

Characterization of Alumina Foam from Casting Process

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Abstract:

A simple direct foaming and casting process using ovalbumin based aqueous slurries for fabricating alumina-zeolite ceramic foam was demonstrated. The characteristics of alumina foam were investigated through porosity, pore size, density and strength. 70 to 90 vol.% of alumina was used with zeolite of clinoptilolite type. Meanwhile, yeast was used as pore former agent in order to increase the porosity. Besides that, ovalbumin acted as a binder to bind the particles and encouraging foam formation. An increment in alumina loading has improved the porosity of ceramic foam but slightly reduced its strength. A ceramic foam with 90 vol.% of alumina showed the highest porosity 66.50% with the strength of 3.72 to 2.77 MPa. Therefore, the performance and utilization of these ceramic foams manufactured using this method may have a potential use in a range of applications including catalysis and filter.

Keywords: ceramic foam, yeast, ovalbumin, porosity, casting

1. Introduction

Ceramic foams are porous brittle materials with closed, fully open, or partially interconnected porosity. Ceramic foams are made from a wide range of ceramic materials; both oxide and non-oxide are being considered for the whole range of potential applications. These include catalysis, filtration, thermal insulation, impact absorbing structures, high specific strength materials, performs for metal-ceramic composites, biomechanical implants, and high efficiency combustion burners [1,2].

Protein such as ovalbumin has been used for the foaming and setting of aqueous ceramic powder suspensions for the preparation of porous ceramics. Overall porosity and foam microstructure could be controlled through ceramic solid loading, ovalbumin amount, foaming time and sintering temperature [1].

Engineered foams have cellular structures which are categorized as either open cell or closed cell foams. Foam consists of an assembly of irregularly shaped prismatic or polyhedral cells connected to each other with solid edge (opened cell) or faces (closed cell). Engineered foams have been

manufactured from polymers, metals, glasses and ceramics. Ceramic foams are a special class of porous materials comprised of large voids (cells), with linear dimensions in the region of 10 μm to 5mm [2].

Closed cell ceramic foams are commonly used for thermal insulation and fire protection materials. Meanwhile, open cell ceramic foams are used for metal melt filtration, hot gas filtration, diesel engine exhaust filters and other range of applications. Due to these and future potential application, there is a need to develop improved processing techniques of ceramic foams [2,3].

Ceramic foams have so far been produced in a variety of materials with various cell sizes, densities and degree of interconnectivity. Foams are usually produced with the density between 10 and 40% of theoretical and the pore sizes between 100 μm and 1 mm. The majority of the development work was carried out on a fine-grained α -alumina, before moving on to alternative materials [4].

Porous ceramics are produced in many ways such as the infiltration of reticulated polyurethane which performs with aqueous particulate ceramic slurries. Another method is the use of insoluble organic fugitive materials in ceramic suspensions, which the burnout leaving the porosity. This method requires a large amount of fugitive materials in order to produce highly porous bodies. The mostly used fugitive materials are starches, carbon black and sawdust. Besides that, a fused deposition method has been used to produce porous mullite bodies [1].

In this study, a simple direct casting route is applied to produce ceramic foam with the use of alumina, zeolite and other organic binder materials.

2. Experimental Method

Alumina powder and zeolite with the mean particle size of 45 μm were used in this study. The alumina loading used for the preparation of zeolite ceramic foam was in the range of 70 to 90 vol.% with 30 to 10 vol.% of zeolite (clinoptilolite). Ovalbumin (freshly extracted from the white egg) was added as a binder to the mixture after mixing. Yeast was used as a pore former in this ceramic foam. The slurries was cast into the mold and allowed to foam. The foam was simply dried under the room temperature. After that, the process was followed by the sintering at 1500°C for 2 hours with a ramp of 2°C/min. The sintering process of the samples was performed in the temperature programmable furnace. The sequence of operation for preparing ceramic foam is depicted in Figure 1. The sintering profile of ceramic foam is shown in Figure 2. Mechanical properties such as compressive strength and flexural strength were determined by using Autograph AG-I Universal Testing Machine. The speed rate of 0.5 mm/min was used for the compressive strength test. As for the flexural strength test, a load was applied at a cross head speed of 1.0 mm/min. The porosity, bulk density and pore size were measured by using mercury porosimetry (Model AutoPore IV 9500, Micrometrics Instrument Corporation).

Meanwhile, the microstructure of the ceramic foam was observed using a JEOL JSM-6380LA scanning electron microscope (SEM).

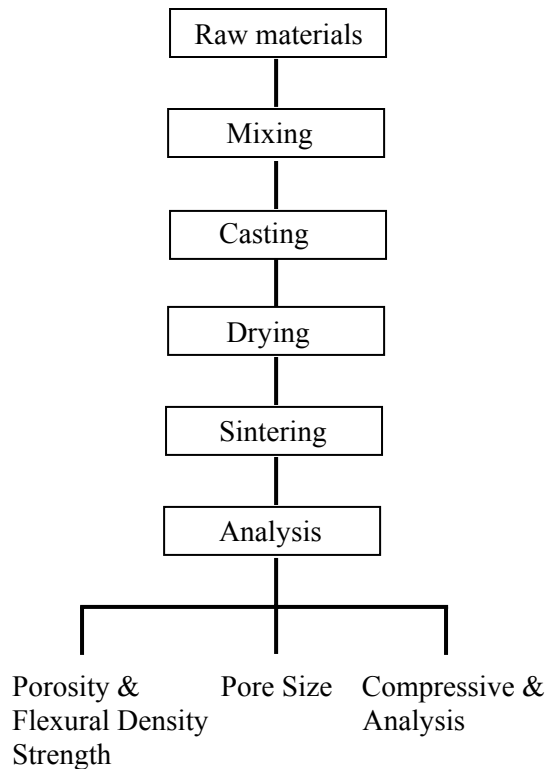


Figure 1: Flow chart for sample preparation and testing of ceramic foam

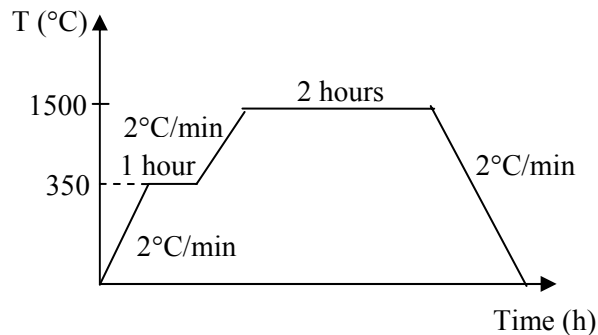


Figure 2: Sintering profile of ceramic foam

3. Results and Discussion

3.1. Porosity and Density Analysis

Porosity is the dominant factor affecting the performance of ceramic materials. From the past research, the use of different starting alumina compounds, the choice of sintering temperature and hold time, as well as heating rate, and the introduction of sintering aid provide the opportunity to control the formation of pores size and porosity distribution in the wide range. The shrinkage during the sintering process tends to the simultaneous decrease of the porosity of the sintered samples [5].

Results in Figure 3 present that porosity increases with the addition of 70 to 90 vol.% alumina loading and provides the maximum porosity of alumina-zeolite foam at 66.5%. Previous studies indicated that the open porosity in alumina foams increased with the increment of total porosity owing to the increased number of interconnections between cells. It indicates that the cell size in ceramic foams is very sensitive to the baking condition and accelerates the cell coarsening [6]. Therefore, the controlling mechanism for porosity can be the alumina grain growth during firing.

In stark contrast to the characteristic of porosity, the bulk density of alumina foam decreases with the rising of alumina loading. The declination of bulk density is due to the increment of porosity in ceramic foams. The bulk density drops dramatically from 1.62 g/mL to 1.27 g/mL between 70 vol.% and 80 vol.% of alumina. This phenomenon possibly caused by heterogeneous of the samples which lead to the coarsening of cells particle [7].

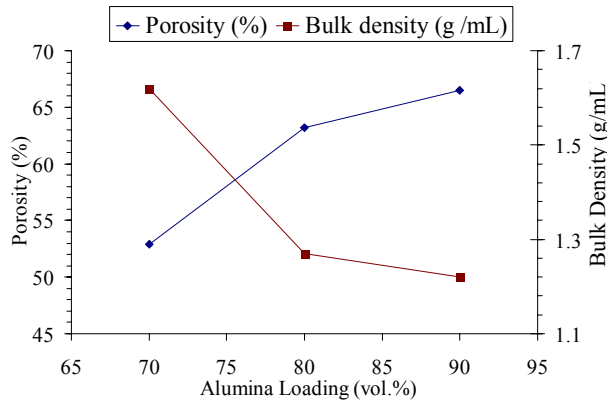


Figure 3: Porosity and bulk density of ceramic foams with different alumina loading

Pore size analysis revealed a wide range of pore diameter for the ceramic foam. The average pore diameter for ceramic foams with 70 vol.% and 80 vol.% of alumina was 51.0 μm and 60.7 μm respectively. However, ceramic foam with 90 vol.% alumina contained smaller pore size with average pore diameter 15.2 μm . Figure 4 and 5 present the SEM micrographs of ceramic foam with 80 vol.% and 90 vol.% alumina loading. These micrographs show the ceramic foams are macroporous with large and small pores size.

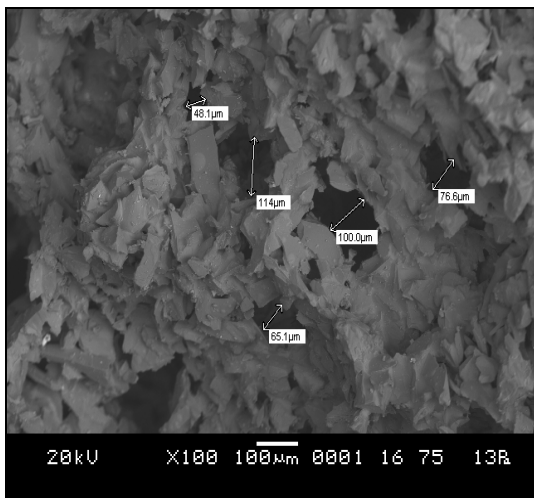


Figure 4: Micrograph of ceramic foam with 80% alumina loading.

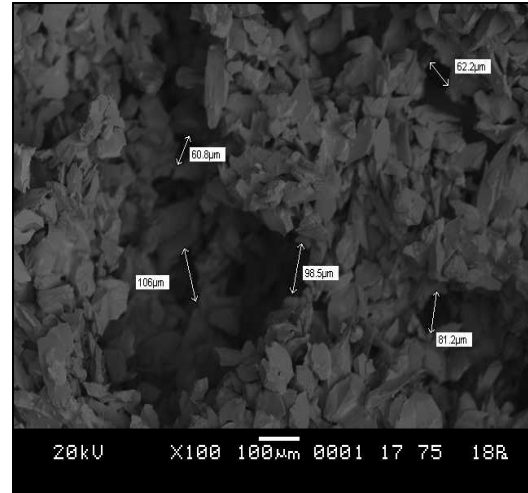


Figure 5: Micrograph of ceramic foam with 90% alumina loading.

Sintered alumina foam obtained by casting method usually consists of pores with different sizes caused by non-uniform size of the bubbles produced in the reaction. High sintering temperature at 1500°C can cause phase transformation in the alumina foam and grain growth resulted in surface morphological changes [8].

3.2 Flexural Strength

Figure 6 shows the graph of flexural strength versus alumina loading. Flexural strength decreases slightly from 3.72 MPa until 2.77 MPa at 90 vol.% of alumina loading. The changes in flexural strength can be related with the increasing of porosity in sintered alumina foam.

Porosity has a significant role to influence the flexural strength of sintered alumina foam. It is well known that the strength of the porous ceramics decreases with the increasing porosity [9]. Figure 7 shows the effect of porosity on flexural strength for the sintered alumina foam.

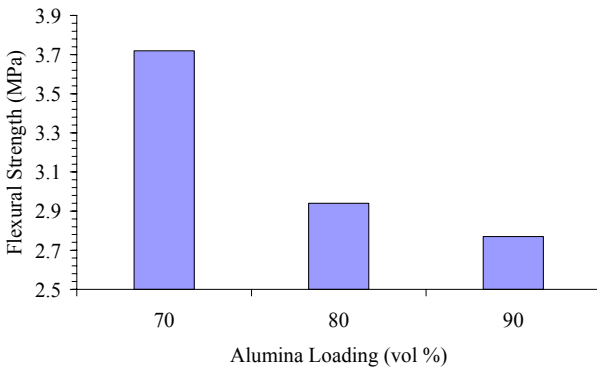


Figure 6: Flexural strength of ceramic foams with different alumina loading

The flexural strength is inversely proportional to the porosity [6]. Previous works indicated that changes of foam strength as a result of grains grew up that led to the foam had more contacting areas. It became the main reason for causing the change of foams strength at that time.

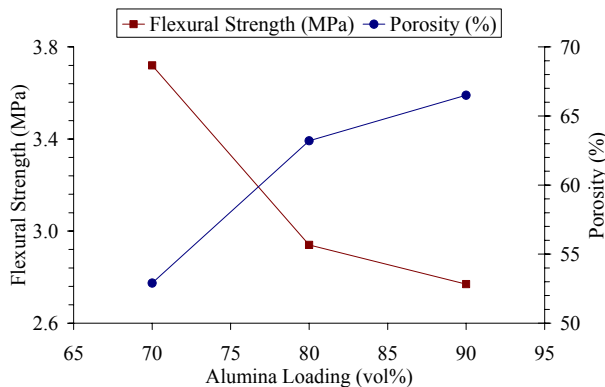


Figure 7: Correlation between flexural strength and porosity of sintered ceramic foams.

3.3 Compressive Strength

A graph of compressive strength versus alumina loading is presented in Figure 8. The testing results for ceramic foams with

alumina loading between 70 vol.% and 80 vol.% show that the compressive strength decreases slowly from 0.11 MPa to 0.08 MPa. As for ceramic foam with 90 vol.% of alumina, the strength continues to drop nearly half until 0.06 MPa.

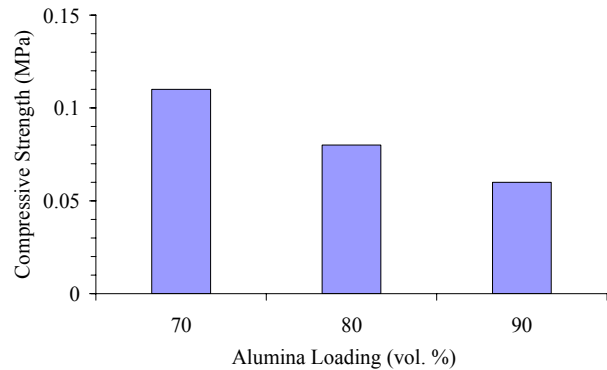


Figure 8: Compressive Strength of ceramic foams with different alumina loading

The declination of compressive strength from 70 vol.% to 90 vol.% of alumina loading not only resulted from the energy losses due to foam alignment, but also from the surface cracks which particularly enhanced by the contaminants during the process. Furthermore, the size and arrangement of pores in alumina foam also affect its strength. As the larger and more numerous the pores, the thinner must be the enclosing walls of the solid material [8,10]. Generally, the strength of ceramic body is almost always lowered by the presence of voids; the greater the porosity, the lower the strength [11].

4. Conclusion

A preparation of ceramic foam using yeast as an organic pore former and ovalbumin as a binder was successfully demonstrated through a simple casting

process. Sintered ceramic foam showed large and small pores size. Based on the results obtained, 70 to 90 vol. % of alumina loading were the suitable composition to fabricate ceramic foam which able to provide 52.9% to 66.5% porosity. Therefore, this ceramic foam exhibits highly potential of development as catalysis and filter. Nevertheless, many others applications may emerge in the near future.

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