behavior [47, 48] and may be a very promising tactic. El-Basheer et al. designed MPPs with jute fabric and they got high absorption with good bandwidth within LF[15]. The perforation ratio, porous material, and air cavity all had an impact on the 3D-printed ceramic perforated panel's SAC by Khosravani et al. [46]. A rigid MPP, an aluminum backing plate, and an ABS printed core are joined together to form a single-layer MPP absorber. This MPP with appropriate panel thickness, (PR), and holes with tiny diameter enables absorption with a broader band-width under low-speed grazing flow [47,48]. Different cross-sections of PLA panels with circular holes are 3D printed. The SAC and frequency bandwidth are influenced by the geometrical differences of perforations. In comparison to traditionally flat perforated panels, the aluminum micro perforated has high absorption qualities. a single or multiple resonance circuit connected to a (MPP) made of piezoelectric ceramic. In order to achieve low-frequency broadband sound dissipation, the PZT increases the vibration of MPP's .

2.5 Applications

Materials that are acoustic or sound absorbent, as noted above, have many uses in many industries. This section provides a quick overview of the main applications in the building, infrastructure, and automotive industries. It is also important to keep in mind that the materials discussed in this review have potential uses besides acoustics. Examples of other uses for rigid or flexible foams include packaging, mattresses, chairs and more specialized medical uses such as biodegradable scaffolds [127].

2.5.1 Automotive:

Nonwoven materials, which have been addressed in previous sections, are frequently used as padding in car hush panels wheel-arch liners, etc. to enhance the acoustic quality of the interior. [128]. Fig. 1 depicts an illustration of how textiles might be employed in an automobile at different points. Additionally, microcellular thermoplastic foams, which are produced using the MuCell® method, are becoming used in passenger cars like those made by Toyota and Jaguar Land Rover. Among these, the attenuation of noise inside the cabin is facilitated by (OC) or (SOC) structured thermoplastic foams. Low bulk density metal foams are also regarded as having promise for use in this industry [129].

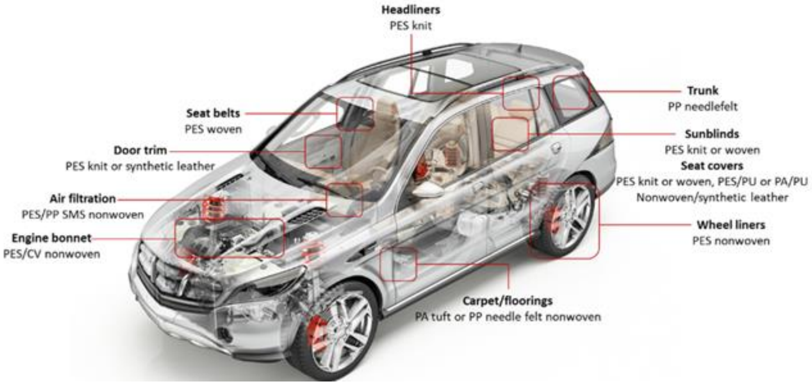

Figure. 1: An example of nonwoven materials used in an automobile[32].

2.5.2 Interior

Cinemas, offices, theatres, recording studios, etc. use sound absorption materials by appending them to the walls, ceilings, and doors to avoid resonance and undesirable noises and enhance the acoustics of a space. (Fig. 2). Improved sound absorption qualities for acoustic foam can be obtained by adjusting shapes in addition to modifying the composition of the foam. Additionally, for the goal of reducing ambient noise, perforated corrugated MPP panels can be employed [130].

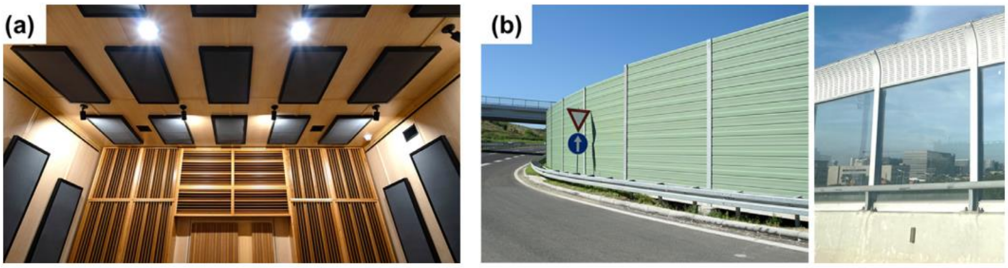

Figure 2. Applications for acoustic materials include: (a) Home theatre room acoustics using acoustic foam panels on the walls and ceilings; (b) Infrastructure applications utilizing thermoplastic and perforated metal sheet; left image borrowed from with permission from acoustic fields [131](source:[32]).

3. Conclusions and Future perspective

This review tackles a huge domain of AMs for various applications in the automotive sector, buildings, and infrastructure, with a detailed analysis of their acoustic characteristics, absorption mechanisms and a variety of methods for enhancing sound absorption behavior. Foam structural characteristics include fabric density, layering order and thickness, open cell content, fibre type, size, and form, (CD)and morphology, structural tortuosity, and porosity, all of which have an impact on how well a material absorbs sound. Based on an understanding of the mechanisms by which sound is attenuated in various porous materials, the use of nanofillers and nanofibers, the creation of hierarchical cellular structures with micro and nanopores, sandwich structures, microcellular foams, and improvements to the design of microperforated panels are just a few of the options listed and addressed. Additionally, combining different strategies results in synergistic effects that enhance the acoustic manner of while introducing wider broadband noise reduction. These techniques are advantageous and important for creating the new descent of AMs.

Future difficulties for the following descent of sound-absorbing materials include:
1. The majority of noise control products now on the market are neither recyclable nor ecologically friendly [134]. The creation of sound absorbers with strong sustainability and recyclability should be the main emphasis of future research. It should be investigated whether there are any sound absorbers constructed entirely or mostly from biobased materials and/or recycled materials.
2. Manufacturing processes must be economical, less complicated, ecologically friendly, and sustainable. There is a need for novel synthesis and fabrication techniques that can adjust 3D cellular architectures in a repeatable and dependable way. Although an even dispersion of the nanofiller is necessary to obtain maximum performance, the challenge of nanofiller dispersion during processing is generally acknowledged for foam-based composites integrating nanofillers like graphene [135]. In addition, scaling issues frequently prevent the widespread use of innovative metallic or graphene foams as sound absorption materials. A potential remedy could be quick prototyping methods like 3D printing [136].
3. Smart sound absorbers, which may be modulated by external stimuli like electrical or magnetic fields, are a subject in which research is currently weak. More initiatives in this area are anticipated and required.
4. By creating artificial structures with periodic or non-periodic parts that display unexpected behaviours to broaden bandwidth and low-frequency absorption, metamaterials open a new path. Particularly, resonant-based membrane-type metamaterials play a crucial role in sound absorption. Larger bandwidth is offered by AMMs with periodic and spaced-coil topologies rather than those with resonant inclusions.
5. Metamaterials that are active or adjustable have a mechanism for compensating for unwanted energy loss. In order to get beyond the constraints of passive metamaterials, active metamaterials have effective properties. By combining vibration suppression and absorption, multifunctional metamaterials offer an effective solution. Acoustic metamaterials of the future will concentrate on capturing undesired sound and recycling it for energy conversions.
6. Adapting the prototypes for large-scale fabrication and real-time electronics will be the next hurdle.

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