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The effect of sago as binder in the fabrication of alumina foam through the polymeric sponge replication technique

Abdul Rashid Jamaludin[a], Shah Rizal Kasim[a], Ahmad Kamal Ismail[b], Mohd Zukifly Abdullah[c], Zainal Arifin Ahmad[a,*]

[a] Structural Materials Niche Area, School of Materials and Mineral Resources, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia
[b] Mechanical Section, Universiti Kuala Lumpur Malaysian Spanish Institute, 09000 Kulim Hi-Tech Park, Kedah, Malaysia
[c] Porous Media Combustion Laboratory, School of Mechanical Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia

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Abstract

Influence of various binders to alumina foam substrate was investigated. The substrate was prepared by the polymeric sponge replication technique using different solid loading ratios and binder agents. The slurries used showed a shear thinning behavior. During replication, a sponge template was coated in alumina slurry, whilst excess slurry was removed manually. The resulting substrate have been studied via the Archimedes method, morphological and phase analysis, and compression test. The total porosities varied between each binder rose from 79.2% to 90.4% depending on their solid loading. The samples with natural binders had a bulky struts and fine surface, contrary to the PVA added samples. Upon compression test, PVA added samples destroyed in fragments whilst natural binders modified samples had a collapsed microstructure but still preserved its structural integrity. Comparison of experimental data and prediction value of Gibson and Ashby model show a quiet big gap between both values.

Keywords: Al_2O_3; Porosity; Morphology; Strength; Fracture

1. Introduction

Ceramics foam has an interconnected cellular structures which attracted a great deal of attention because of the large specific surface area besides having high permeability and ease of flow for both liquid and vapor.[1] These properties were influenced by the nature of materials, shape of open cells, percentage of porosity, and cell size itself. Besides, the mechanical properties of ceramics foam, which is mostly brittle, are closely associated to the density, pore morphology, and material of the skeletal structure.[2]

Foam-based ceramics have usefulness in the area of industrial and environmental applications. These include low and high-temperature filters, biomaterials, membranes, lightweight building materials, and porous radiant burner.[3–7] There are various processing routes available to produce ceramics foam such as tape casting,[8] slip casting,[9] consolidation casting,[10] direct foaming,[11] sacrificial templating,[12] and gel-casting.[13] However, the most popular and versatile methods to fabricate ceramic foam with uniform three-dimensional (3D) interconnected structure is the polymeric sponge replication technique (PSRT).[14–17] Moreover, improvement of PSRT by impregnating pore-former agent for the purpose of pore refinement had been previously studied by some researchers.[15,18]

The PSRT involves an infiltration of reticulated polymeric sponge (template) into a ceramic slurry or suspension with certain viscosity. This is followed by drying and sintering to an appropriate temperature. During the sintering action, the burning of polymer sponge and binder contributed to formation of micro-size pores and cracks (mainly at the edge of the struts). These conditions exposed alumina foam to low strength and fracture toughness, thus limiting their application. In order to overcome

* Corresponding author. Tel.: +60 45996128; fax: +60 45941011.
E-mail address: srzainal@usm.my (Z.A. Ahmad).

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Table 1
Batch composition used in the experiment.

Code	Binder system	Weight percent (wt%)		
		Solid loading (Al_2O_3)	Liquid loading (deionized water)	Binder
Al.5:5.PVA0.8		50	50	
Al.6:4.PVA0.8	Polyvinyl alcohol (PVA)	60	40	8
Al.7:3.PVA0.8		70	30	
Al.5:5.S0.8		50	50	
Al.6:4.S0.8	Sago	60	40	8
Al.7:3.S0.8		70	30	
Al.5:5.T0.8		50	50	
Al.6:4.T0.8	Tapioca	60	40	8
Al.7:3.T0.8		70	30	

Symbols (Al, $\#^1:\#^2, \#^3$0.8) of the sample notations are: “Al” is alumina, $\#^1$ and $\#^2$ are solid and liquid loading, respectively whilst $\#^3$ represent type of binder. The number “0.8” refer to amount of added binder.

this situation, several improvement have been proposed, including varying the sintering temperature of alumina foam[19] and recoating of alumina foam.[14,20] However, the improvement in coating slurry is rarely discussed. The alumina slurry used for PSRT usually contains binders and other additives (surfactant, stabilizer, etc.). The purpose of binders typically to increase plasticity and assists the body forming aside functioning as bonds between particles.[21] Besides facilitates the coating process and integrity of the coating, binders also act as pore forming agent.

Evidently, by impregnating certain binder agent the strength of ceramic foam can be improved. Nowadays, corn starch and agar[22] potato starch,[23] wheat starch,[24] natural fibers,[25] and rice husk[26] were utilized as natural binder and pore former. However, the occurrence of sago (*Metroxylon sagu*), is currently neglected. Sago starch is easy to gelatinize, acceptably high viscosity, low gel syneresis, and ease of molding.[27] These benefits makes it preferred as thickening agent in food and adhesive industry.[28] Previously, sago was compared with commercial synthetic binder (PVA) in the fabrication of porcelain foam.[15] Therefore, an idea to improve the strength of alumina foam by incorporation of sago binder was proposed in this paper. Furthermore, the effect of sago in the fabrication of alumina foam is not widely explored. Besides that, this work can be used as reference to explore the possibility of using sago to fabricate other types of cellular ceramic in the near future.

2. Experimental procedure

2.1. Materials

Alumina powder with an average particle size of 16.57 μm was supplied by Sulzer Metco (Westbury) Inc., USA. Synthetic binder, reagent grade polyvinyl alcohol, 98–99% hydrolyzed, medium molecular weight (PVA, C_2H_4O) was purchased from Alfa Aesar, GB. Meanwhile, the treated natural binders; tapioca powder and sago pearl were acquired from the local grocery shop with average particle size of 13.85 μm and 99.43 μm, respectively. A flexible commercial polyurethane (PU) polymer sponge (CCT Automation Sdn Bhd) with an average open cell size of 20 ppi (pores per linear inch) was chosen as the template. The sponge was cut into smaller pieces (100 mm × 100 mm × 25 mm) prior to replication process.

2.2. Processing

The solid content of the slurries were varied at 50, 60, and 70 wt% and the amount of binder was fixed at 8 wt% from total solid loading. Prior to the preparation of slurries, deionized water was heated to between 60 and 70 °C for dilution of the sago, tapioca, and PVA particles, respectively. Alumina powder was then added to the diluted solution according to the subjected solid loading content. All compositions (Table 1) were mixed for 24 h using polyethylene bottle, alumina balls were used as the mixing media. The values of viscosities for all slurries were measured using a viscometer (Polyvisc, Viscostar-H, GB) at different shear rates.

The replication process begins by fully submerging the sponge template whilst being compressed in the alumina slurry to ensure adequate filling of slurry into the template’s cell, and purging out any entrapped air. Subsequently, the impregnated template was taken out, squeezed manually by hand and passed through two preset rollers. These actions were repeated for three times to ensure satisfactory filling of slurry, to remove excess slurry as well as to achieve a well-distributed and uniform coating of the template.

2.3. Drying and sintering

The coated template was dried at room temperature for 48 h for slow drying before being put in an oven for another 24 h at 80 °C. The dried templates were slowly sintered in an electric furnace (Unitek Muffle Furnace 1600) in normal atmosphere according to the schedule as follows: the furnace was operated from room temperature up to 500 °C at 5 °C/min (soaked for 1 h) and then further heated up to 1600 °C for 2 h before cooled down to room temperature.