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Porous Alumina-Zirconia Prepared by Foam Technique for Applications as Cooling Systems of Artificial Satellites

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Abstract. The interest in porous ceramics has increased concurrently with new processes and new applications. This material has been used in several industrial applications such as filters, catalysis and sensors. The objective of the present investigation was to produce porous alumina with 3 % mol yttria stabilized zirconia in tetragonal crystalline structure (Y-TZP). This material will be used in cooling systems of satellites, due to its mechanical properties and chemical inertia. To obtain the porous ceramics was used the direct foaming technique, which is a method based on the preparation of a stable foam slurry and a slurry of alumina and zirconia that are later mixed and blended for incorporation of air in the mixture. The sintered ceramics was characterized by scanning electronic microscopy, mercury porosimetry and permeability measurements. The porous Al_2O_3–ZrO_2 ceramics obtained showed high porosity and uniform microstructure with 20–100 μm open pores. The results from these alumina zirconia composites showed a potential to apply in heat pipes.

Introduction

Porous structures are currently used in loop heat pipes (LHP). The porous structure is employed to generate the capillary pumping pressure required to transport a working fluid throughout two-phase heat transfer loops. In the space technology one of the most promising applications rely on satellite cooling systems because they maintain the temperatures between narrow operating limits and use no moving parts, working on a passive basis.

Those systems can operate passively by means of capillary forces generated in the porous structure, as heat is transferred from a high temperature source by conduction to the structure causing the evaporation of a working fluid that is in its pure state [1]. In recent years, a great deal of interest has been given in the use of wick in the evaporators of heat pipes. Wicks can be made from plastic, metals or ceramic by powder processing technique that involves the sintering of the powder material at the temperature close to its melting point.

For the ceramic wicks, different techniques are used to produce the porous materials, such as sacrificial template, replica, and direct foaming methods [2]. The choice of the technique depends on the desired structure and pore size.

The sacrificial template technique usually consists of the preparation of a biphasic composite comprising a continuous matrix of ceramic particles or ceramic precursors and a dispersed sacrificial phase that is initially homogeneously distributed throughout the matrix and is ultimately extracted to generate pores within the microstructure. This method leads to porous materials displaying a negative replica of the original sacrificial template, as opposed to the positive morphology obtained from the replica technique described above.

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The replica method is based on the impregnation of a cellular structure with a ceramic suspension or precursor solution in order to produce a macroporous ceramic exhibiting the same morphology as the original porous material [3].

In direct foaming methods, porous materials are produced by incorporating air into a suspension or liquid media, which is subsequently set in order to keep the structure of air bubbles created. In most cases, the consolidated foams are afterwards sintered at high temperatures to obtain high-strength porous ceramics [4]. The total porosity of directly foamed ceramics is proportional to the amount of gas incorporated into the suspension or liquid medium during the foaming process. The pore size, on the other hand, is determined by the stability of the wet foam before setting takes place. Wet foams are thermodynamically unstable systems which undergo continuous Ostwald ripening and coalescence processes in order to decrease the foam overall free energy. These destabilization processes significantly increase the size of incorporated bubbles, resulting in large pores in the final cellular microstructure. Therefore, the most critical issue on direct foaming methods is the approach used to stabilize the air bubbles incorporated within the initial suspension or liquid media.

The objective of this work was to produce porous ceramic nanostructured composite of alumina and yttria stabilized zirconia (Y-TZP) using the direct foaming method. This technique generates wicks with homogeneous porosity and interconnected pores, which is necessary for the good performance of the LHP.

Experimental procedures

Materials. Commercially available powders used in this work were the α Al_2O_3 (Op1000 - Alcan-USA) and ZrO_2 with 3% mol yttria stabilized of Shandong Zhongshun Sci. & Tech. Dev. CO. Ltd, with average size of particles between 20 and 30 nm, characterized by an equipment of the mark CILAS. These compositions were prepared with mixture. Mechanical milling was performed in isopropilic alcohol with 50wt% of solids content for 3h.

After the mixture Al_2O_3 and ZrO_2 was prepared aqueous suspension, using diammonium citrate – DAC (Sigma-Aldrich), tenor of $0{,}31x10^3$ g/m^2, was used to shift the alumina isoelectric point toward slightly acid pH range of 8-9. For a better consolidation of the ceramic, sodium alginate (Fluka Chemie, Switzerland) was used in tenor of 0,15%-p. The suspension was agitated for 30 min.

The anionic surfactant (Cognis, Brazil) foam was prepared apart. This aqueous solution was mixed with a blender to incorporate largest quantity of air. Later the stabilizer and viscosificant were added for physical and chemical stabilization.

The stable foam was added to the ceramic suspension and then the mix was homogenized. After this stage 0,4% -p of hydroxyaluminum diacetate – HADA (Aldrich, EUA) The suspensions were mixed thoroughly during the addition of HADA so as to prevent particle agglomeration. The suspension was then cast in molds and left to air exposure for 8hs.

The sintering was accomplished in 1400 ^oC and 1500^o C for two hour, using heating rate of 2 ^oC/min.

Figure 1 shows the flow chart schematics of all stages in the acquisition of porous ceramics.

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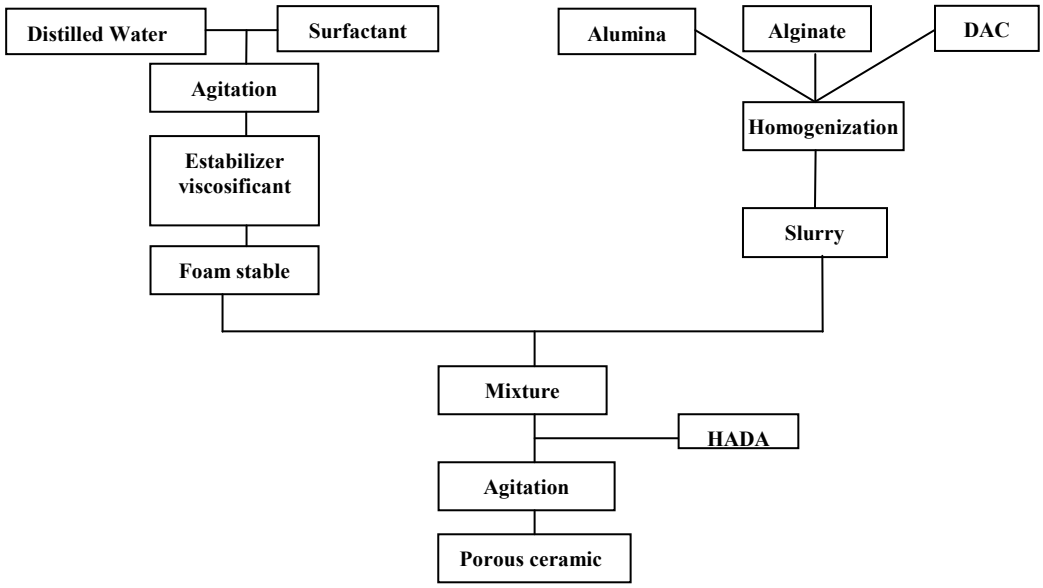


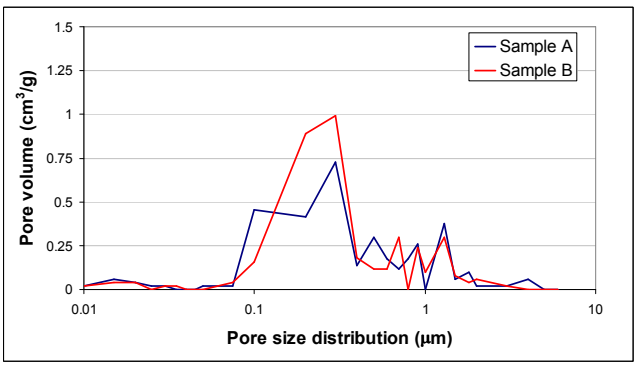
Fig. 1 – Porous ceramics process flow chart

Results and discussion

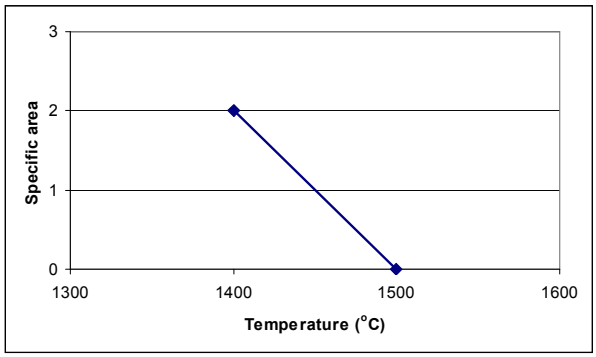
Porosimetry Hg. The figure 2 (a) show the results of porosity after burn of 1400°C e 1500°C to 2h.

For materials burned at temperature of 1500°C a small reduction of porosity is verified due to materials density increase. However for analysis mercury porosimetry the samples were prepared with even volumes of foam and ceramic suspension, that is, Vfoam/Vsusp =1. In this technique high porosity with small pore diameter can be pointed out. This characteristic could be confirmed from the analyses of the results obtain mercury porosimetry

A straight relationship between the increase in sintering temperature and the corresponding reduction of the pores specific area was observed, i.e., the ceramic becomes denser and consequently presenting lower porosity Figure 2 (b).



(a)



(b)

Fig. 2 - Accumulative pore size distribution, sample A 1500°C and sample B 1400°C. (b) Specific surface area of ceramics sintered at 1400°C and 1500°C.

The analysis of the X – ray diffraction presented the presence of the two phases: Al_2O_3 and ZrO2. One proved that in the sintering temperatures two components had formed a solid solution.

Image analysis. The image analysis technique was used to determine the pore size distribution of the microstructure. The levels of porosity as well as its pore size distribution were measured on images acquired by scanning electronic microscopy (SEM). Figure 3 shows the fracture surface of ceramics bodies sintered at 1400°C and 1500ºC where the small different porous size can be observed.

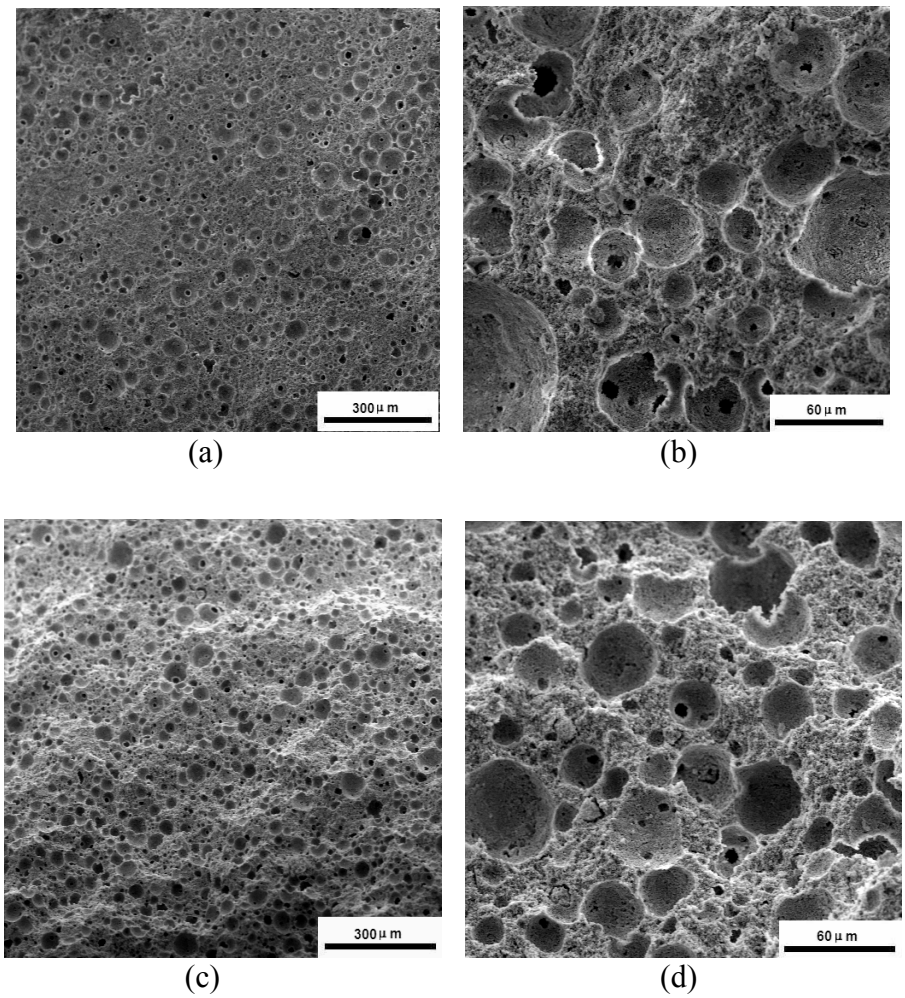


Fig. 3 - SEM of products sintered at different temperatures. (a), (b) 1400°C and (c), (d) 1500°C.

Conclusions

In case increase in material porosity is required, the proportion in foam volume in the ceramic suspension can be altered. It must, however be considered that the increase in porosity acts directly in mechanical resistance material.

The results obtained for specific area, distribution curves of pore size and microstructure, crystalline phases showed that the Al_2O_3- ZrO2 ceramic presented a satisfactory porosity level to be applied in heat pipes, loop heat pipes (LHP). It is important to control the pore size for the capillary pumping structures. The smaller the pores size, the higher the capillary pumping pressure.

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Acknowledgments

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