Virtual AM CERAMICS at ceramitec conference 2020

Under the roof of a combined organisation by ceramitec/Messe München/DE, Lithoz GmbH/AT and Fraunhofer IKTS/DE, Additive Manufacturing (AM) was the topic of the ceramitec conference 2020 dedicated to the well-know AM CERAMICS launched in 2016 by Lithoz. During two days on 16.–17.09.2020, two keynote sessions and 12 technical presentations were given, enriched by so-called video snacks offering a virtual lab tour at IKTS with AM highlights (VAT Photo Polymerisation, Fused Filament Fabrication, Binder Jetting and Multi Material Jetting) and presenting as well various research topics from Lithoz. Approximately 500 live participants enjoyed this program online.

Keynotes

Fraunhofer IKTS and Lithoz were responsible for the technical program. Alexander Michaelis (Fraunhofer IKTS) reported on **Multi-Materials Additive Manufacturing and 5D-Printing**. Additive Manufacturing (AM) with ceramic materials is particularly challenging due to the needed pre- and post-shaping processes such as ceramic paste or ink preparation and thermal post treatment (de-binding, sintering). In the case of multi-materials printing, the thermal expansion behaviour of the materials has to be carefully adjusted for the co-sintering process.

An important demand for all AM technologies is the improvement of reliability and performance of the manufactured components. Due to the time-consuming manufacturing processes and the layer-wise building process it is necessary to control the quality of each layer in order to repair a defect layer or to stop the building process to avoid waste of time and expensive material loss. Therefore, it is important to access the quality of the printed parts as early as possible. This requires in-operando non-destructive evaluation methods. For this, new optical methods such as laser speckle spectroscopy and optical coherence tomography are available now. For a further functionalization of the AM parts, 2D-printing technologies are applied. First results on this combination of 3D- and 2D-printing what is called 5D-printing were presented.

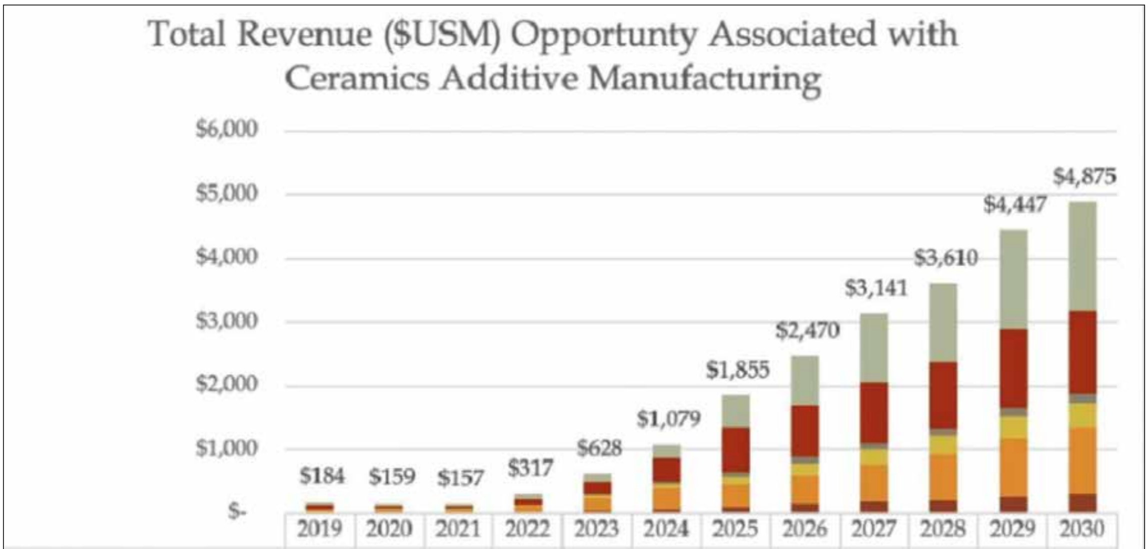
Johannes Homa (Lithoz) highlighted in his keynote the **Empowering Digital Transformation with Additive Manufacturing Technologies**. With the current situation limiting physical interaction, digital communication strategies have allowed organisations and businesses to stay connected and continue making progress. Digital manufacturing technologies are also being effectively utilised by different industries to overcome the shortcomings of conventional forming technologies.

Digital storage and independency from suppliers are, along with the freedom of design, some of the main advantages motivating companies to adapt and use additive manufacturing for their own fields. Additionally, one can see a growing trend of decentralized manufacturing where the final product is produced closer to or directly at the end consumer's location. In a world that is becoming ever more digital, AM has a bright and bold future ahead. The innovation potential offered by these technologies is huge, particularly when it comes to new application development; entirely new markets and revenue streams have been pioneered using these latest product offerings. However, innovation comes not only from developing applications, but also from new machines, technologies and materials.

Components and thermal processing

Tobias Fürderer (DOCERAM Ingenieurkeramik/DE) gave insights to a usually long journey product development. He presented the story of an ongoing project from the beginning to the final marketing of the products and described all the pitfalls and challenges developers, project managers and sales people face when embarking on the adventure of a new product. The first ideas have to be evaluated and the application must be defined.

But when the applications evaporate, what do you do? The most competent development partner must be found. But what to do if they drop out? Usually there is a major market



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total Ceramics AM	$184	$159	$157	$317	$628	$1,079	$1,855	$2,470	$3,141	$3,610	$4,447	$4,875
Technical Applications	$43	$40	$37	$75	$132	$206	$504	$775	$1,081	$1,237	$1,554	$1,694
Traditional Applications	$77	$46	$44	$99	$184	$383	$695	$814	$954	$1,041	$1,226	$1,296
Traditional Materials	$6	$5	$7	$11	$17	$35	$77	$91	$107	$116	$140	$147
Technical Materials	$16	$14	$13	$24	$42	$65	$126	$189	$231	$280	$337	$395
High-end HW Revenues	$36	$48	$50	$91	$210	$322	$357	$447	$581	$713	$912	$1,027
Low-cost HW Revenues	$5	$7	$7	$18	$43	$67	$95	$154	$187	$224	$279	$316

Fig. 1
Ceramics AM global market

you focus the product on. Then along comes a reorganisation and completely wrecks for beautifully engineered plans. An agile mindset and robust networks combined with good project management help to cope with these challenges and lead to good results.

In most spacecraft mechanisms used today, the angular position is measured using potentiometer or optical encoders, explained Christian Melzer (RUAG Space/CH). On the one hand, potentiometers provide moderate performance at very low costs, however, are often characterised by low reliability. On the other hand, optical encoders provide very high performance but are rather sensitive to radiation. In addition, costs are significant. Since 2015 RUAG Space Germany, together with Sensitec GmbH, develop a sensor system called Magneto Resistive Angular Sensor for Space Applications (MRS), which is an angular sensor based on the Magneto-Resistive effect, specifically developed for the use in spacecraft mechanisms.

In the frame of this activity ceramic packages for carrying the MRS under space environment has been developed, designed, manufactured and tested. Ceramic AM technology was investigated under the focus of cost-effective production of a small batch size. The main technical challenges were high demands on manufacturing tolerances of the package to meet performance requirements of the sensor, to produce hermetically sealed vias for electrical contacting of the chip in the ceramic package as well package closure by soldering.

The final performance tests provided evidence in terms of high precision manufacturability of ceramic packages. It can be stated that the accuracy of 0,1° [±0,05° linearity error] can be achieved under all tested environmental conditions.

Christian Schenk (CARBOLITE GERO/DE) presented new furnace designs tailored for the needs of AM. Printed ceramic parts sometimes have large component dimensions in combination with large variances in the wall thicknesses and therefore pose great challenges in terms of furnace geometry, gas flow and temperature distribution. For this purpose, CARBOLITE GERO offers ceramic fibre-insulated furnaces up to 1800 °C in air and cold-wall vacuum chamber furnaces (with tungsten or graphite heating) up to 2200 °C under inert gases, hydrogen or high vacuum, which are adapted to special sintering conditions.

Data collection and processing

Inline process control in AM of ceramic components was presented by Daniel Wagner (DIAS Infrared/DE) and Johannes Abel (Fraunhofer IKTS). For this purpose the Fused Filament Fabrication (FFF) process was chosen in which a highly filled thermoplastic Al_2O_3 filament is melted in a heated nozzle and placed underneath. The material is solidified by cooling after its deposition. This results in a component built up layer by layer. To investigate the thermal conditions of the extruded material close to the nozzle a pyrometer was attached to a commercial FFF printer and the deposition of superimposed layers was thermally monitored. The type of

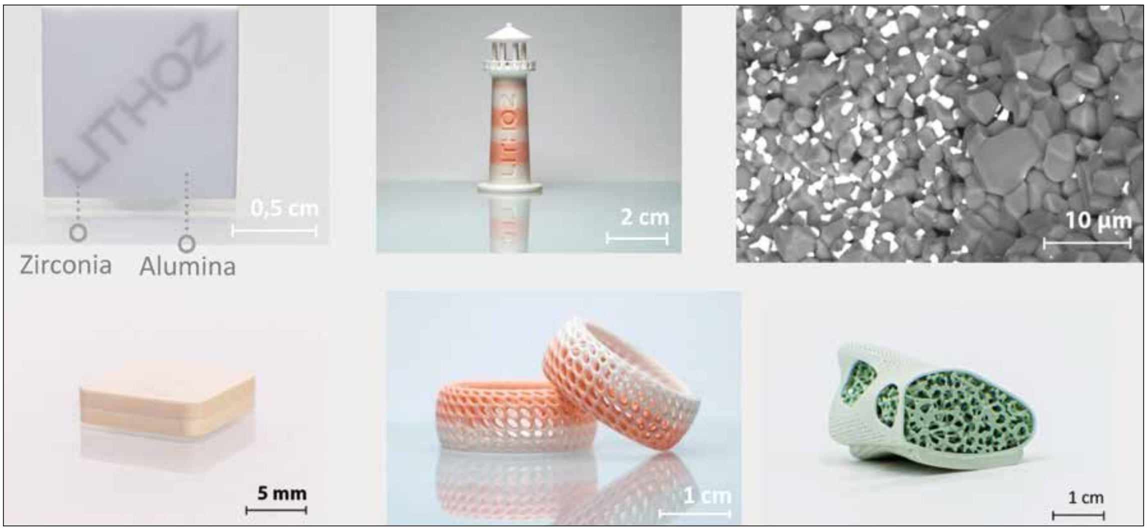


Fig. 2
Multi-material 3D-printing

(Figs: Lithoz)

defects introduced has been chosen on the basis of defects occurring during printing (over extrusion, short material dropout, layer binding defect). The insertion of defects could be detected by means of the high resolution IR-sensor technology which can path the way for inline process control of thermal AM processes.

Martin Juhrisch (Symate/DE) presented Detact – a platform with which distributed, heterogeneous data from the most diverse sources, such as plant control systems, sensors, databases and even manual protocols, can be linked to one another and parameter interactions detected throughout the entire process. The use of Artificial Intelligence (AI) – encapsulated in Detact Apps to support machine operators and engineers was demonstrated on real process chains. The greatest potentials of digitization lie on optimisation experiences from small pilot projects which can be transferred to complex factories.

Valentin Lang (TU Dresden/DE) presented how Artificial Intelligence (AI), can contribute to improving the 3D-printing process by evaluating and predicting quality of the printing process in order to avoid errors in the final product and thus lead to better results. AI, AM and Industry 4.0 are being attributed major impact on economy, existing production and application systems. AI comprises procedures helping machines perceiving their environment, drawing logical conclusions and acting accordingly, thus representing a broad spectrum of data processing in fields like linguistics, image processing, motor and robotics. AI is promising in optimisation problems, as causes of problems can be identified and dependencies drawn automatically. Quality management urges for the systematic determination of problem causes, analysis and structuring of processes, as well as for visualisation and weighting of relationships in complex structures. Challenges to the application of AI in manufacturing include the interaction of complementary competencies uniting information technology and manufacturing knowledge.

Technical and medical applications of AM

In the last decades, advances in bone tissue engineering mainly based on osteoinduction and on stem cell research. Franz Weber (University of Zurich/CH) reported that new efforts focused on the micro- and nanoarchitecture were undertaken to improve and accelerate bone regeneration. By the use of AM, libraries of diverse microarchitectures were produced and tested to identify the ideal pore size or rod distance for osteoconduction to occur. Presently, the approach is to elucidate the dependency of osteoconduction on microporosity and expand the view on micro- and nanoarchitecture of bone substitutes for optimal bone augmentation.

For the production of scaffolds, for titanium-based scaffolds selective laser melting and for ceramics the CeraFab 7500 from Lithoz, a lithography-based AM machine were used. By AM enabled libraries of microarchitectures were generated to search for the most osteoconductive microarchitecture and the ideal microarchitecture for bone augmentation purposes. Moreover, AM appears as a promising tool for the production of personalised bone tissue engineering scaffolds to be used in cranio-maxillofacial surgery, dentistry, and orthopedics.

Highly loaded parts, such as hip or knee prostheses, require strong mechanical prostheses, so metal components are preferred – despite their lower osteointegration. On the other hand, there are several joints, often affected by arthritis, that don’t bear high loads.

The work of Ambra Paterlini (Lincotek Medical/IT) aims to create entirely ceramic parts for orthopaedic implants by taking advantage of benefits offered by lithography-based ceramic manufacturing. In particular, the high density achieved on printed parts (around 99 % after sintering) results in promising mechanical properties, comparable to conventional processed materials, while the good shape accuracy allows to reproduce details of around 25 µm. The main goal of this study is the production of semi-porous implants, to guarantee a high mechanical resistance and poor friction on joint head, as well as improved vascularization and bone adherence given by the porous surface. After an initial modeling simulation screening, mechanical analyses were carried out to compare the different lattice geometries: regular and randomized structures were evaluated. Alumina, zirconia and zirconia toughened alumina samples were compared in terms of tribological behaviour – several parameters were considered: surface finishing, material combination and polishing treatment.

For Radio Detection And Ranging (RADAR) a novel application, which will make mobile material transceivers for the generation of precise topography and material maps possible, is new, explained Niels Benson (University of Duisburg/DE). This application can e.g. aid fire rescue operations by enabling an automated situation survey. For this purpose, sub-mm localisation accuracies are required, which is only possible when RADAR technology is able to make use of the sub-mm wavelength range.

However, when complex 3D-structures are required, with structural features on the sub-500 µm length scale, the usability of classical subtractive manufacturing techniques is limited. This limitation is related to alignment issues and intermodulation losses, when multi-component integration is required on the discussed length scale. Additive Manufacturing in the form of Lithography-Based Ceramic Manufacturing (LCM) is a potential solution for this issue. The LCM technology with a DLP-based pixel resolution of 25 µm and achievable ceramic densities of >99 % has excellent boundary conditions for the implementation of monolithic multi-component integration in mm- and sub-mm wavelength application scenarios.

New developments in material and technology

Dr Thomas Konegger (TU Wien/AT) explained that aluminium nitride (AlN), a ceramic material with outstanding thermal, chemical, and electric characteristics had to be adapted to a system suitable for additive manufacturing employing the Lithography-Based Ceramic Manufacturing (LCM) technology. In a first step, AlN powder compositions with varying sintering additive mixtures were evaluated in terms of consolidation properties during sintering at atmospheric pressure, using test specimens shaped by conventional cold-isostatic pressing. After screening of the densification behaviour, the most promising compositions were tailored towards maximisation of thermal conductivity values, reaching thermal conductivities up to 180 $W \cdot m^{-1} \cdot K^{-1}$.

Subsequently, the insights were transferred towards the development of AlN-based slurries facilitating LCM, allowing for the fabrication of additively manufactured AlN-based green bodies. By employing a well-tailored debinding regime followed by sintering at up to 1700 °C, LCM-shaped AlN materials with near-full densification were obtained. In-depth characterisation of sintered specimens showed that AlN specimens prepared by LCM are indeed comparable to conventionally consolidated materials in terms of both mechanical and thermal characteristics. The project results demonstrated the high potential of the LCM technology for obtaining complex-shaped AlN ceramics with exceptional thermal properties in combination with chemical and thermal stability, rendering this technology highly relevant for prospective applications involving high-power electronics, as mounts for LEDs, nozzles used in plasma spraying processes, heat exchangers operating in aggressive environments, or heat dissipators in high-speed trains.

In order to meet the requirements for novel components, Fraunhofer IKTS in Dresden developed Multi Material Jetting (CerAM MMJ, previously Thermoplastic 3D-Printing). Steven Weingarten (Fraunhofer IKTS) explained the possibility to additively manufacture functionally graded components (FGC) and thus to realise novel products. In the CerAM MMJ technology, melted particle-filled thermoplastic feedstocks are selectively deposited as individual drops and fused directly during deposition, resulting in a three-dimensional component, the so-called green body, which subsequently has to be thermally processed.

The focus here is on the processing and combination of high-quality ceramic and metallic materials such as zirconium oxide and stainless steel or electrically conductive silicon nitride with electrically insulating silicon nitride. Through the parallel use of up to four dosing systems, up to four different materials or material mixtures and thus their specific properties can be combined in one ceramic, metallic or metal-ceramic component within one manufacturing process for the first time. The MMJ device was also developed by Fraunhofer IKTS and will be commercially available in the near future.

The focus of the work of Erik Adolfsson (RISE Research Institute Sweden/SE) on AM of zirconia ceramics was to develop new suspensions for AM of zirconia materials. This work included powder preparation, where the powders were ball milled, freeze granulated, freeze dried and then finally mixed with the monomer system to obtain a printable zirconia suspension.

The additively manufactured materials were prepared in a Lithoz Cerafab 7500 printer using different printing parameters. The debinding of the prepared materials have been studied by special debinding furnace and based on the results, debinding cycles for high temperature furnaces have been designed. The main target has been to develop a reliable process to prepare materials that can be mechanically evaluated, which has been a general problem for additively manufactured ceramics. By changing the composition, printing parameters, debinding cycle, the result have slowly been improved and the frequency of the cracks present been reduced, finally bending bars were printed, debinded and sintered without problems with delamination. KS