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Different methods to synthesize ceramic foams

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Abstract

Ceramic foams are cellular structures composed of a three-dimensional network of struts. These highly porous materials have a lot of applications as filters for molten metal, hot gas and diesel engine exhausts filters, catalyst carriers, biomaterials, thermal insulators for furnaces and aerospace applications, gas combustion burners and lightweight building materials.

As the application domains for these materials vary widely, the ultimate properties of the foam posed by the specific use are also diverse. As a consequence, different routes for the production of these foams have been developed, each with their own window of properties.

In this contribution we focus on three manufacturing techniques: (1) reaction bonded modified polyurethane technique, (2) gel casting and (3) a hollow beads method. The flow sheets of these manufacturing routes are explained with the main accent on the shaping aspect of the method.

The advantages and disadvantages of these methods are described on the hand of their structure, characterized by field emission scanning electron microscopy (FESEM), computer-assisted microtomography (μCT), image analysis (IA) and mechanical tests.

Finally, some examples of ceramic foam projects are presented as the recycling of Al, the trapping of the particles of diesel engines, and the synthesis of scaffolds for bone substitutes.

Keywords: Ceramic foams; Synthesis; Characterization; Applications

1. Introduction

Ceramic foams can be produced following different manufacturing routes.[1] The three methods which are discussed here starts from a ceramic powder slurry which is transformed in solid ceramic foam. The most conventional method to produce ceramic cellular structures is the reticulated sponge method or replica technique. Here a polymeric sponge is coated with a ceramic slurry, dried, calcined and sintered.[2,3] An alternative method for obtaining a ceramic foam is gel casting, in which a ceramic suspension to which a foaming agent has been added is foamed by mechanical action.[4,5] A third route, the hollow beads method, consists of the coating of different organic or polymeric shapes with a ceramic slurry. After packing in a mould, the coated beads are joined together by a second slurry coating. As the manufacturing parameters determine the ultimate properties of the foam structure and thus the domain of application, a characterization of the process parameters, the microstructure and the internal architecture of the foam is essential for the manufacturers and end-users. Therefore, different analysis techniques are used to characterize the synthesis procedure: laser diffraction, zeta potential and viscosity measurements and thermogravimetry. An analysis of the microstructure of the foam was done using field emission scanning electron microscopy (FESEM), image analysis and computer-assisted X-ray microtomography. Also mechanical tests, bending and compression, were performed.

2. Experimental procedure

As model powder, we used Al_2O_3 powder (CT 3000 SG Alcoa). For the reaction bonded (RBAO) material, an Al/Al_2O_3 mixture was made in a ratio 40/60 by weight. The Al powder (Baudier Poud. Met.) has a mean particle size of 8 μm. Darvan C (Vanderbilt Co.) was the dispersant agent. Ceramic foams by gel casting were realized starting from slurries containing agar as gel former and Tergitol TMN 10 (Fluka) as foaming agent.

Several sacrificial cores (peas, styrofoam granules and seeds) were applied.

For the modified PU-replica technique, the PU template (kindly supplied by Recticel, Wetteren, Belgium) was coated with the powder slurry and after squeezing out the excess slurry, the structure was dried. The PU was calcined and the Al fraction

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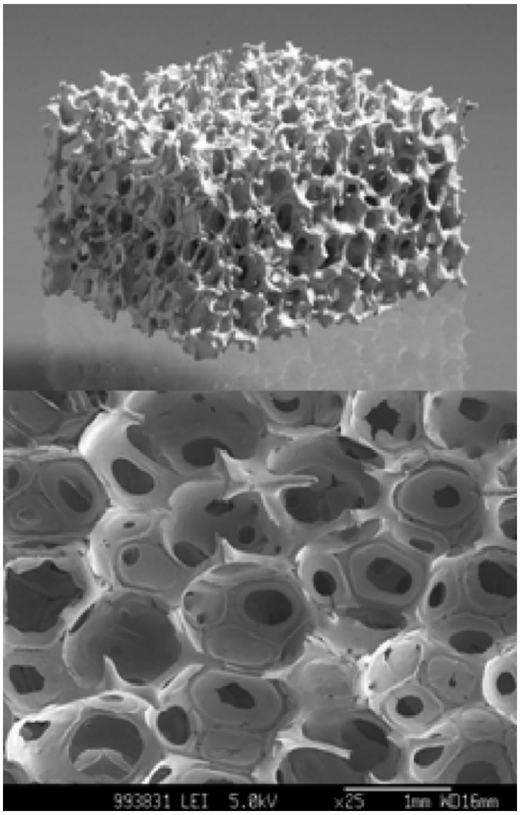

Fig. 1. Ceramic foam with his special micro–macro structure.

was oxidized. Finally, the sintered material was followed and machined to the right dimensions.

For the gel casting method, a powder slurry was prepared containing a foaming and gelling agent. The second step was the mechanically foaming of the suspension which was casted in mould and gelled. Hereafter, the structure was thermally treated: the drying, the calcining and the sintering.

The hollow beads method starts with the coating of sacrificial cores, which were dried and eventually calcined. Hereafter, the hollow cores were packed together in a mould and joined by a second slurry casting. Finally, the components were dried, calcined and sintered.

3. Results and discussion

Examples of components realized with these three methods are illustrated in Figs. 1–3. RBAO foams with 3p bending strength up to 8 MPa could be realized for materials with a density of 25% of the theoretical density. The big advantaged is that very open structures without windows could be realized with sufficient strength (up to 3 MPa in 3p-bending). Moreover, the PU-replica technique allows to vary the cell size by changing the PU template. Fig. 4 summaries the structural measurements performed on the different foams produced with the replica technique.[6] The results of the visiocell and the image analysis are in reasonable agreement when corrected for the two-dimensional aspect of the later technique. The μCT indicate for the most specimens a lower value. Probably it can be explain by a difference in threshold procedure.

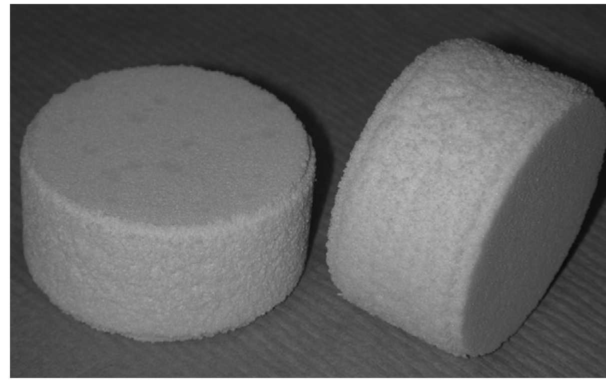

Fig. 2. Gel casted Al_2O_3 foam.

In contrast with the foams produced with the PU-replica technique, gel-casted foams have dense struts but their cell size can only be varied in a limited way. Strong foams can be obtained in the cell size range of 50–800 μm. Fig. 5 shows the μCT analysis of a gel-casted foam with, respectively, the measurement of the cell size and the strut thickness.

The hollow beads method[7,8] allows the production of different shapes just by using different building blocks. Important here is that the sacrificial cores can be wetted by the ceramic slurry.

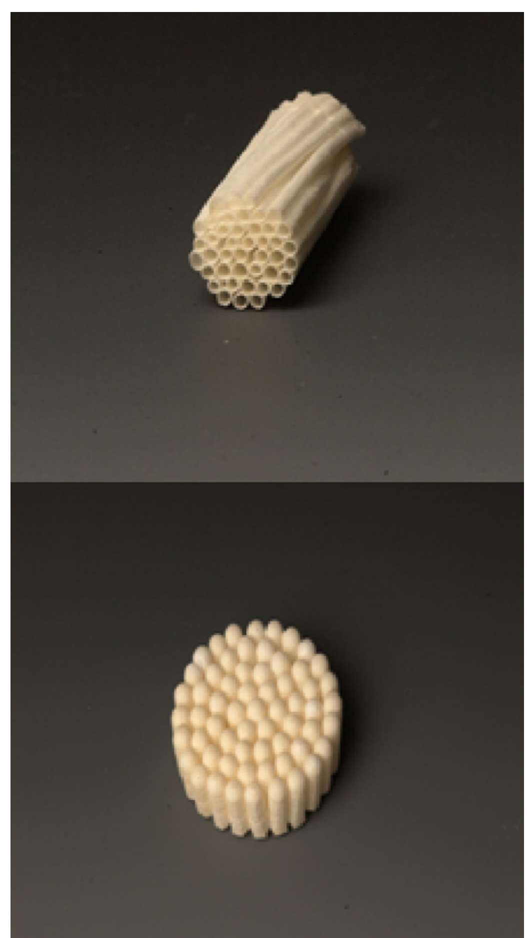

Fig. 3. Examples of the hollow beads method.

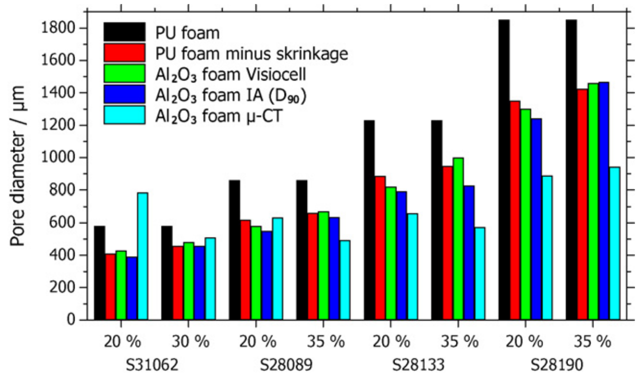

Fig. 4. Overview of results on the cell size of alumina foams prepared by PU replica technique using PU foams with increasing cell size, each coated with a low (20 vol.%) and a highly viscous (30–35 vol.%) suspension.

The strength of the packed beads component can be varied in function of the density. It can easily be performed by repeating the second slurry casting increasing the density between the beads.

The different foams were used in several applied projects. One of them is a project for the recycling of Al. In that EC-project, different separation techniques are tested out to separate intermetallic components from the molten Al. Mullite foams prepared with the PU template method were used due to the need of foams with relative large pores.

Another foam project aims at trapping soot particles from the diesel engines. To obtain a filter with sufficient efficiency but with a minimum of pressure drop, the density and the cell sizes of the foam were adapted. Fig. 6 shows the foam surface at the inlet and outlet side of the diesel engine.

In a third project, foams produced by the different techniques were applied to produce scaffolds for bone replacement. We try to produce foams of materials which are allowed in the medical world: different calcium phosphates as hydroxyapatite and beta TCP, and different metals as Ti, Ti_6Al_4V, stainless steel, and NiTi.

One of the objectives is to mimic the strength and the *E*-modulus of the trabeculair bone. The trabeculair bone has a

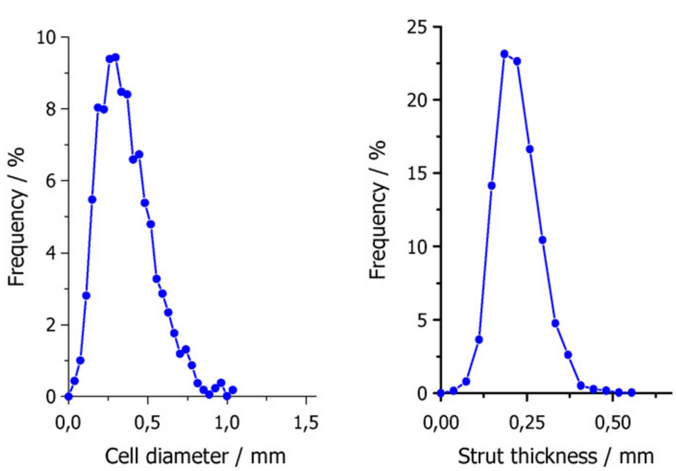

Fig. 5. Cell diameter and strut thickness measurement by μCT (kindly provided by Scheffler and Zeschky, University of Erlangen).

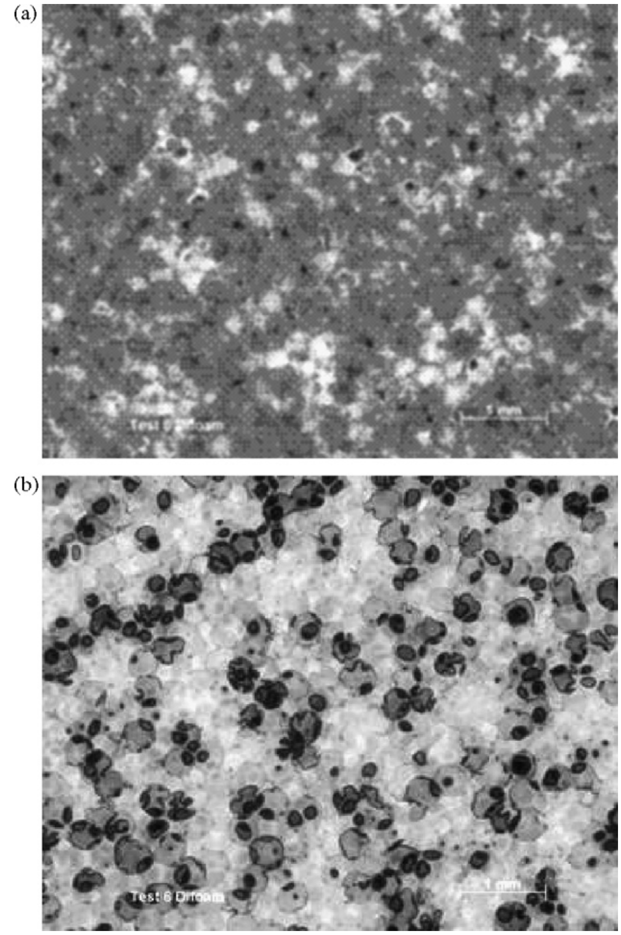

Fig. 6. The inlet side (a) and the outlet side (b) of the soot filter.

E-modulus between 0.2 and 2 GPa and a compression strength between 15 and 50 MPa. These values can easily be realized with metal foams also having sufficient strain values.

4. Conclusions

It was shown that ceramic foams can be manufactured by different methods: a modified RB replica technique, gel casting with biopolymers and the hollow beads method. In this way we can get for every application a foam structure with the right parameters.

The structural and mechanical properties were analyzed with different techniques and it was demonstrated that these foams could be used in different projects: as filters for molten Al, as soot filter for diesel engine cars and as scaffold for bone replacement.

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