Multifunctional properties and applications of ultra-light porous metal materials

Jianru Chen, Da Zhang

School of Materials Science and Engineering, Shandong University of Technology, Zibo City, Shandong Province, 255000, China

Abstract. Porous metallic material is a new type of material with a special structure, which undergoes structural changes under certain conditions, thus forming a new structural unit. Due to their unique porosity and pore size structure, ultralight porous metallic materials have unique multifunctional properties, such as absorption and buffering of vibration energy, energy absorption and weight reduction, thermal insulation, vibration and noise reduction, and tunable performance, and thus are widely used in aerospace, energy industry, transportation, and biomedical fields. This paper reviews the research progress of ultra-light porous metal materials at home and abroad in recent years, including the basic structure and main properties of ultra-light porous metal materials, and discusses their application fields. Although China started late in this field, it has taken a place in the international arena with the continuous research work. In the future, we should focus on basic research and engineering application research to lay a solid foundation for China to achieve technological breakthrough in this field.

Keywords: ultra-light porous metal materials; functional properties; application analysis.

Ultra-light porous metal material is a kind of metal material with special structure, which has a large number of internal pores, most of which are connected, while a small portion of pores are connected or partially connected. As the porous metallic material will undergo structural changes under certain conditions, thus forming a new structural unit with unique multifunctional properties, such as absorbing and buffering vibration energy, energy absorption and weight reduction, heat insulation, vibration and noise reduction, and adjustable performance. Therefore, the material has broad application prospects in the fields of aerospace, transportation, energy industry and biomedicine. At the same time, due to its unique structural characteristics and performance advantages, it is widely used in manufacturing equipment and special equipment, such as the aerospace field for the manufacture of flight control systems, thermal management systems and anti-vibration systems; transportation field for the manufacture of aircraft engine blades, aircraft engine fans and turbocharger blades; energy industry for the manufacture of gas turbines and nuclear reactor fuel cladding and combustion chamber The biomedical field is used to manufacture artificial heart valves and medical implantable artificial organs.

1. Basic structure and performance

The basic structural unit of ultra-light porous metal materials is a porous structure obtained by a certain composition of metal monomers, in accordance with certain process requirements, by melting and casting, rolling and other processes. It mainly includes composite structural materials made of metal matrix and porous materials and direct composite structural materials made of metal matrix and porous materials.

The main properties of ultralight porous metallic materials are closely related to their porosity, pore size and distribution, phase interface and surface state. Due to their unique physical, mechanical and thermodynamic properties, they are widely used in aerospace, energy industry, transportation and biomedical fields. Ultra-light porous metallic materials can be divided into small pore size metallic materials and large pore size metallic materials according to the pore size. Small pore size metallic materials are generally made of high porosity matrix (such as aluminum and aluminum alloy) and low porosity porous phase (such as austenitic stainless steel) composite, its structure and properties are shown in Table 1. large pore size metallic materials are made of low porosity matrix (such as carbon fiber, glass fiber, aramid fiber, etc.) and high porosity porous phase (such as pure aluminum, magnesium alloy) composite.

1.1 Mechanical properties

Because of their unique pore structure, porous metallic materials can achieve properties with different strengths, different deformation patterns, and different forms of energy absorption. Compared with traditional metallic materials, porous metallic materials have significant advantages in terms of strength and stiffness. The fracture toughness of ultralight porous metallic materials is much higher than that of traditional metallic materials, and they also have good damping properties and energy absorption characteristics, so they can effectively absorb energy, absorb vibration energy, and do not cause damage to the surrounding environment. In addition, it also has good dimensional stability and good processability.

At present, ultra-light porous metal materials are mainly used in the aerospace, energy industry and transportation fields. Among them, the aerospace field is mainly used in aircraft fuselage and other structural components, spacecraft hull and engine combustion chamber and other parts; the energy industry is mainly used in wind power blades and battery shells.

1.2 Energy absorption and weight reduction

In the process of car collision, due to the impact load, the body will be deformed, if the energy absorption capacity is poor, it will lead to serious deformation of the body or even a car damage accident. In order to solve this problem, a large number of energy-absorbing and weight-reducing devices need to be installed on the body. If the traditional structural design method is used, a large number of additional parts and materials are needed to achieve energy absorption and weight reduction. However, the use of ultra-light porous metal materials for energy absorption and weight reduction can achieve structural lightweighting because of its excellent energy absorption and weight reduction performance.

Since the pore structure of ultralight porous metal materials is irregular, the lap between different pore structures of ultralight porous metal materials can be used to achieve the energy absorption and weight reduction function. In this way, energy absorption, volume and weight reduction as well as cost reduction can be achieved, so it has great application prospects. At present, the research on energy absorption and weight reduction of porous metal materials mainly focuses on reducing the density of porous metal materials to achieve. By optimizing the design of porous metal materials, the density can be reduced to about 1/5 of the original, so that the effect of energy absorption and weight reduction can be effectively improved.

Research shows that when the car collision speed reaches 50 km/h, the maximum deformation of the body is 0.075 mm without any additional parts and materials, while when the collision speed reaches 100 km/h, the maximum deformation of the body is 0.001 mm, which indicates that the energy absorption capacity of the body is greatly improved.

1.3 Insulation

Due to their high thermal conductivity, ultralight porous metallic materials are widely used in aerospace applications. According to the International Council for Thermal Transport, porous metallic materials are defined as porous structures with a pore size of less than 20 μm, while metallic materials are solids composed of pure metals or alloys. In the aerospace field, metallic materials can absorb and consume most of the heat and provide thermal insulation.

For ultra-light porous metal materials, their thermal conductivity is much higher than that of ordinary metal materials of the same density, but their thermal conductivity is only 1/3~1/2 of that of carbon fiber of the same mass, which has a great advantage in thermal insulation. Usually, when designing porous metallic materials using traditional thermal insulation methods, the thermal conductivity inside the material is difficult to determine. When porous structure design is used, there will be a large free energy potential difference at the atomic-molecular level due to the presence of a large number of free electrons and ions in the pore space, which makes the material obtained by porous structure design have a high thermal conductivity. Therefore, how to improve the thermal insulation performance of porous metallic materials is one of the hot research topics in this field.

At present, many researchers have introduced new thermal insulation materials into the design of porous metal materials, the most representative of which is porous carbon fiber composite. This material has extremely high thermal insulation performance, but the relatively heavy carbon fiber makes the comprehensive cost of the material high, so few people use this material for porous metal material design. Combining ultralight porous metal materials with carbon fiber composites can effectively reduce the cost of the material and improve its comprehensive performance. As shown in Figure 6, the combination of ultralight porous metal and carbon fiber composite material can not only reduce the cost of the material, but also improve the comprehensive performance of the material, which meets the requirement of comprehensive performance of metal insulation material in aerospace field.

1.4 Vibration and noise reduction

Porous metal materials have a unique porous structure, and their porosity and pore size structure can effectively absorb vibration energy, and thus have vibration and noise reduction properties. Due to their unique pore structure, porous metal materials can be used in many fields. For example, they can be used in the aerospace industry for vibration and noise reduction, and in automobiles and ships for vibration isolation and damping.

Due to the unique aperture structure of ultra-light porous metal materials, they have great potential in vibration energy absorption. When using porous metallic materials as sound insulation materials, not only can structural acoustic radiation noise be reduced, but also the sound insulation effect of the sound insulation layer can be improved. For example, the combination of ultralight porous metallic materials with conventional materials can significantly reduce structural acoustic radiation noise and structural vibration noise. When using ultra-light porous

metal materials as sound insulation materials, the sound source can be effectively isolated from the sound insulation layer, thus achieving the effect of noise reduction. At the same time, porous metal materials also have good performance advantages in vibration absorption. When porous metal materials are used as vibration absorbing materials, they can effectively absorb structural vibration energy and reduce structural vibration noise. When the porous metal material has a porous structure, its vibration absorption capacity is obviously improved.

Therefore, porous metal materials have great potential for application in vibration and noise reduction. In addition, with the rapid development of new high-tech manufacturing industry and the increasing attention to noise pollution control in various countries, the vibration and noise reduction performance of ultra-light porous metal materials has put forward higher requirements. Therefore, the study of new high-tech manufacturing industry with ultra-light porous metal materials is of great significance to solve the vibration and noise problems faced by the aerospace, transportation and energy industries.

2. Second, the application analysis of ultra-light porous metal materials

2.1 Application to the transportation and manufacture of mechanical parts

Porous metallic materials are characterized by high strength, low density, and light weight, and are naturally superior in the delivery and manufacture of mechanical components. For example, an extremely light, porous metallic material can be used as a raw material for steel plates, and the steel plates produced from this raw material have the same light weight, durability, and performance as conventional metallic materials. In addition, the present invention allows the application of this extremely light, porous metal material to mechanical skins and automotive parts, thereby achieving a reduction in their mass.

2.2 isolation noise application

It has a large number of holes, which are filled with air. Therefore, the ultra-light porous metal material has a better sound insulation effect and can be used as a sound insulation material, which can be used in noisier roofs and can effectively stop the transmission of noise. In the near future, porous metal materials can also be used on vehicles so that engine noise can be reduced to a minimum, which has positive practical implications for chain maintenance.

2.3 Communication business

Due to its special energy-absorbing properties, it has been widely used in communication engineering. It has better wave-absorbing performance than other conventional materials, which can improve the communication quality and enhance the communication environment, making communication more convenient and smooth.

2.4 Environmental Engineering

The porous metal material is also sensitive to some gases, so it can play a role in environmental engineering. This method can be applied in areas such as environmental monitoring. From the reaction of a porous metal with a certain gas, it is possible to tell whether there is environmental pollution in this area, and also to determine the source of the pollution from the detected gas.

2.5 Bone material

In addition to the above characteristics, porous metallic materials have properties and structures similar to those of biological materials; therefore, they do not cause rejection when used as bone repair materials, and therefore, they have broad clinical application prospects. In future research, porous metallic materials will become an ideal bone material.

2.6 as a plate

Extremely light porous metallic materials are also used in military applications. The ultra-lightweight metal material takes advantage of the material's strength, stiffness and stretchability to create a stainless steel sandwich structure. This material is lightweight, stiff and durable. Metal panels made from this material have properties such as heat insulation, heat dissipation, heat resistance, and sound absorption. Nowadays, military fire partitions are made of perforated, extremely light metal sheets to avoid heat and sound disturbance to the occupants in the cabin.

2.7 for anti-electromagnetic interference

Power electronic devices and systems, on the one hand, are very sensitive to electromagnetic interference in the environment; at the same time, they also generate a certain amount of electromagnetic interference to the surrounding environment. Therefore, electromagnetic shielding has also become a hot topic At present, China has made some initial progress in using lightweight porous materials to absorb waves, but its specific applications are yet to be studied and analyzed in depth.

2.8 Other areas

In the aerospace field, ultra-light porous metal materials can absorb vibration energy, reduce structural mass, increase structural stiffness and improve starting performance. In the energy industry, ultra-light porous metal materials can be used as electromagnetic shielding, heat shielding materials, absorb vibration energy and radiant heat; in the transportation field, ultra-light porous metal materials can be used for vibration isolation, cushioning and energy absorption inside the car; in the biomedical field, ultra-light porous metal materials can be used to reduce sound pressure, absorb and release sound energy; in the aerospace field, ultra-light porous metal materials can be used for noise reduction and heat

insulation. In the field of aerospace, ultra-light porous metal materials can be used for noise reduction and heat insulation. Many units have already conducted research on ultra-light porous metal materials.

3. Concluding remarks

To conclude, porous metal material is a new material obtained through long time research, which has more features and functions than traditional materials, and can combine the double advantages of structural and functional materials. With the continuous development of society, our living space will become smaller and smaller, and resources will become less and less. The only way to ensure that our life will not be threatened is to find more efficient and environmentally friendly materials through in-depth research on new materials. In addition, with the development of science and technology, we already have the ability to conduct in-depth research and development on porous metal materials, which will become an inevitable trend for human survival in the future. Only through continuous innovation and discovery of various uses and applications of porous metal materials can we bring more convenience to our life and more vitality to our life.

References

1. T.J. Lu, D.P. He, C.Q. Chen, et al. Multifunctional properties and applications of ultralight porous metallic materials [J]. Advances in Mechanics, 2006, 36(4): 517-535.
2. Hou Xiuhui. Optimal design of porous metallic materials and its new characterization of wave propagation problem [D]. Xi'an: Northwestern Polytechnical University, 2010.
3. Yan Jun. Multi-scale analysis and collaborative optimization design of ultralight metal structures and material properties [D]. Dalian: Dalian University of Technology, 2007.
4. Qiu Liang, Liu Yaohuan. Ultralight porous metal materials for military applications[J]. Science and technology innovation and application, 2014, (22): 83-83.