Preparation and Applications of Foam Ceramics

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Abstract. As a new type of porous material, foam ceramics have properties such as the high strength and hardness, the good plastic toughness, corrosion resistance and the high temperature resistance. This paper summarizes the preparation methods of foam ceramics such as organic foam impregnating method, foaming method, freeze-drying method, etc. The paper also introduces development status of foam ceramics at home and abroad as well as the application of foam ceramics in environmental protection, metal casting, construction and other fields. Finally, the current situation and developments of foam ceramics are discussed.

1. A brief introduction of foam ceramics
Foam ceramics have continuous network of ceramic skeleton structure and three-dimensional continuous through holes, shaped like "steel foamed plastic" or "porcelain fused sponge" [1]-[2]. As a new type of inorganic nonmetallic material, foam ceramics have high hardness, high temperature resistance, corrosion resistance and other general ceramic materials of good properties. They also have good plastic toughness, high porosity, thermal stability, thermal shock resistance and good filtration adsorption. They are widely used in metal smelting, chemical industry, aerospace, automotive, construction, medical and other fields.

According to whether the holes have solid walls surface, foam ceramics are generally divided into two types: open-hole ceramics and closed-hole ceramics. At present, the main research of foam ceramics at home and abroad is the opening type.

2. The preparation methods

2.1. Organic foam impregnating method.
The organic foam impregnating method is the most widely used in industry. The method utilizes a unique three-dimensional mesh skeleton structure of a foam ceramic to coat ceramic slurry on a polyurethane organic foam mesh body, then the organic foam is dried at room temperature and burned to degrade it so that a foam ceramic can be obtained. This method is able to produce high-performance foam ceramics, and the disadvantage is that it can’t make closed-cell products with small diameter. Among them, Sun Wenfei, Du Qingyang and others [3]-[4] used this method to prepare excellent silicon carbide foam ceramics.

2.2. Foaming method.
The basic principle of the foaming method is to use a chemical reaction of a foaming agent to generate a certain amount of volatile gas to foam the slurry, and then to obtain a foam ceramic by drying and sintering. This method is easy to control the shape and density of the product, and can be used to prepare small-pore-size closed-cell ceramics. The disadvantage is that the process condition is difficult to control...
and the raw material requirement is relatively high. Among them, Chai Yuxin and Li Weidong [5]-[6] prepared high porosity aluminum oxide foam ceramics with different foaming agents.

2.3. Add the pore-forming method.
The pore-forming agent method utilizes the pore-forming agent to occupy a certain space of the black body, and then the sintered pore-forming agent is burned and converted into gas to form pores after sintering to prepare a foam ceramic. The preparation process is simple and easy to form, and can produce ceramic products with complex shape. The disadvantage is that the uniformity of pore distribution is poor, and it is generally not possible to prepare high porosity products. Among them, Lu Anxian and others [7] used fly ash to prepare foam ceramics with high porosity and high strength.

2.4. Sol-gel method.
The sol-gel method uses the hydrolysis and condensation process of metal compounds to gradually gel the sol, and then is dried and heat-treated to prepare the foam ceramics. The advantages of the method are simple steps and adjustable aperture. The drawback is that the shape of the product is easily restricted. Among them, Guo Xinshuang [8] made use of calcined bauxite and alumina to prepare high strength foam ceramics.

2.5. The new methods.

2.5.1. Gel injection molding method.
In 1991, Professor Mark. A. Janney [9] of Oak Ridge National Laboratory in the United States proposed a gel injection molding process. This method utilizes the polymerization of organic monomers in the catalyst and initiator to obtain the required foam ceramics by in situ curing and drying. The foam ceramics with complex shape and even pores can be prepared by this method. Among them, Yi Zhong Zhou [10] used organic monomer acrylamide to produce zirconia foam ceramics with high porosity, high strength and good toughness.

2.5.2. Self-propagating high temperature synthesis method.
Self-propagating high-temperature synthesis is a highly exothermic inorganic chemical reaction process. This method utilizes the energy provided by the ignition and other operations to induce the reaction of the reaction inside the reactant and then to the combustion synthesis reaction of the entire system, thereby preparing the desired ceramic foam. This method does not require additional energy, low energy consumption and high production efficiency. Among them, Lin Hongsheng [11] prepared a nitrogen alumina high-porosity foam ceramic by the \( \text{Al} \left( NO_3 \right)_3 \cdot 9H_2O \) thermal decomposition.

2.5.3. Freeze-drying method.
The freeze-drying method is an environment-friendly foam ceramic preparation method. This method freezes the ceramic slurry directly, and then the slurry is dried, vacuumed and heated to sublimate the ice to leave holes in the body. Finally, the desired ceramic foam is obtained by calcining. This method can produce foam ceramic products with high porosity and complicated pore structure. Among them, Chinese scholar Li Huamin [12] used this method to obtain \( \text{Al}_2\text{O}_3 - \text{ZrO}_2 \) foam ceramics with different porosity and strength.

So far, there have been advanced preparation methods for foam ceramics such as mechanical stirring method, ion exchange method, hot-pressing method, phase separation method, gas phase deposition method, cement curing method and so on. In actual production, suitable preparation methods can be selected according to the process conditions.
3. The development and application of foamed ceramics

3.1. The status of foam ceramics at home and abroad.
In 1978, F. R. Mollard and N. Davidson [13] of the United States and others took the lead in using alumina, kaolin and others to produce foam ceramic filters for filtering metal melts, and successfully applied it to the casting gating system. In 1984, the British FOSECO company and the CONSOLIDATED aluminum alloy company of the United States successfully developed a foam ceramic filter for filtering non-ferrous metal liquid [14]. Up to now, many countries have advanced production technology and supporting production facilities.

In the early 1980s, China began to study foam ceramic filters. In recent decades, more than a dozen research institutes and manufacturers have actively explored foam ceramics. Among them, Ye Rongmao [15] and others of Harbin Institute of Technology successfully developed a foam ceramic filter for aluminum alloy, cast iron and stainless steel in 1985. At present, China has developed a series of filters such as silicon nitride, silicon carbide, alumina, zirconia and so on, China's foam ceramics are developing rapidly.

3.2. Application of foam ceramics.
As a new type of material, foam ceramics have the advantages of high porosity, large specific surface area, high strength and high temperature resistance, which make the application scope of foam ceramics expended continuously. It is widely used in industrial sewage treatment, automobile exhaust equipment, heat and sound insulation materials, and filtration of molten metal. In recent years, it has been extended to the field of aviation, electronics and biochemical fields.

3.2.1. Application of foamed ceramics in the prevention and control of environmental pollution.

3.2.1.1. Application in wastewater treatment.
The process of foam ceramic treatment of sewage is mainly [15] combined with adsorption, surface filtration and deep filtration, and deep filtration is the main process. Compared with the traditional water treatment filter material, its unique pore structure and large specific surface area can greatly improve the efficiency of water treatment and reduce the processing cost. Ran Hongtao [16] and others prepared foam ceramic which can be used as an oil removal filter for waste water, and found that the degreasing rate of ceramics was approximately 80% within 60 minutes.

3.2.1.2. Application in automobile exhaust treatment.
At present, the method of catalytic conversion of the catalyst is the main method to deal with the exhaust gas, and the three-dimensional connected mesh structure of the ceramic foam can improve the efficiency of the exhaust gas conversion. At the same time, the high temperature resistance and thermal stability can ensure that it can work in the complex environment.

3.2.1.3. Application in sound absorption and noise reduction.
The principle of sound absorption in foam ceramics is that when the external sound waves are incident on the surface of foam ceramics, the air that causes the voids to move back and forth, and part of the sound energy is transformed into heat energy under the action of friction and air resistance. Foam ceramics are more suitable for use in wet, oily environments than traditional sound-absorbing materials (cork boards, foam glass, etc.).

3.2.1.4. Application in solid waste management.
China's solid waste is mainly waste slag, waste glass, fly ash and so on. They seriously pollute the environment and occupy limited land resources. Among them, Lu Xiaobin and others [17] used solid waste to prepare high strength thermal insulation materials.
3.2.2. Application of foam ceramics in the production of metal castings.
A large number of studies have shown that the use of ceramic foam filters can effectively filter out tiny inclusions and oxide films present in the molten metal due to eddy currents and turbulence, which greatly improves the quality and mechanical properties of metal castings. Sun Weicheng [19] and other tests showed that the metal inclusions after filtration by foam ceramics significantly reduced.

3.2.3. Application of foam ceramics in construction.
Closed-cell foam ceramics are known as the best insulation materials in the world. Foam ceramics have a large number of closed cells, which are resistant to corrosion and do not pollute the surrounding environment. At present, China has made use of foam ceramics as thermal insulation materials for walls and roofs.

4. Conclusion
Foam ceramics with good mechanical properties have received extensive attention and applications, and have achieved good economic benefits. However, from the current production status, various preparation methods all have some disadvantages more or less, such as: the method is more complex and the production cost is high. How to improve the deficiencies of the preparation methods, how to make their production more automated, how to obtain higher porosity, how to improve the sintering process to obtain better plastic toughness and thermal shock resistance, and how to prepare multifunctional foams Ceramics, these are issues we urgently need to solve.

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