Review on Research process of Sound reduction Materials

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Abstract. Noise pollution, air pollution, water pollution and solid waste pollution are recognized as four major environmental pollution sources in the world. Based on the principle of noise reduction, noise reduction materials mainly include sound absorbing material, sound insulation material and noise damping material. In this paper, the mechanism, research progress and development trends of the three kinds noise reduction materials are reviewed and discussed.

1. Introduction

With the development of society and the improvement of industrialization, noise pollution is becoming more and more serious, which seriously affects people's normal life and work. Noise pollution, air pollution, water pollution and solid waste pollution are recognized as four major environmental pollution sources. At present, people mainly control noise in following three ways: 1) Controlling the noise source; 2) Controlling the noise during its propagation; 3) Controlling the noise at the noise receptor. And the way of controlling noise during its propagation is most widely used and effective. Fig. 1 shows the typical interaction process between sound waves and matter. Where, \( E_i \) is the incident sound energy, \( E_r \) is the reflected sound energy, \( E_a \) is the sound energy absorbed by the material, and \( E_t \) is the transmission sound energy.

![Figure 1. Typical interaction process between sound waves and matter.](image)

Based on the principle of noise reduction, noise reduction materials mainly include sound absorbing material, sound insulation material and noise damping material. In this paper, the mechanism, research progress and development trends of the three kinds noise reduction materials are reviewed and discussed.
2. Sound absorbing materials

Sound absorption coefficient $\alpha$ is an important parameter for evaluating the sound absorption performance of materials, which is defined as:

$$\alpha = 1 - \frac{E_t}{E_i} = \frac{E_i - E_a}{E_i}$$

Based on the sound absorption mechanism, sound absorbing materials can be divided into two types: porous sound absorbing materials and resonant sound absorbing materials (structures). The resonant absorption structure is mainly a Helmholtz resonator structure, and the acoustic energy is consumed by the resonance generated by sound waves inside the structure.

2.1. Porous sound absorbing material

A porous sound absorbing material is a solid that contains cavities, channels or interstices so that sound waves are able to enter through them. Based on the microscopic configurations, porous absorbing materials can be classified as porous fiber materials and porous foam materials.

2.1.1. Porous fiber materials. According to the physical characteristics and appearance of fiber sound absorbing materials, it can be divided into organic fiber absorbing materials, inorganic fiber absorbing materials and metal fiber absorbing materials. The sound absorbent materials of organic fiber (such as cotton fiber and polypropylene fiber) have good sound absorption performance at high frequency and low cost, but with poor performance in fire resistance, anticorrosion, moth-proof and moisture proof. Inorganic fiber sound absorbing materials (such as glass fiber and rock wool) have advantages of good sound absorption, light weight, non-decay, non-aging and non-combustibility. But due to the properties of brittle and soft, it has some problems in engineering application, such as fiber powder pollution and the sound absorption deteriorates after damped. Metal fiber sound absorbing materials (such as aluminum fiber) have the advantages of high strength, impact resistance and high temperature resistance. Due to the high production costs, they are generally used in poor working environment and special sound absorption places, and also used as sound absorbing decoration material.

Youngjoo et al. prepared a nanofiber fabric through an electrostatic process with melt spin polyamide fibers of nano diameters, and then examined the effect of layers of nanofiber webs on regular fiber knitted fabric on sound absorption [1]. Ao Qingbo et al. studied the porous stainless steel fibrous felt materials with thickness of only 1 to 3 mm, and optimized the structure by changing preparation processing and structure parameters [2]. Yu et al. used hot-pressing method to combine thermoplastic polyurethane with waste polyester fiber, which is a good mechanical fiber composite [3]. Sun Zhixing et al. demonstrated a novel reuse of the fiberglass recovered from waste printed circuit boards (PCBs) for noise reduction application. The test results indicate that the reuse of RFG for noise reduction represents a promising way to realize high value-added utilization of waste PCBs [4].

In summary, developing new fibers with good sound absorption properties and preparing composite fiber materials are the development trend of fiber sound absorbing materials. At the same time, preparation of fiber material using waste fiber as raw material has received much attention, which can realize the rational allocation of waste resources.

2.1.2. Porous foam materials. Foam sound-absorbing materials can be divided into foam metal, foam glass, and foam plastic three categories. For the foam metal integrates, it has the characteristics of continuous phase metal, dispersed phase porosity, good electromagnetic shielding performance and corrosion resistance. But its water resistance, weathering resistance, corrosion resistance and candle resistance are poor and the preparation process is complex. For the foamed glass, it has the advantages of light weight, non-combustible, non-aging, non-smell and non-deformation after water absorption. While it has the disadvantages of low strength, easy-damage, processing difficultly and high cost.
Foam plastic materials have advantages of wide applicable frequency, moisture-proof, low cost, good toughness, good ductility, but it also has disadvantage of poor fire resistance and easy-aging.

Maysenh et al. simplified the relaxation model to establish the relationship between the micro-structure of snow and the sound absorption properties. The calculated results are in good agreement with the experimental data [5]. Dong Guan et al. applied the generalized regression neural network model (GRNN) to evaluate the influence of structural parameters of semi-porous aluminum foam on its sound absorption performance [6]. Saetung et al. synthesized a polyurethane foam based on natural rubber. The effects of rubber particle size and formula parameters on its morphology mechanical properties and sound absorption properties were studied. Qin Dong et al successfully prepared a kind of porous acoustic absorption ceramics by gel injection molding method. The first sound absorption frequency is about 2500Hz with peak value of 0.98, and the noise reduction coefficient (NRC) can achieve 0.6 [7].

The porous foam sound absorbent materials have excellent performance in many aspects, but most of them are in the laboratory research stage, the high production cost limits its extensive engineering application, and how to reduce the production cost will be the main research direction in the future.

2.2. Resonant sound absorption structure

Resonant sound absorption structure mainly includes perforated plate resonant, thin film/plate resonant and micro-perforated plate resonant structure. Due to the large perforation diameter with a small acoustic resistance and large sound quality, the sound absorption bandwidth of perforated plate resonant structure is generally narrow and always needs to add porous sound absorber behind the plate to achieve enough absorption bandwidth. However, while the diameter of the perforation is reduced to less than 1mm, the acoustic resistance can be increased without any additional porous material, which is called micro-perforated plate structure and proposed by Ma Dayou [8].

In order to improve the sound absorption effect of micro-perforated plate structure, Xiong Honglian et al. added the sound insulation film with a fold structure into the cavity after the micro-perforation plate. Zhao Xiaodan et al. optimized the sound absorption structure of three-layer micro-perforated plate with genetic algorithm. The sound absorption coefficient of the three-layer micro-perforated plate is better in the selected frequency range, and the sound absorption coefficient of resonance is close to 1 [9]. Wang C H and Kimihiro Sakagami et al. designed a parallel micro-perforated plate structure with variable cavities [10]. The results show that the effective absorption band range of different cavity is different and the sound absorption bandwidth is broadened to a certain extent. He Liyan and Xu Ying studied the influence of three different hole sections on the sound absorption performance of thick micro-perforated plate. The experimental results show that the large conical hole has the most obvious effect on improving the sound absorption performance, which not only broadens the sound absorption band, but also increases the sound absorption coefficient [11].

At present, the sound absorption properties of sound absorbing materials have been greatly improved, and also been widely used in various fields. However, with the development of society and environmental protection awareness improving, people put forward higher standards and requirements for the sound absorption. Therefore, new sound absorbing material is developing towards the direction of environmental protection and safe characteristic. How to reduce the production cost and realize the reuse of solid wastes are also important development trends in the future.

3. Sound insulation material

The sound insulation effect of materials is usually evaluated by transmission coefficient $\tau$ or sound insulation $R$, the size of which can be expressed as:

$$\tau = \frac{E_i}{E_s}$$

\[2\]
\[ R = 10 \log \left( \frac{E_t}{E_i} \right) = 10 \log \left( \frac{1}{\tau} \right) \] (3)

Where, \( E_t \) is the transmission energy and \( E_i \) is the incident energy. The smaller the transmission coefficient and the higher the sound insulation, means the better sound insulation effect.

The sound insulation material can be divided into metal, inorganic and polymer composite sound insulation material. In recent years, due to the heavy quality, high cost, easy corrosion and other problems, metal sound insulation plate does not meet the requirements as modern sound insulation materials. Inorganic soundproof panels are usually used in the field of building sound insulation, mostly cement and concrete. In addition to good weathering resistance, inorganic materials also have characteristics of high surface density, high strength and good insulation. However, it has problems of heavy weight, heavy consumption and poor sound insulation effect. Polymer composite has the merit of high process-ability, easy modification and low cost, and it provide many possibilities for the development of new vibration and noise reduction materials.

Particle filled or fiber reinforced polymer matrix composites is a new type of polymer composite sound insulation materials, which not only has high performance of sound insulation and heat insulation, but also has advantages of light weight, easy processing, corrosion resistance, easy construction. Liang and Jiang studied the propagation process and the law of acoustic wave in inorganic particle filled polymer composites, and put forward the sound insulation mechanism of polymer or inorganic particle composites [12]. Yan et al. studied the sound insulation properties of polypropylene/nano-clay composites, and obtained the change of sound insulation in different mass fraction range of nano-clay [13]. Gao Yun et al. filled polyester woven fabrics, polyester nonwovens and glass fiber woven fabrics into EPVC respectively, and found that the sound insulation properties of polyester nonwovens composites were superior to those of the other two kinds of composites. Zhou Geng filled steel slag powder on the basis of slow rebound polyurethane foaming material, and studied the influence of the addition of steel slag powder filler and the composite of different material layers on its sound insulation performance.

The sound insulation performance is mainly affected by two aspects: the density and thickness and the micro-structure. Therefore, special structure of the composite can be used to prepare high-strength, light-weight and ultra-thin sound insulation materials. Environmental protection, lightweight, multiplex and low cost will be the main development direction for new sound insulation materials in the future.

4. Noise damping material

So far, the research and application of damping noise reduction materials have been decades. The study of damping materials is mainly focused on metal materials at the initial stage. "Law of mass" is also applicable to metal-based damping materials, the vibration and noise can be effectively reduced by increasing the quality of damped materials. Later, viscoelastic damping materials attracted much attention for its high damping properties. Damping materials can be classified into three categories: viscoelastic damping materials, high damping alloys and composite damping materials.

Sophiea et al. have synthesized the epoxy damping materials many years ago, which has good noise reduction performance in the range of \( T_g \), and the modification based on epoxy resin by copolymerization and blending method was studied for a long time. Hu et al. studied the sound insulation properties of different rubber damping materials, and found that butadiene rubber damping material is an excellent polymer material with wide temperature range and high damping, which can be widely used in various fields [14]. Jiang Duxiao et al. studied the polysiloxane and acrylate interpenetrating network damping materials, and found that the damping factor \( \tan \delta \) can reach the maximum value of 1.4%. Furthermore, they found that the damping characteristic is improved with a structure of effective interpenetrating and certain micro-phase separation. Hajime et al. filled carbon fiber into epoxy resin matrix, and laminated with various thermoplastic elastomers. The composite not
only has high hardness, but also has remarkable damping effect.

Many achievements have been made for the damping materials, including the principle of noise reduction, effective analysis method and related summary of various influencing factors. The development of damping materials with excellent comprehensive properties, such as ultra-high-speed internal friction damping noise reduction materials, wide temperature range and wide band damping noise reduction materials, will be research focuses in the future. In addition, it is an important development direction to develop economical, green and functional damping materials.

5. Conclusion
The research and development of noise-reducing materials have not only made certain achievements, but also formed a certain theoretical system, which has been widely used in various fields such as construction, chemical industry, transportation and daily life. However, with the development of society and environmental protection awareness improving, people will put forward higher standards and requirements. New sound reduction materials are developing towards the directions of environmental protection and safe characteristic. How to reduce the production cost and realize the reuse of solid wastes are also important development trends in the future.

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