GERMANY

Additive Manufacturing: Processes and Applications in Ceramics

On 1.–2.12.2015, the Process Engineering Committee of the German Ceramic Society (DKG) organized a symposium on Additive Manufacturing in the Stadthalle Erlangen. In order to map development in this new technology a panel debate was organized. "Szene Additiv" is a new DKG-platform for this topic.

Talks

T. Reiher/Direct Manufacturing Research Center – University of Paderborn reported on "FE-Supported Optimization and Design of Structural Components with the Application of Additive Manufacturing". Thanks to the wide freedom of design, the process offers interesting potential for optimizing the stiffness and weight of components. The possibility of manufacturing highly complex structures without any restrictions with tool concepts enables optimum utilization of the materials and therefore significant product optimization derived from material and weight savings. In design, FE-based topology optimization is used.

L. Wrede/DIN e.V. – Berlin spoke on "Standardization of Additive Manufacturing – Basis for Industrialization". The technical committee ISO/TC261 is responsible for the national work in standardization for Additive Manufacturing. Last year, on European level, the CEN/TC 438 was set up with the same objective. An international approach is required overall in order to avoid duplicate standards. Since 2011, there has already been cooperation between DIN and ASTM. The objective of these efforts is to cover the entire process chain (e.g. preparation, shaping, inclusive relevant test methods).

"Direct and Indirect Selective Laser Sintering (SLS) of Ceramic Microcomponents" was presented by H. Exner/Laser Institute – Mittweida University of Applied Sciences. He discussed laser microsintering – a variation on selective laser sintering with much improved resolution. It can be used for alumina or silicon carbide or even cermets. Submicron particles are used to build up the components.

The "Additive Manufacturing of Ceramics by Means of Extrusion Freeform Fabrication (EFF) and Laminated Object Manufacturing (LOM)" was presented by N. Travitzky/Material Sciences – University of Erlangen-Nuremberg as methods for low-cost fabrication of near-net-shaped components for structural and functional ceramics.

EFF is a method to build up freeform components with water-based pastes. LOM is a fabrication process from additive manufacturing with which a workpiece is formed layer-by-layer from films. Every new layer is laminated onto the existing layer and then the contours are cut.

"New Aspects and Possibilities of Additive Manufacturing of Ceramics by Means of Direct Inkjet Printing" was presented by R. Telle/Institute of Mineral Engineering at RWTH University of Aachen. The binderless powder-bed-free inkjet printing of suspensions enables the simultaneous three-dimensional build-up of shapes from a wide range of materials and material combinations without complex debinding of organic components. Thanks to the high possible solids content in aqueous suspensions (>30 vol.-%) in thermal inkjet printing, green and sintered densities can be achieved that match those of dry-pressed components.

W. Kollenberg/WZR ceramic solutions GmbH-Rheinbach reported on "Ceramics and Multi-Material 3D-Printing – Current Situation and Prospects". The multi-material 3D-printing offers the unique possibility to process several materials to one component in one work step. Not only is maximum individualization achieved, the process also enables the fabrication of complex components that have not been possible up to now. The challenge is the production of inks on the basis of liquid binders that have to be filled with different materials to be able to process them in inkjet printers.

"3D-Printing of Calcium-Phosphate-Based Bone Substitute" was explained by A. Butscher/Bio- & Structural Mechanics Group – RMS Foundation. Despite excellent biocompatibility, bioactivity, osteoconductivity and osteoinductivity, calcium phosphate requires improvement in respect of mechanical properties (ductility) and structure (porosity). 3D-printing is now opening up new design possibilities to improve these properties.

F. E. Weber/Department of Oral and Maxillofacial Surgery at University Hospital Zurich/CH reported on "Ceramic Bone

Fig. 1
cfi-Awards 2015:
Guido Falk, Jens Günster, Norbert Müller, Karin Scharrer (f.l.t.r.)

Substitute for Generative Manufacturing". Bone regeneration can be difficult when the bone quality is poor or weakened with large defects. As standard, an autologous bone material is used that is taken from a healthy area and implanted at the defective area. Therefore, two surgical procedures are necessary. With Additive Manufacturing, bone substitute materials can be produced, which eliminates the need for the second procedure. Studies with titanium-based components fabricated by means of laser melting as well as calcium triphosphate structures produced by means of stereolithography were presented.

A. Lynen/Schunk Ingenieurkeramik GmbH reported on "Generative Fabrication of Complex, Large-Volume Components Made of Technical Ceramics for Plant Engineering". In the installed equipment, components with maximum external dimensions of 4 m × 1 m × 1 m can be produced from reaction-bonded SiC. These components open up completely new applications in industrial precision measurement and production technology. In addition, components have already been manufactured for use in the iron, steel, ceramics and glass industries as well as energy conversion.

M. de Bruijcker/ADMATEC Europe BV spoke on "Printing of Ceramics – a New Process for Industrial Production". On the market there is an increasing demand for small zirconia or alumina components with complex geometry. The established manufacturing methods reach their limits here, but the rapidly developing Additive Manufacturing offers solutions.

U. Scheithauer/Fraunhofer-IKTS spoke on "3D-Thermoplastic Printing (3DTP) – an Additive Process for the Production of Mono- and Multi-Component Components". With this method, it is possible to work at 100 °C with solid content of 68 vol.-% at low viscosities. In this way, both the deposition of filaments as well as individual droplets is possible. Ceramic and metal powders can be used. The combination of different materials in one component gives greater freedom in respect of component design.

"Two-Photon Polymerization of Organic/Inorganic Hybrid Materials" was presented by U. Hinze/Laser Zentrum Hannover e.V. Two-photon polymerization, also referred to as multi-photon polymerization (MPP), is a process in which a strongly localized focus of an ultrashort pulse laser is moved through an appropriate photomaterial to selectively harden the material. Structure sizes from sub-100 nm to 10 cm and larger can be produced. The structures can be produced with a largely freely defined volume, as they are not formed layer by layer as in stereolithography.

"Selective Mask Sintering" was explained by P. Gingter/Institute of Mineral Engineering at RWTH University of Aachen. In the selective mask sintering process, a powder bed is exposed over the entire surface. Spray-dried ceramic-polymer granulates are used – generally on the basis of polyolefins – to build up multilayer green bodies. The thermally treated green bodies (debinding/sintering) exhibit porous structures as the polymer component is decomposed.

"3D-Printing of Preceramic Polymers" was explained by A. Zocca, Department of Industrial Engineering, University of Padova/IT. He gave an overview of the different manufacturing technologies and addressed a method in which preceramic polymers and fillers are processed and then have to be pyrolysed to achieve a "ceramicization".

Talks awarded with the cfi-Awards 2015

Every year cfi – ceramic forum international sponsors EUR 2000 to award the best presentations chosen by a technical jury. The award-winners in the Industry Category were R. Gaignon/3DCeram and N. Müller/Lapp Insulators GmbH. In the Institutes Category, U. Gbureck/Department of Functional Materials in Medicine and Dentistry, University of Würzburg; and J. Günster/BAM were honoured with an award.

"Additive Manufacturing: SLA for Technical Ceramics" was presented by R. Gaignon/3DCeram/FR. Laser stereolithography (SLA) has proven effective as a method for the production of dense ceramics. Pastes with 80 % solids content and 20 % resin are processed. The first components were made with this process back in 2005. He pointed out that in Europe compared to in the USA, the approach to this technology is still very restrained. Even China has now become very ambitious with regard to catching up in these fields. He said that there would have to be a rethink to really achieve advances in this new technology.

N. Müller/Lapp Insulators GmbH spoke on "Additive Manufacturing of Ceramic Components for Structural Applications". He gave an overview on the components already produced from a dense-sintered alumina by means of stereolithography (e.g. heat exchanger components or components for millireaction systems). The route of "integrative design" of ceramic components is taken and the new degrees of freedom that additive manufacturing offers with regard to component design are also exploited.

The advantages of "3D-Powder Printing of Ceramic Implant Materials" was explained by U. Gbureck/Department of Functional Materials in Medicine and Dentistry – University

of Würzburg. With 3D-powder printing, relatively large structures can be produced from bioceramics. As the process works at room temperature, temperature-sensitive materials can be processed. If reactive cement systems are used, sintering is not necessary. This enables substances to be locally deposited in the structure during printing to achieve a target-oriented biological reaction of the scaffold combined with an auto-regeneration of the defect. 3D-powder printing allows the formation of a substance depot or gradient which in combination with polymer diffusion barriers in the material leads to control of the release kinetics.

"Powder Beds with High Packing Density for Additive Manufacturing of Ceramics" were presented by J. Günster/BAM. In the case of ceramic powder, good flowability is given from a particle size >40 µm. With finer powders, however, better sintering activity could be achieved. As the density of the powder bed with coarser powders is too low, no sufficiently compacted green and sintered bodies can be produced. In the layer-by-layer build-up of the structures, there is also a risk of the previously produced, already consolidated layers becoming displaced. For this reason, support structures are used, which anchor the component with the build platform. The removal of these structures is a time-consuming additional process step that can hardly be automated. Different strategies for stabilization of the powder bed were shown and alternative processes, such as layer-wise slurry deposition and gas-flow-assisted powder deposition were presented.

Panel discussion: Additive Manufacturing – euphoria or sobering up?

With the founding of the "Szene Additiv" at the end of 2014, DKG responded to the growing interest in the ceramics industry in Additive Manufacturing technologies. The "Szene Additiv" was founded with the objective of providing comprehensive information on the topic of Additive Manufacturing of ceramics and support the dialogue on this topic between research institutes and industry. The activities within the "Szene Additiv" are currently coordinated essentially by representatives of five research institutes (Dr Tassilo Moritz/Fraunhofer-IKTS), Dr Guido Falk/University the Saarland, Dr Nahum Travitzky/FAU Erlangen, Prof. Dr Rainer Telle/RWTH and Prof. Dr Jens Günster/BAM as Chairman). The above-mentioned institutes have engaged in intensive research work in the fields of raw materials preparation and process development in the Additive Manufacturing of ceramics and the characterization of additive-manufactured components for several years.

The idea of the short panel discussion was to present "Szene Additiv" to the auditorium and also to communicate industry aspects (ceramic manufacturers, system providers). The moderator Karin Scharrer/Göller Verlag presented the panel members Joachim Heym/Schunk Ingenieurkeramik, Dr Johannes Homa/Lithoz/AT, Dr Nahum Travitzky/FAU Erlangen as well as Prof. Dr Jens Günster/BAM and pointed out special aspects of the application of the technology to ceramic materials. A special feature of Additive Manufacturing of ceramics compared to polymer and metallic materials

Fig. 2
Panel debate: Karin Scharrer, Joachim Heim, Nathum Travitzky, Jens Günster, Johannes Homa (f.l.t.r.)

is that there is a wide range of different technologies that have particular advantages but also weaknesses. In addition, in contrast to polymers and metals, ceramics demands a high degree of classical ceramics process know-how. So ready-to-use components cannot yet be produced by means of additive manufacturing, so far we are still at green component manufacturing with downstream sintering process. Depending on the material and dimensions, a suitable process must be selected and optimized in order to match the property parameters of conventionally manufactured components. Additive Manufacturing delivers wide freedom with regard to design, even bionic structures can be manufactured. Production is independent of unit costs and therefore more suitable for small and medium lot sizes. As a digital process, it can be integrated in Industry 4.0 concepts.

For industrial realization, integration in existing production chains is the goal. Closing gaps in the process chain and the still existing deficiencies of many Additive Manufacturing processes for ceramics requires comprehensive know-how of Additive Manufacturing processes and the ceramic process chain.

Prof. Dr Jens Günster explained that extensive research work on the basic principles and selective application-oriented topics is available. This R&D work is continued. "Szene Additiv" in the DKG is an open platform and sees itself as a service, technical and lobbying office for the Additive Manufacturing of ceramics. With the provision of this know-how, "Szene Additiv" is intended to help seriously assess risks in the introduction of additive manufacturing in industrial production. Besides technological issues, legal and design aspects as well as sustainability and conservation of resources have to be taken into consideration. For example, questions regarding copyright, copy protection as well as product liability on account of the flexible and decentralized production possibilities of Additive Manufacturing have to be reassessed. The "Szene Additiv" aims to promote dialogue between research institutes and industry on this complex topic. Planned are regular events and the set-up of an internet platform on the topic of Additive Manufacturing of ceramic in the first half of 2016 (www.dkg.de). KS