doi:10.4028/www.scientific.net/AMR.795.5

Short Review: Ceramic Foam Fabrication Techniques for Wastewater Treatment Application

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Keywords: Cellular structures, polymeric sponge method, density, porosity

Abstract. Ceramic foam is a class of highly porous materials that are used for wide range of technological applications, specifically as absorbents and membrane for wastewater treatment process. Among the potential materials include silicon carbide (SiC), alumina (Al_2O_3), zirconia (ZrO_2), titania (TiO_2), and silica (SiO_2). The review clarifies on the broad types of ceramic foam, and the common techniques of foam fabrication, such as polymeric sponge method, starch consolidation, direct foaming, and gel-casting of foam. The parameters of each fabrication techniques will be discussed crucial based on the new research findings in the field of ceramic foam.

Introduction

Ceramic foams consist of cellular structures composed of a three-dimensional network of struts [1]. It can be classified as lightweight materials that exist as a cellular structure, struts, and windows [2]. Ceramic foams are porous and brittle materials comprising of large void cells, with linear dimensions in the range of 10 µm to 5mm [3]. Nonetheless a solid material that contains cavities channel or interstices can also be regarded as porous material.

Ceramic foam comes with closed, fully open, or partially interconnected porosity. It can be produced from a broad range of ceramic materials, specifically both oxide and non-oxide, which includes metallic oxides, silicates, carbides, and aluminosilicates that are being considered for the diverse area of potential applications [3-4]. The application compatible with ceramic properties, such as low density, low thermal conductivity, stable towards high temperature, and high resistance to chemical attack [5-6].

Foams have cellular structures that are categorised as either open cell or closed cell foams. They consist of an assembly of irregularly shaped polyhedral cells or prismatic, which are connected to each other with solid edge for open cell, and faces for closed cell. Closed cell ceramic foams are commonly used exactly for thermal insulation and fire protection materials. On the other hand, open cell ceramic foams are particularly used for molten metal filtration, diesel engine exhaust filters and hot gas filtration [3,7]. Moreover, potential applications of this foam are include membrane, absorbents, catalytic converter, insulation, biomedical devices, and as core materials for sandwich construction [8-9]. Table 1 shows the characteristics of cellular ceramics with type of foams.

Table 1 : Characteristics of cellular ceramics

Cellular Ceramics	Type of Foams	Cell Structure	Production	References
Macro-cellular	Ceramic foam	Open cells	Replica method, direct foaming	[10-11]
Micro-cellular	Plastic foam	Closed cells	Conventional plastic forming technologies	[12]

Macro-cellular ceramic foams are ceramic bodies with a large volume of porosity, typically ranging from about 70 to more than 90% of the total volume, but differ in the general morphology of the cells as well as in the properties of the foams [10]. Macro-cellular foams with a cell size in the range between 100-600 µm and a bulk density ranging from about 0.25-0.58 g/cm^3, depending on the processing parameters, that were fabricated using a direct foaming approach [13].

In comparison to macro-cellular ceramic foam, micro-cellular plastics have a cell densities greater than 10^9 cells/cm^3 and fully grown cells smaller than 30-50 µm. Meanwhile, micro-cellular foams with a cell size of about 8 µm, and the bulk density ranged from about 0.31-0.48 g/cm^3, depending on the material, pressure, temperature and the other parameters that were fabricated using conventional plastic forming technologies [13-15].

The common types of ceramic foam are such as silicon carbide (SiC), alumina (Al_2O_3), zirconia (ZrO_2), titania (TiO_2), and silica (SiO_2). The examples of ceramic foam that has been extensively studied such as, silicon carbide, alumina and partially stabilized zirconia [16].

Alumina (Al_2O_3) is a traditional adsorbent for heavy metals. It is important material that can be prepared in several different phases. The phase includes γ-Al_2O_3 and α-Al_2O_3. The structure of γ-Al_2O_3 is anticipated to be more adsorptive active than α-Al_2O_3 [17].

Technique of Foam Fabrication

Ceramic foam can be produced using the various methods, including replication method [18], starch consolidation [19], foaming method [20], and gel-casting of foam [21].

Replication Method (Polymeric Sponge). The process involves coating of open-cell polymeric foam with ceramic slurry followed by burning out of polymeric foam through sintering process, which yields a replica of the ceramic foam that are made from original polymeric foam [8]. In particular, foams obtained by the replication of a polymeric sponge using ceramic slurry tend to possess a lower mechanical strength, and a higher permeability.

Starch Consolidation. In particular starch, these techniques of foam fabrication have gained a prominent position, because it is cheap, non-toxic, environmentally friendly, and exhibit defect free burnout between approximately 300 and 600 °C [22]. Processing of starch consolidation which is ceramic slurry is prepared by introducing starch such as, food grade, fine rice flour, and others as gelling agent, and ceramic powder into distilled water. Then, the mixtures are mixing by stirring, tapping, casting, gelatin and coagulation, demolding, drying and sintering.

Direct Foaming. The processing of foam method begins with ceramic slurry which is ceramic suspension, foaming, polymerization, removal from mould (demolding), drying and sintering. High versatility and the ability to produce highly porous green bodies that are comparatively strong, and can easily withstand machining [23].

Gel-casting of Foam. Gel-casting has established for simplicity and ability to produce a high degree of homogeneity as well as green body strength, that resulting in good machinability. The fabrication process begins with mixing of a colloidal ceramic suspension containing water soluble monomers and a foaming agent. After foam formation, the suspension is rapidly gelled by means of the polymerization of the monomers, giving rigid ceramic foam. The green body is then dried and sintered, resulting in ceramic foam with nearly spherical pores and highly dense struts [24]. Table 2 summarizes various methods of Al_2O_3 foam fabrication.

Table 2 : Summary of Al_2O_3 foam with different type of fabrication

Ceramic Foam	Type of Fabrication	Pore Sizes (Cell Size)	Porosity (%)	Bulk Density (kg/m^3)	References
Al_2O_3	Polymeric sponge (polyurethane sponges)	200µm-3mm	40-95	314-1370	[25]
	Direct foaming	30µm-1mm	45-97	156-1560	[25]
	Gel casting of foam	30-800µm	-	390-1170	[1,23]

Al_2O_3 is the most popular ceramic material that is applied in form of ceramic foams. Al_2O_3 foams are usually produced by the polymeric sponge method which involves impregnation of polyurethane sponge with slurries containing Al_2O_3 particles followed by pyrolysis and sintering for solidification of the foam [26].

Direct foaming method utilizes silica and alumina as raw materials. It is firstly prepared by ball-milling silica glass. Lactic acid was adopted as dispersant, meanwhile a commercial liquid detergent (cationic surfactant) was used as foaming agent [27].

In gel casting method, industrial and mining wastes such as glass bottles and low grade silica and alumina were used as raw materials. Powder slurry was prepared containing a foaming and gelling agent. Ammonium lauryl sulfate was used as a surfactant, and ammonium citrate as a dispersant. The next step was the mechanical foaming of the suspension which is casted in mould and gelled. Then, the structure was thermally treated in the next process specifically drying, calcining and also sintering [1]. In comparison to the polymeric sponge method, gel-casting of foam method allows fabrication of small-pore-sized closed-cell foams, which cannot be made by an impregnation technique.

Conclusion

It can be abridged that ceramic foams are lightweight materials with a cellular structure. Due to the combination of properties resulting from the ceramic material and the cellular structure, these foams have a high potential for many applications, specifically in wastewater treatment process. Al_2O_3 was found to be one of ceramic material that is most extensively studied in order to produce ceramic foam. The technique of foam fabrication that have been listed shows that Al_2O_3 foam obtained by the replication of a polymeric sponge using ceramic slurry tends to possess a lower mechanical strength and a higher permeability compared to the other methods. Thus, the replication method is the most feasible method that can be used to fabricate Al_2O_3 foams for the wastewater treatment application.

Acknowledgement

The authors would like to thank to the Universiti Tun Hussein Onn Malaysia for their Long Term Research Grant Scheme (LRGS) for the support in providing the grant to implement the project entitled “High Performance of Polymeric Materials”. The authors also want to thank to Advanced Membrane Technology Research Centre (AMTEC), Universiti Teknologi Malaysia in collaboration with this project.

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