GERMANY

ceramitec conference: AM CERAMICS Making Innovation Happen

After a year and a half of purely virtual events, the AM Ceramics 2021 team was very eager to once again finally meet experts from the ceramic industry face-to-face in Munich (15.–16.09.2021). Despite the ongoing uncertainty surrounding the pandemic, the event – held in cooperation with the ceramitec conference – was able to go ahead, with the well-prepared Messe München team hosting an engaging and informative mixed format of online and in-person lectures and discussions. With over 300 people attending the event, it was clear that in-person events and face-to-face contact are simply irreplaceable and the AM Ceramics team was truly motivated to making this year's event the best and most informational yet.

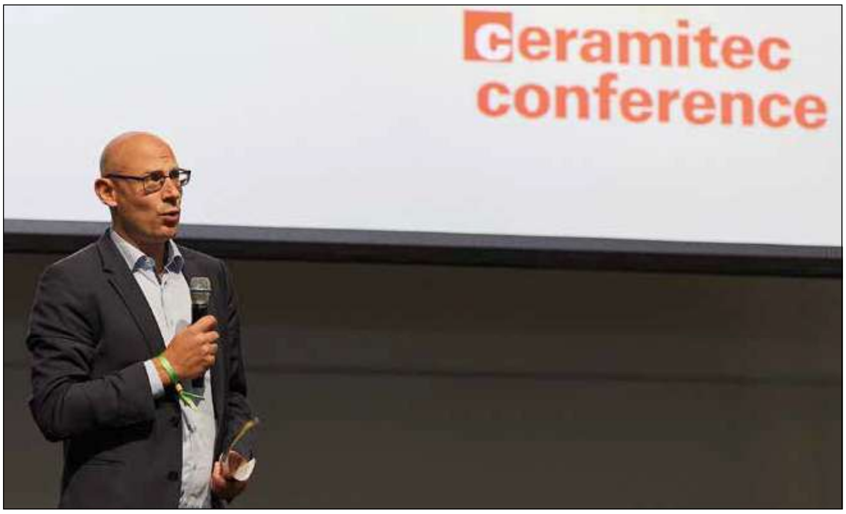


Fig. 1
Dr Johannes Homa, CEO Lithoz, hold the welcoming speech

As one of three tracks at the ceramitec conference, one main focus of AM Ceramics 2021 was the medical and dental applications of Additive Manufacturing (AM) and ceramics. In view of the discussions, whether or not events and congresses with physical presence and networking opportunities will be driven out by virtual platforms, the aim of the team was nothing less than both, to reaffirm the global reputation of AM Ceramics as the place where the future of ceramics happens and to prove that no other format can replace a trade show. Through its excellent international network of speakers on the stage, even with some talks being online, the smoothly working connections and a well-equipped venue ensured a successful merge of the online and real world. At the end, the feedback received from visitors and speakers was excellent and thus proved that the AM Ceramics indeed could meet both goals.

With highlight talks often sharing content not yet released, the range of gripping insights covered everything from the newest lithium disilicate achievements in the dental field, research on specific industrial applications, test results from comparing complex structures, the evolution of application stability or the latest findings in process improvements to business related topics such as IP issues and the sharing of an in-depth market overview of technical ceramics. The information available was fresh and sure to be of great interest to visitors from every industry. The depth of knowledge available thanks to the wide range of speakers meant that every lecture was, without exception, packed full of useful and inspiring news. Adding to the vivid discussions and general excited atmosphere of once again taking part in a face-to-face event was the 10 Year Anniversary of AM Ceramics organiser Lithoz/AT. The Happy Birthday Hour at the end of the first day gave participants the perfect opportunity to chat, network and get to know other experts in the field of ceramics and 3D printing.

Market insights and innovative strategies

Davide Sher (3D pbm/GB) held a paper entitled **Market Potential for Technical Ceramics AM Part Production.** When AM of ceramics is discussed, one needs to always differentiate between AM processes for technical ceramics, which leverage certain high resolution technologies such as stereolithography in particular, and AM processes for traditional ceramics, which mainly use binder jetting processes.

Applications of technical and traditional ceramics differ greatly: the first are used to produce advanced, high performance parts that usually weigh just a few grams while the latter are mainly used to produce very large moulds and foundry cores that weight several kilograms. There are many other applications for AM of both technical and traditional ceramics, which sometimes blur the lines between technologies and materials (for example in the case of glass), however there are generally two very distinguished ceramics AM markets that need to be described and analysed.

In a niche market such as ceramics AM, the challenges in accurately estimating and mapping the market that 3D pbm identified in its metal market study are more evident. In particular, large data and market analysis firms are not able to understand the complexities and the diversification among market operators in a market segment that they cannot and do not consider large enough to invest significant resources on.

As a leading media and market research firm entirely focused on AM, 3D pbm Research is uniquely positioned to address these issues. By leveraging its proprietary index – the 3D Printing Business Directory – which is the largest global directory of validated and verified AM companies around the world, 3D pbm was able to identify 80 firms that have an invested in ceramics AM, representing nearly the entirety of ceramics AM market segments, intended as metal AM hardware, metal AM materials and metal AM services companies.

Fig. 2
Auditorium

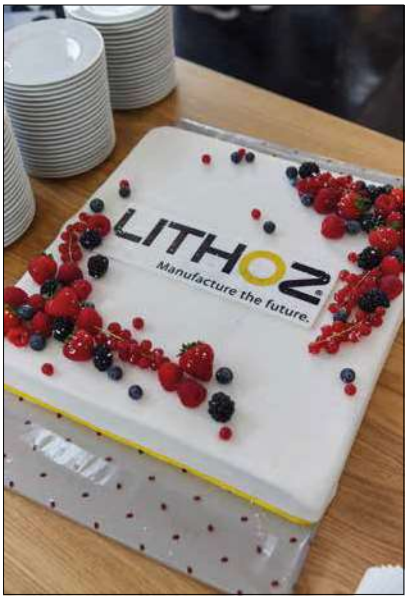
Patents in AM and Why they Matter was the topic of the presentation made by Judy Ceulemans (European Patent Office). AM is still developing at a high speed. This is also reflected in the increasing number of patent applications filed at the European Patent Office (EPO) and worldwide on the topic. A landscaping study on AM by the EPO published in 2020 provided some clear insights on the geographical origins as well as on the sectors and applicants. Patents but also IP rights in general have proven to be an essential factor for success, not only for large companies but also for SME's. Especially in a technology-driven business environment, having the right IP strategy can pave the way for high growth.

Industrial applications and production
AM of Novel Piezocomposite Structures were introduced by Barry Robinson (MSI Transducers Corp/US). Lithoz-America, LLC has applied a patented method of AM, called Lithography-Based Ceramic Manufacturing (LCM), to repeatably create PZT-5H (DoD Type VI) structures. The LCM method utilises a Digital Micromirror Device (DMD) to quickly create piezoelectric ceramic parts with customizable geometry and high feature resolution of 100 µm or less. Compared with conventional manufacturing practices, LCM utilises a photopolymerization process that imparts little stress on the green part and allow for the creation of highly resolute, periodic structures.

MSI Transducers Corp. has pioneered material preparation and post-processing methods unique to the AM material to yield sintered piezoelectric parts with properties comparable to conventionally manufactured piezoelectric ceramic. Early studies indicate that AM test geometries compliant with ANSI/IEEE Std 176-1987 possess material density, dielectric constant values and piezoelectric charge coefficient values consistent with those measured from traditionally manufactured material.

An AM 1-3 piezocomposite resonant at 88 kHz was fabricated into a simple transducer and was compared to a bulk transducer of the same specification. The MITRE Corporation has been engaged with modeling and simulation efforts to predict acoustic performance of the AM material, using Finite Element Analysis (FEA), as well as the design of novel structures previously not accessible through traditional manufacturing methods. The LCM process has shown feasibility in the creation of spatial apertures, periodic 3-3 piezocomposite and auxetic structures that demonstrate AM's ability to not only streamline manufacturing processes of piezoelectric ceramics but also augment the piezoelectric performance in acoustic transducers.

AM and Material Considerations for Medical Devices were made in his paper by Mark Mirigian (Boston Scientific Clonmel Ireland/IE). The medical devices industry has been a relatively slow adopter of additive technology compared to aerospace and automotive. In the author's experience, there are significant advantages with respect to component prototyping, rapid iteration, and novel designs when the technology is utilised to its full potential. Additive has a wide range of applications for all of Boston Scientific's Divisions: endoscopy, interventional cardiology, neuromodulation, peripheral interventions, rhythm manage-



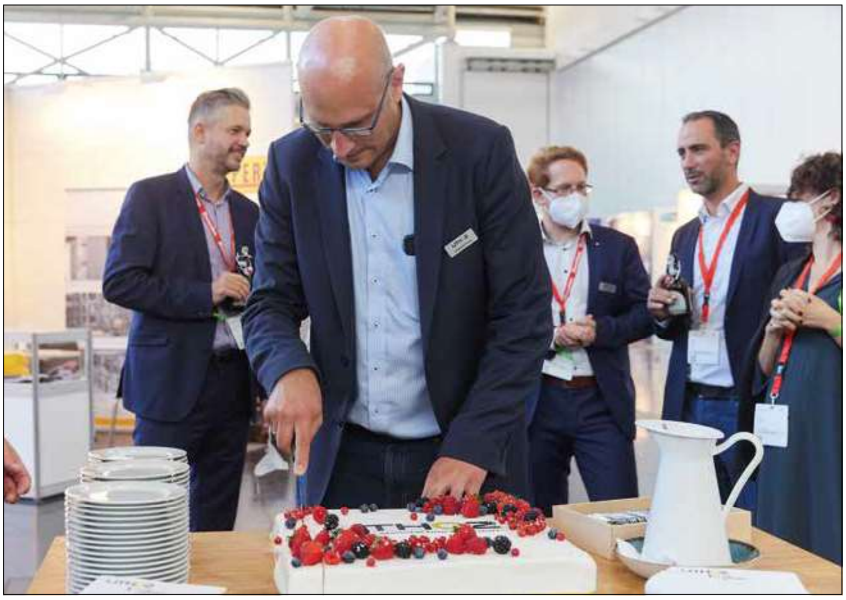


Fig. 3
Happy Birthday Hour – the 10th Anniversary of AM Ceramics organiser Lithoz

ment, and urology and pelvic health. The main challenges and considerations include resolution and tolerances, capacity and throughput, technology cost, and biocompatibility.

The smallest commercial machines available are suitable for small tooling and large components; and more customised technology is required for printing smaller components, which are most common in minimally invasive devices. The current standard for the company's applications is metal powder bed fusion. However, there are some drawbacks and challenges associated with metal powder for certain applications. These applications could benefit from resin-based raw materials, such as ceramics, that have a variety of biocompatible properties. Finding applications that have "market pull" represent the fastest way to develop a technology and achieve commercialisation. This requires a confluence of factors including an unmet clinical need, a committed technology partner, and medical device supplier that believes in additive technology.

Dr Clara Minas-Payamyar (Schunk Ingenieurkeramik/DE) spoke about **Powder Bed 3D-Printing for the Production of Reaction-Bonded Silicon Carbide.** Binder jetting, classically also known as three-dimensional printing, is one of the most efficient AM technologies to create large and complex shaped ceramic parts. It enables the production of prototypes as well as final products, which may not be realised by established shaping techniques. One main drawback of the technology is the immanent porosity of printed green bodies, due to dry powder deposition methods. This usually prevents the creation of parts with material properties which are technically sufficient.

In contrast to the vast majority of technical ceramics, powder bed porosity is not an obstacle for the production of components made of Reaction Bonded Silicon Carbide (RBSiC). Instead a porous network is a prerequisite for the Liquid Silicon Infiltration (LSI) process which follows the creation of green bodies. However, green part porosity as well as microstructural inhomogeneity have to be kept on a very low level to be able to produce technical components by binder jetting.

The presentation gave some insights into material and process development, which was key to enable the production of three dimensional printed RBSiC with excellent properties. Today, process-related advantages of AM can be exploited providing a new dimension of constructive design potentials and address demanding market segments of lithography, metrology and thermal process technology.

The topic **3D-Printing of Ceramics: Binder Jetting vs. Material Extrusion** was analysed by Dr Wolfgang Kollenberg (WZR ceramic solutions/DE). The technological fundamentals of binder jetting go back to developments at MIT at the end of the 1980s. In this process, a binder is applied locally to a powder bed by means of a print head, which bonds individual powder particles together. Particles can also be added to the binder liquid. The printed powder layer is lowered by a defined amount and covered with a new layer of powder. The printed binder also ensures that the layers are bonded together. In this way, layer by layer, the three-dimensional body is created, which must be made free of loose powder after the binder has cured.

In material extrusion, a viscous material is forced through a nozzle, which is moved along a predefined path. The basic requirement for the material to be processed is that it solidifies after being deposited as a strand. Two basic mechanisms are possible for this purpose:

- Analogous to Ceramic Injection Moulding (CIM), a mixture of the ceramic powder with thermoplastics or wax is converted into a viscous liquid by increasing the temperature near the nozzle. If the material cools down, the viscosity increases rapidly and solidification occurs. This approach is followed with filaments or granules.
- Pastes based on either clay or powder mixtures with organic plasticizers, for ex-

ample cellulose, can be processed in the cold state. The paste solidifies by drying and/or chemical processes.

During the presentation, the possibilities and limitations of binder jetting and material extrusion were presented comparatively and discussed in the context of industrial applications.

Design, AM and Testing of a 500 000 rpm Rotor for Micro-Turbine Applications was the title of the presentation made by Lukas Badum (Technion Israel Institute of Technology/IL). Owing to the high energy density of hydrocarbon fuels, ultra-micro gas turbines with power outputs below 1 kW have clear potential as battery replacement in drones. However, previous works on gas turbines of this scale revealed severe challenges due to air bearing failures, heat transfer from turbine to compressor, rotordynamic instability and manufacturing limitations. To overcome these obstacles, a novel gas turbine architecture was proposed based on conventional roller bearing technology that operates at up to 500 000 rpm and an additively manufactured monolithic rotor in cantilevered configuration, equipped with internal cooling blades. A preliminary rotor has been designed based on an interdisciplinary approach considering thermodynamic analysis, compressor and turbine design, structural design, heat transfer management, generator design and rotordynamic constraints.

In this scope, clear advantages of ceramic AM could be highlighted. Subsequently, monolithic rotor prototypes containing shaft, turbine and compressor have been manufactured using lithographic ceramic manufacturing technology and subsequent precision grinding. The same geometries were manufactured from Inconel 718 using more conventional selective laser sintering technology. Following high-precision rotor balancing, high-speed tests were on-going reaching up to 500 000 rpm and yielding valuable performance data of compressor and turbine.

Dale Cillessen of Sandia National Laboratories – SNL/US made the presentation **Lithoz CeraFab 8500 at Sandia National Laboratories – a Year in Review**. The presentation covered SNL and Lithoz America teaming together to develop custom slurries, mechanical characterisation, sintering, shrinkage, and the impacts of having access to ceramic AM.

Samad Firdosy (NASA Jet Propulsion/California Institute of Technology/US) hold online the last presentation titled **AM at JPL: Research and Applications.** Additive processes allow for the possibility of fabricating complex geometries with functional and structural materials that have been traditionally difficult to manufacture by traditional means. Selected research and applications being developed at JPL for enabling critical applications in support of robotic space exploration missions were discussed for additively manufactured metals, ceramic and polymers. Fabrication, post process and testing of laser powder bed fusion additively manufactured heat exchangers for the MOXIE technology demonstrator on NASA's Perseverance rover were presented.

Dental applications and implants

Dr Francesco Moscato (MedUni Vienna/AT) made a short survey about **Multi-Material Ceramic AM for Medical Applications** followed by a presentation of current R&D activities performed within the research project INKplant (ink-based hybrid multi-material fabrication of next generation implants). In this project, multi-material ceramics are used for manufacturing sub-periosteal implants. The medical background as well as the challenges of implant design and 3D-printing were presented together with some remarks about what will be needed to move towards clinical trials and approval.

Dr Jens Tartsch (European Society of Ceramic Implantology/CH) introduced **Ceramic Dental Implants – 3D-Printed Applications.** Dental implants made of ZrO_2 have become a serious addition to the treatment spectrum to implants made of titanium. In addition to increased health awareness on the part of patients, the clinical advantages of the material ZrO_2 have also led to this development. For dental implants, not only aesthetics, comfort and biocompatible materials are of great importance – above all, they must also grow well into the bone and withstand the high daily loads in the long term. In this context, in addition to implant geometry and material selection, it is the manufacturing processes that play an important role in this stability and the long-term clinical success of the implants.

Recently, new manufacturing methods such as 3D-printing for the production of dental implants from ZrO_2 have increasingly become the focus of interest and research. The advantage of AM is that three-dimensional objects can be designed on the computer in an almost unlimited variety of shapes and complexity, and can thus be implemented cost-effectively with reduced material input. However, AM is currently still in competition with conventional manufacturing methods such as CIM or hard machining and must be measured against these.

In this context, two-piece implants, for example, also entail different clinical manufacturing requirements than one-piece implants. Furthermore, although a microrough surface design of a ceramic implant has an important influence on long-term clinical success, inadequate surface finishing can lead to loss of stability and implants. From a clinical point of view, does the advantage of AM "customised design" also apply to implants or does standardised manufacturing offer advantages after all? Why should we deal with ceramic implants at all? With answers to these questions and with further clinical background on AM in connection with ceramic implants, the lecture addressed in particular developers and experts from the field of biomaterials and technology, as well as manufacturers of ceramic implants and research institutions. This is because knowledge of the background and actual clinical requirements for ceramic implants is an important prerequisite for the further development and establishment of AM. Only through intensive cooperation between research, technology and clinical application can successful products be created for the benefit of patients.

Prof. Dr Annelie-Martina Weinberg (MedUni Vienna) spoke about **Bone Regeneration with 3D-Printed Biodegradable Ceramic Scaffold**. Availability and regeneration of bone are crucial topics in surgical field concerning the skeleton. Age and pathologies are major challenges in these fields. Therefore, there is a major effort to maximise healing and reduce complications by guiding scaffolds. 3D-printed customised scaffolds are among the most advantageous artificial materials for bone regeneration. They can provide increased time efficiency, decreased complication risks, enhanced healing capabilities, and allow for complex scaffold architecture and patient specific geometry. To evaluate a novel biodegradable 3D-printed β-TCP (LithaBone TCP 380 D, Lithoz GmbH) scaffold in regard to biocompatibility and osteoconductivity proximal tibiae and calvariae of rats were chosen. Goal was a possible use in guided bone regeneration in oral surgery and orthopaedics.

Bilateral calvaria critical size defects (Ø 5 mm) together with mono cortical proximal tibia defects (Ø 1,5 mm, depth: 6 mm) were applied in 36 (12/group) adult male Sprague Dawley rats. Left side defects were sham control, were experimental. Experimental side was filled with one of the following bone substitutes: 1) a novel biodegradable 3D-printed β-TCP (LithaBone TCP 380 D) by Lithoz; 2) a proven 3D-printed β-TCP (LithaBone TCP 300) by Lithoz, and 3) Bio-Oss®Block by Geistlich Pharma AG/CH. For analysing bone volume in the defect area and scaffold volume, in-vivo micro-CTs scans at wek 2 and 4 and ex-vivo scans were performed. Assessing biocompatibility, newly formed bone area, penetration depth, vessel number, vessel area and bone apposition rate were done with histological undecalcified thin ground sections.

Preliminary qualitative results showed a high bone regeneration and therefore high osteoconductivity after four weeks compared to the sham and no adverse effect for biocompatibility. Biodegradable 3D-printed β-TCP scaffold could be a candidate for guided bone regeneration in implant placement, orthopaedics, traumatology, and neurosurgery to promote bone regeneration in flat and long bone defects in case of confirmation of the qualitative results.

Ceramic AM in Prosthetic Dentistry was presented by Dr Ing. Franziska Schmidt (Charité Universitätsmedizin/DE). Lithium disilicate ($LiSi_2$) is a unique dental ceramic due to its great optical characteristics, especially translucency in combination with good mechanical properties, such as strength and fracture toughness. The translucency of $LiSi_2$ is on par with other glass ceramics such as feldspar, whereas it is exceeding them in mechanical strength. There it is only rivalled by oxide ceramics, such as zirconia and alumina, which in turn do not satisfy aesthetic requirements. Therefor, $LiSi_2$ is favoured for restorations especially in the anterior region.

Conventional processing of $LiSi_2$ is either by hot-pressing precrystallized blanks in the so-called lows wax technique or by milling of blocks or blanks. The former method is quite intricate, time and material consuming. Milling as a Computer Aided Manufacturing Method (CAM) is embedded in the digital workflow, where patient data is acquired by intraoral scanning and the model and restauration are designed by designated Computer Aided Design (CAD) software. The milling process however is also material consuming, as it is a subtractive method, and furthermore it is limited in the freedom of design. Especially thin restorations, such as non-prep veneers with thicknesses below 1 mm cannot be easily produced by milling. AM technologies are promising approaches to overcome these limitations of the CAD-CAM production of $LiSi_2$ restorations. Especially Lithography Based Ceramic Manufacturing (LCM), as developed by Lithoz, is an AM technology with high resolution and precision. It was shown a possible clinical application of LCM produced $LiSi_2$ restorations in the anterior region, which to the best of the author's knowledge has not been applied until now.

Multi-material 3D printing

New Possibilities through Multi-Material Printing in Ceramics was the topic of the presentation made by Sebastian Geier (Lithoz GmbH). The medical, electrical and aerospace fields are just some examples of industries that are using 3D printing to push past previously established applications. Multi-material 3D printing is garnering particularly widespread attention in this way due to the wide range of possibilities it offers to manufacture parts with improved functionalities and properties. New applications are just waiting to be discovered thanks to multi-material 3D printing and this technology is finding new uses in different industries every day.

Lithoz's CeraFab Multi 2M30 is a powerful multi-material 3D printer which utilises the full capacity of AM to combine ceramics, metals and polymers in one single component. This innovative machine enables complete freedom in design, allowing for the manufacture of parts and structures with combined material properties and thus opening the door to 3D printing in entirely new applications and industries.

Powered by industry-leading Lithography-based Ceramic Manufacturing technology (LCM), the CeraFab Multi 2M30 creates multi-functional components for applications ranging from electronics and embedded sensors to biomedical implants and devices, as well as in the aerospace and automotive industries.

Prof. Dr Raul Bermejo (Montanuniversität Leoben/AT) talked about **Exploring New Concepts to Design Damage Tolerant Ceramics Using AM**. The combination of ceramics with other materials has enabled the fabrication of hybrid systems with exceptional structural and functional properties. However, a critical issue affecting the functionality, lifetime and reliability of these systems is the initiation and uncontrolled propagation of cracks in the brittle ceramic parts, yielding in some cases very high rejection rates of component production.

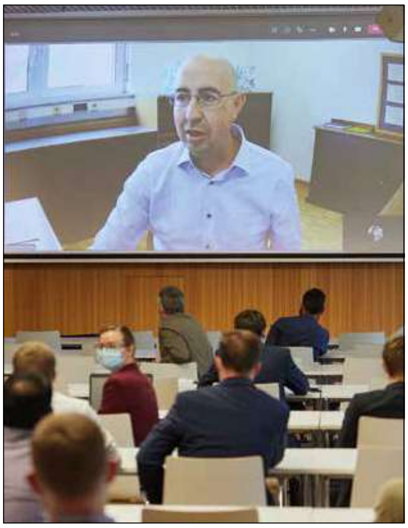


Fig. 4
Prof. Dr Raul Bermejo during his online presentation

In previous work, design concepts that combine different approaches used in current ceramics engineering have proved successful in obtaining highly reliable ceramic materials with enhanced fracture resistance. For instance, tuning the location of "protective" layers within a ceramic multilayer architecture can significantly increase its fracture resistance, while retaining high strength. The use of tailored residual stresses in embedded layers can act as an effective barrier to the propagation of cracks from surface flaws, providing the material with a minimum design strength, below which no failure occurs. Moreover, by orienting (texturing) the grain structure, similar to the organised microstructure found in natural systems such as nacre, crack propagation can be controlled within the textured ceramic layers. Two examples showing the potential of employing the LCM process to design multi-phase layered architectures were presented.

Regarding the first example, a multi-material approach was employed to combine alumina-zirconia layers sandwiched between pure alumina layers, in order to introduce significant compressive residual stresses in the latter. A characteristic strength higher than 1 GPa was measured on the alumina multi-material system, compared to ~650 MPa in monolithic alumina, taken as a reference. This was the first report of employing AM to tailor the strength of alumina ceramics, taking advantage of the layer-by-layer printing process.

As a second example, 3D-printed highly textured alumina was fabricated combining the LCM technology and Templated Grain Growth (TGG) during sintering. Relative densities of >93 % were reached for textured alumina, compared to 99 % on equiaxed reference samples. A high degree and quality of texture was achieved with 3D printing. A characteristic strength of 640 MPa was measured for textured alumina, comparable to 570 MPa obtained in equiaxed alumina. The aim was complex 3D ceramic-based multi-material geometries with tailored microstructures, with outstanding mechanical strength and reliability.

Philip Ninz (IFBK, University Stuttgart/DE) reported on **AM of Alumina Ceramics for the Selective Laser Induced Metallization.** Laser induced activation and autocatalytic metallization is a process enabling the selective and fully additive metallization of ceramic materials. Hereby a pulsed laser beam is used to structure and activate the surface. Subsequently, the parts are immersed in an electroless metallization bath in which the deposition of metal takes place selectively on the activated surface areas. The process is used for the application of conducting paths, antennas or other metallic structures on complex shaped three dimensional ceramic components. Thereby, a high degree of design freedom is achieved and structural and electronic functionalities can be integrated. This enables miniaturisation and leads to reduced weight and volume of electronic components.

Recent material related research on ceramic substrates promises new application fields for three dimensional mechatronic integrated devices (3D-MID) by exploiting the beneficial properties of ceramics compared to state-of-the-art polymers. The substrate material composition, its microstructure and surface properties are important factors for the effectivity of the metallization process besides the type of laser source and parameters and the composition of metallization bath. The metallization efficiency of alumina can by drastically increased by doping with few percent of oxides such as Cr_2O_3 or NiO. For the LCM process, these intransparent dopant powders propose a challenge. The LCM process is relying on a certain amount of transparency of the powder loaded suspensions in order to solidify a suspension layer with a certain thickness and to reliably interconnect the layers to form a solid, defect free part.

A different way to incorporate dopants into the ceramic substrate material is by a subsequent dip infiltration after the shaping process. Hereby a pure alumina part is shaped, debindered and pre-sintered. The resulting porous body is infiltrated with a precursor solution of the respective dopant. During drying the precursor is decomposed and the oxide dopant is deposited within the pore volume and then diffuses into the alumina during sintering. The drawback of this method is that the dopant concentration is inhomogeneous over the volume and leads toto a higher concentration on the surface. The presentation addressed challenges connected to AM via LCM and showed first results of the successful selective metallization of doped alumina substrates.

New applications

Dr Uwe Scheithauer (Fraunhofer IKTS/DE) dealt in his paper with the **Characterisation of the Components as a Function of the Orientation in the Installation Space.** AM components often have step-like surfaces due to the layer-by-layer structure. To be able to characterise their influence on the properties as a function of the component alignment, a special test method was developed at Fraunhofer IKTS, which is now being further developed within the CharAM project. In addition, the method is being validated by means of a round robin test with six partners.

Dr Sadaf Sobhani (Cornell University/US) spoke about **AM of Ceramic Porous Structures for Application to Combustion Systems.** In Porous Media Burners (PMBs), a solid porous matrix embedded within the combustion chamber accumulates heat from the hot gaseous products and preheats incoming reactants. PMBs have been shown to achieve combustion properties superior to those of free-flame systems, including higher burning rates, reduced propensity for flame instabilities, decreased pollutant emissions, and lower lean-flammability rates. Furthermore, the large surface area-to-volume ratio of PMBs can be applied to facilitate effective adsorption and conversion of impurities.

The local porous structure of PMBs directly affects the total heat transfer across a porous material, reactivity, and flow behaviour. However, conventional fabrication methods for the ceramic structures applied in PMBs produce locally random pore geometries and sizes within a range of global parameters. Architected porous materials, however, enable tuning of flame stability and pollutant formation, which can have significant impact on combustors prone to lean flame blow-out, e.g., gas turbine engines, or systems that require robust operation for a wide operating range, e.g., household boilers. In this research, the fabrication of architected porous ceramics with predefined and reproducible microstructures to enable advanced PMBs was demonstrated. Using Digital Light Processing ceramic AM, five different mullite and alumina burners were designed, printed, and tested.

Astrid Lang (Bayern Innovativ GmbH/DE) presented **AM – Activities and Success Stories from the Ceramic Industry.** The

Bavarian Coordination Centre for Additive Manufacturing at Bayern Innovativ is a hub that links all experts and newcomers and all activities to 3D printing within Bavaria but also on an Germany-wide and international level, from and to Bavaria. Practical examples from partners and stakeholders provided insights in the successful work performed by the companies and research institutions.

The last presentation was made by Wadih Yared (IMTCCC, University of Stuttgart) and was titled **Uncovering the "Hows" and the "Whys" of Colloidal Stability in Ceramic Resins for Stereolithography.**

Polymeric dispersants are frequently used to provide steric and electrostatic stabilisation of ceramic particles in photocurable resins intended for Digital Light Processing (DLP). However, the dispersant's type, functionality and concentration directly influence its effectiveness.

This contribution is a characterisation study of more than ten anionic, cationic, nonionic and amphoteric dispersants, with the goal of identifying the optimum polymeric dispersant for ceramic-filled photo-curable acrylate formulations.

The compatibility and miscibility of the different dispersants were tested in a typical photo-curable acrylate monomer (methyl methacrylate).

Two different ceramic powders, viz. Al_2O_3 and β-$Ca_3(PO_4)_2$, were functionalised with the selected dispersants using shear mixing and an agitator bead mill. Micrographs revealed that anionic dispersants offer a promising dispersibility in acrylate formulations, while different types of anionic ammonium polyacrylate dispersants showed varying levels of effectiveness. The operational pH of the suspensions was monitored for varying concentrations of the dispersants.

This revealed the dissociation mechanism of the different dispersants. The concentration of each adsorbed dispersant on the surface of the ceramic particles was measured using centrifugation followed by UV/VIS spectroscopy.

Moreover, flow curves generated on a modular rheometer were used to analyse the influence of the dispersant type and concentration on the flow and viscoelastic behaviour of the resins. The sedimentation stability was assessed using amplitude sweeps followed by frequency sweeps. The highest levels of adsorbed dispersant induced the lowest viscosity, storage and loss moduli.

High levels of adsorbed dispersant, coupled with the right electrochemical interaction, offered superior colloidal stability. This resulted in a more reliable feedstock for stereolithography.

Remark from the Editor
The next AM CERAMICS will take place in Dresden/DE on 12.-13.10.2022
For further information visit:
http://www.am-ceramics.dkg.de

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Advertising Manager
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Phone: +49(0)7221-502-237
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