GERMANY

Porous Ceramics in Medical Engineering: Requirements, Fabrication Methods and Characteristics

The two-days Conference of the German Ceramic Society (DKG) focussed on "Porous Ceramics – Fabrication Processes and Applications". Latest processing techniques and findings concerning development, processing and machining of products made of or with the help of ceramic materials were addressed. The cfi-Awards 2017 were also presented.

Fig. 1
G. Falk, Chairman of the DKG-FA3 Process Engineering during the welcome address

Keynote papers

Additive Manufacturing of Ceramics Using Inorganic Polymers was addressed by P. Colombo (Department of Industrial Engineering, University of Padua/IT). He provided an overview of direct and indirect additive manufacturing methods suitable for ceramics. The main feature of these methods is that the material is built up in the required form of the end-product. This is realized by means of inkjet printing (IP), robocasting/direct ink writing (DIW) and fused deposition modelling (FDM).
The indirect methods include: powder-bed 3DP, selective laser sintering (SLS), stereolithography (SLA), laminated object manufacturing (LOM) and digital light processing (DLP).

Porous Ceramics: On Industrial Scale! was presented by U. Werr (Rauschert Heinersdorf-Pressig/DE). For the production of porous ceramics on industrial scale, the following methods are applied: use of place holders, stopping the sintering process at an early stage, use of gap grading and moulding of carrier structures. Porous ceramics are regarded as a two-phase system (ceramic matrix and pore volume).
Typical applications are: radiation panels, evaporators, filters, catalyst substrates, salt bridges for pH combination electrodes and high-temperature insulating materials for furnace engineering.

Ceramic Membranes – Latest Developments: Nanofiltration in the Treatment of Waste Water from Ceramic Production and in Gas Separation was reported by V. Prehn (Rauschert Kloster Veilsdorf/DE). Ceramic membranes offer essential advantages in material separation: chemical, physical and thermal resistance, suitability for sterilization in an autoclave and backwashing, resistance to abrasives, high filtrate flows, considerable aging resistance, bacteria resistance (bioinert) and optimum ability for regeneration. New standards in nanofiltration today are: pore sizes of 0,9 nm and retention in aqueous solution at 450 Da.

Characterization and Simulation of Porous Ceramic Structures was discussed by T. Fey (Institute of Glass and Ceramics, Friedrich-Alexander University of Erlangen-Nuremberg/DE).

Replica processes

Fabrication of Open-Celled Aluminium-Nitride Foams with the Reticulate Process was explained by U. Betke (Institute of Materials and Joining Technology, Otto-von-Guericke-University of Magdeburg/DE). The process starts with aqueous AlN dispersions. Y_2O_3 is added as a sintering aid. Mechanically stable ceramics with a total porosity of 92 vol.-% can be produced.

Framing Ceramic Foam Filters – Product Properties and the Resulting Potential was presented by A. Baier (FOSECO Foundry Division, Vesuvius GmbH/DE). It is possible to stabilize ultrafilters with frames, and in this way to enable the use of relatively small and/or fine filter materials. In this way the pressure loss can be reduced, and accordingly the productivity of the filters increased. In foundries, potential savings amounting to 15 000–25 000 EUR/a have already been proven.

Fabrication and Characterization of Transparent SiO_2 Sponges for Applications in Water Treatment was described by F. Löffler (Institute of Applied Materials (IAM-KWT), KIT/DE). These transparent, open-celled glass structures are to be used to distribute light as uniformly as possible in a medium. The paper merited a cfi-Award (Institutes) and has been published in cfi Ber./DKG **96** (2018) [3].

Direct foaming processes

Application of the Direct Foaming Process for the Fabrication of Novel Foam

Ceramics was presented by O. Lavrentyeva (Morgan Advanced Materials Haldenwanger GmbH/DE). As a simple, industrially scalable and safe method in terms of workplace health and safety, this mechanical process is suitable for the fabrication of ceramic foams. It is possible to obtain an exceptionally homogeneous pore structure, which has a positive effect on the physical properties. The paper merited a cfi-Award (Industry).

Subtractive processes

Nanoporous Alumina – a Platform for Multifunctional Applications was described by P. Göhring (SmartMembranes/DE). Nanoporous alumina ceramics are formed with an anodizing process from pure aluminium. This enables the introduction of a controlled arrangement of extraordinarily dense and regular nanopores in a planar membrane. The high porosities and aspect ratios of the materials are interesting for applications e.g. in biotechnology and sensor engineering.

New Oxide Fibre Composites with Porous Matrix was presented by G. Puchas (Department of Ceramic Materials, University of Bayreuth/DE). Oxide fibre composites combine lightweight concepts as well as high-temperature and corrosion resistance. In addition, comes a quasi-ductile fracture behaviour.

A freeze-drying process and a process based on conventional drying were developed for the fabrication of these components (publication in cfi Ber./DKG **96** (2018) [4–5], in print).

Additive processes

Freeze Foam – the Somewhat Different Cellular Structure was presented by T. Moritz (Fraunhofer-IKTS/DE). Freeze foaming is a novel, particularly environmentally friendly process in which an aqueous suspension or paste is exposed to negative pressure in the vacuum chamber of a freeze dryer. Blowing agents for foam formation are exclusively dependent on the process. After removal of the suspension medium by means of freeze drying, a predominantly open-pored foam structure with bimodal pore size distribution is obtained. Wide-ranging potential applications include thermal insulation or bone substitute material. The paper merited a cfi-Award (Institute).

Slurry/melt infiltration

High-Porosity Oxide Ceramics as a Matrix System for Ceramic Fibre Composites was addressed by H. Richter (German Aerospace Centre/DLR, now SGL Carbon/DE). He explained the requirements for high-purity oxide ceramics for use as matrix systems in ceramic fibre composites. To be able to evaluate this, mechanical tests are conducted for indirect identification of relevant material parameters. Predicative estimation of the material properties based on micromechanical simulation is also applied.

Phase separation

Nanoporous Glass Membranes – Renaissance of the Porous VYCOR Glass was presented by B. Oberleiter (Boraident/DE). Porous glass membranes are fabricated by means of thermal phase separation and chemical extraction with subsequent shaping of speciality glasses with suitable composition. This goes back to the VYCOR glass developed back in 1930. With this method, the pore diameter can be defined. That is also possible in nanometer range – for this reason these materials can be used for material separation and filtration. Thanks to their optical properties, they are also used in photosensors and photocatalysis.

Pyrolysis and sintering processes

Tailored C-Precursors for the Formation of a Porous Carbon Matrix in SiC/C Composites – New Synthesis Strategies for

Fig. 2
P. Colombo (Department of Industrial Engineering, University of Padua) during the opening paper

Carbon Hybrid Materials was explained by S. Spange (Polymer Chemistry, Institute of Chemistry, Chemnitz University of Technology/DE). SiC/SiC composite materials are ceramic materials that thanks to their resistance in high-temperature oxygen

Fig. 3
Presentation of the cfi-Awards 2017 (f. l. t. r.): T. Moritz, T. Fey, F. Löffler, M. Götz, O. Lavrentyeva, G. Falk, and K. Scharrer

atmosphere are used in aerospace applications. They can be fabricated with the liquid siliconizing process. Synthesis strategies for porous carbon materials are cationic polymerization of carbonates and the hydrolysis of catechol oxalate.

Modification of Porous SiCN Ceramics with Metals for Catalytic Applications was addressed by G. Motz (Department of Ceramic Materials at the University of Bayreuth/DE). A widening of the property profile of porous SICN ceramics with metals can lead to selective adjustment of the electric and thermal conductivity, but also special catalytic properties. With the addition of polystyrene or polyethylene particles before pyrolysis, the porosity can be selectively adjusted.

Porous Ceramics in Medical Technology: Requirements, Fabrication Methods and Characteristics was reported by M. Götz (CeramTec/DE). The goal is to develop porous, purely ceramic implants from the cranium to the toe joint, which offer improved mechanical stability and/or osseointegration compared to existing solutions. This is to be achieved on the basis of a flexible and rugged foaming process for ceramics. The paper showed the specific medical requirements such as excellent biocompatibility with osseointegration as well as the necessary patient safety of the implants and named regulatory preconditions for later application. Against this background, the direct foaming process has been established as an ideal method. With this process, surfaces can be textured, and volumes structured, and therefore highly complex implant geometries realized. The paper merited a cfi-Award 2017 (Industry).

Characterization methods

Characterization of Porous Structures by means of Gas Adsorption and Hg-Porosimetry was reported by J. Adolphs (POROTEC/DE). Both methods return as results surface and pore size distributions. In gas adsorption, at condensation temperature gas molecules are deposited on the surfaces and prematurely condense in the pores depending on their size. In Hg-porosimetry, non-wetting mercury is pressed into the pores. The pressure applied is inversely proportional to pore size.

3D-Characterization of Materials by Means of Synchrotron, X-Ray, Neutron and Focussed Ion Beam Tomography was presented by T. Arlt (Berlin University of Technology, Institute of Material Sciences and Technologies/DE). In past years, research on energy materials has become one of the most important applications for synchrotron X-ray imaging. Most materials used for energy storage and conversion have a complex three-dimensional structure and morphology on nano- and microscale. To obtain knowledge about these materials, radiographic and tomographic measurement systems are excellently suitable.

High-Resolution NanoCT for the Characterization of Complex Porous Ceramics was explained by F. Sieker (GE Sensing & Inspection Technologies GmbH/DE). With computer tomography, a trouble-free analysis method is available for the interior of material structures.

Every difference in density and material leads to an absorption difference in the X-ray beam and can be imaged and evaluated. Accordingly, the method can be used for the analysis of cracks, pores, inclusions and deviations in the geometry of different materials.

Modelling porous ceramics

Microstructure and Electrolyte Conductivity of Porous Ceramics was addressed by D. Penner (ZHAW Zurich University of Applied Sciences/CH). The development of models for predicting the influence of changes in microstructural parameters leads to ideas on how microstructures can be empirically adjusted to optimise their required functionality. The method was demonstrated based on the example of the optimization of a ceramic diaphragm for use in pH electrodes (published in cfi Ber./DKG **96** (2018) [3]).

Stochastic Modelling of 3D-Microstructures for the Prediction of Microstructure-Property Correlations of Porous Ceramics was discussed by V. Schmidt (University of Ulm, Institute of Stochastics/DE). As in microstructure analysis, the capture of 3D-image data is very complex, with stochastic 3D-modelling, virtual but realistic microstructures are generated. With reference to the example of ionic and electric conductivity in real porous microstructures of solid oxide fuel cell anodes, the solid phase of which consisted of nickel as well as ceramics, the method was validated.

Application in water filtration

Ceramic Membranes in Monolithic Design – Applications in the Industrial Waste Water and Potable Water Treatment was addressed by C. Göbbert (Nanostone Water GmbH/DE). Recent developments of ceramic membranes with increased membrane packing densities and lower production costs make these more competitive against polymer membranes in the market for waste water and potable water treatment. This was only possible thanks to the development of a semi-mechanized production process.

The **Filter in Tank System – a Rotating Disk Filter in the Process Reactor** was presented by F. Ockert (GEA Westfalia Separator Group/DE). This system is focussed on downstream processes after fermentation in the pharmaceuticals industry. Several steps (harvesting, washing and filtration) are reduced to one step. In addition, the yield can be increased by 35 %. Compared to traditional cross/flow filtration, energy consumption is reduced by 75 %.

cfi-Awards 2017

The awards were presented in the name of the jury (Björn Schunck and Guido Falk) by Karin Scharrer (Göller Verlag Publishing House). The following were awarded EUR 500 prize money:

Industry:

- M. Götz (CeramTec) for the paper "Porous Ceramics in Medical Technology: Requirements, Fabrication Methods and Characteristics" and
- O. Lavrentyeva (Morgan Advanced Materials Haldenwanger GmbH) for the paper "Application of the Direct Foaming Method for the Fabrication of Novel Foam Ceramics".

Institutes:

- T. Moritz (Fraunhofer-IKTS) for the paper "Freeze Foam – the Somewhat Different Cellular Structure" and
- F. Löffler (Institute of Applied Materials (IAM-KWT, KIT) for the talk "Fabrication and Characterization of Transparent Sio_2 Sponges for Applications in Water Treatment".

The autumn symposium 2018 on the subject of Ceramics in Energy Technology – Fabrication Processes and Applications is to be held at the Heinrich-Lades Hall in Erlangen/DE on 06.–07.11.2018 (www.dkg.de).

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