Deutsche Keramische Gesellschaft e. V.

# KERAMIK

## CERAMICS 2024

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University of Applied Sciences

## Book of abstracts

**99. DKG-Jahrestagung**
99th DKG Annual Meeting

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# Grußwort des Programmausschuss

Liebe Mitglieder der DKG und Freunde der Keramik,

hiermit laden wir Sie herzlich zur KERAMIK 2024, der 99. Jahrestagung der Deutschen Keramischen Gesellschaft (DKG), ein. Gastgeber der KERAMIK 2024 / 99. DKG-Jahrestagung ist die Hochschule Koblenz (HAW Koblenz).

Jedes Jahr zieht es Millionen Menschen von Nah und Fern an den Rhein, insbesondere an den Mittelrhein, der auf der 180 km langen Strecke zwischen Köln und Mainz unbestritten am schönsten ist und auf halbem Weg die Hochschule Koblenz liegt. Das Weltkulturerbe Mittelrhein gehört zu den wärmsten und trockensten Regionen Mitteleuropas - und auch zu den schönsten. An drei Standorten - RheinMoselCampus Koblenz, RheinAhrCampus Remagen und WesterWaldCampus in Höhr-Grenzhausen - können Studieninteressierte zwischen mehr als 70 Studiengängen wählen. Eine hervorragende Ausstattung, moderne Labore und die große Praxisnähe machen die Hochschule Koblenz besonders attraktiv. Momentan studieren rund 8.500 junge Frauen und Männer an der Hochschule Koblenz.

Am familiären WesterWaldCampus in Höhr-Grenzhausen dreht sich dabei alles um Glas und Keramik. Die Wurzeln der keramischen Ausbildung der Hochschule Koblenz reichen bis ins 19. Jahrhundert zurück. Die Keramikausbildung in Höhr-Grenzhausen besteht seit 1879 damals als „Keramische Fachschule", bis sie 1971 als Fachbereich „Keramik" an der Fachhochschule Koblenz angegliedert wurde. Seit 2012 gehört der WesterWaldCampus mit seiner vollumfänglichen Keramik- und Glasausbildung zur Hochschule der angewandten Wissenschaften und gilt als forschungsstärkster Standort der Hochschule mit einer modernen Laborausstattung.

Keramik erleben – ob als Besucher oder Studierender – das haben sich das Bildungs- und Forschungs-Zentrum Keramik (BFZK) sowie eines der größten europäischen Keramikmuseen in Höhr-Grenzhausen auf die Fahnen geschrieben. Die Stadt Höhr-Grenzhausen ist zudem Mitglied der „European Route of Ceramics" und im „Verband der deutschen Keramikstädte e. V." und liegt im Herzen des Kannenbäckerlandes. Das Bildungs- und Forschungszentrum Keramik e.V. (BFZK) ist mit seinen acht Institutionen, die auf den Gebieten der Forschung und Entwicklung, der Lehre, der Unternehmensgründung, der Gestaltung, Kunst und musealen Bewahrung der Historie tätig sind, ein Dachverband keramischer Institute und in seiner Konstellation europaweit einzigartig. Praxisnahe Forschung (FGK und ECREF), die Gründertätigkeit (CTC), die Lehre an der Hochschule (Ausbildung zum Bachelor, Bachelor Dual und Master of Engineering »Ceramic Science«), an der Fachschule (Staatlich geprüfter Keramik-Techniker, Keramik-Gestalter) sowie an der Berufsbildenden Schule sind eng miteinander verknüpft. Das Institut für Künstlerische Keramik und Glas (Bachelor und Master Ausbildung) und das Keramikmuseum, mit 5000 qm Fläche größtes Europäisches Fachmuseum für Keramik in Historie und Moderne, sind Drehscheiben lokaler wie internationaler Präsentationen.

Weitere Informationen zum Standort Höhr-Grenzhausen und zur KERAMIK 2024 erhalten Sie vor Ort. Wir wünschen allen Teilnehmenden eine erfolgreiche Tagung und einen anregenden Austausch.

Wir freuen uns, Sie in Höhr-Grenzhausen persönlich begrüßen zu dürfen.
Im Namen des Programmausschusses

Prof. Dr. techn.
**Antje Liersch**
Vorsitzende
Chairwoman

# Greeting by the Program Committee

Dear DKG members and friends of ceramics,

We cordially invite you to CERAMICS 2024, the 99th Annual Meeting of the Deutschen Keramischen Gesellschaft (German Ceramic Society / DKG). The host of CERAMICS 2024 / 99th DKG Annual Conference is the Koblenz University of Applied Sciences (HAW Koblenz).

Every year, millions of people from near and far are drawn to the Rhine, especially to the Middle Rhine, undisputedly the most beautiful on the 180 km stretch between Cologne and Mainz, with Koblenz University halfway along. The Middle Rhine World Heritage Site is one of the warmest and driest regions in Central Europe - and also one of the most beautiful. At three locations - RheinMoselCampus Koblenz, RheinAhrCampus Remagen and WesterWaldCampus Höhr-Grenzhausen - prospective students can choose from more than 70 courses of study. Excellent facilities, modern laboratories and a high degree of practical relevance make Koblenz University of Applied Sciences particularly attractive. Currently, around 8,500 young men and women are studying at Koblenz University.

At the familiar WesterWaldCampus in Höhr-Grenzhausen, everything revolves around glass and ceramics. The roots of ceramics education at Koblenz University go back to the 19th century. Ceramics training in Höhr-Grenzhausen has existed since 1879, at that time as the "Ceramics Technical School", In 1971 it was affiliated with the Koblenz University of Applied Sciences as the "Ceramics" department. Since 2012, the WesterWaldCampus with its fully comprehensive ceramics and glass education has been part of the University of Applied Sciences and is considered to be the most research-intensive location of the university with modern laboratory equipment.

Experiencing ceramics - whether as a visitor or student - is what the Ceramics Education and Research Center (BFZK) and one of Europe's largest ceramics museums in Höhr-Grenzhausen are all about. The town of Höhr-Grenzhausen is a member of the "European Route of Ceramics" and the "Verband der deutschen Keramikstädte e. V." and is located in the heart of the Kannenbäckerland. The Bildungs- und Forschungszentrum Keramik e.V. (BFZK), with its eight institutions active in the fields of research and development, teaching, company foundation, design, art and museum preservation of history, is an umbrella organization of ceramic institutes and unique in its constellation throughout Europe. Practice-oriented research (FGK and ECREF), the founding activity (CTC), teaching at the university (training for Bachelor, Bachelor Dual and Master of Engineering "Ceramic Science"), the technical school (state-certified ceramics technician, ceramics designer) and the vocational school are closely linked. The Institute for Artistic Ceramics and Glass (Bachelor and Master education) and the Ceramics Museum, with 5000 square meters the largest European museum for ceramics in history and modernity, are hubs for local and international presentations.

Further information about the Höhr-Grenzhausen location and KERAMIK 2024 will be available on site. We wish all participants a successful conference and a stimulating exchange.

We look forward to welcoming you personally in Höhr-Grenzhausen.
On behalf of the program committee

Prof. Dr. techn.
**Antje Liersch**
Vorsitzende
Chairwoman

# Grußwort Bürgermeister Thilo Becker zur 99. Jahrestagung der Deutschen Keramischen Gesellschaft

Seien Sie herzlich willkommen in Höhr-Grenzhausen im Kannenbäckerland, einer Kulturlandschaft mit dem größten Tonvorkommen in Europa. Ich freue mich sehr, dass die 99. Internationale, wissenschaftliche Keramik-Tagung der Deutschen Keramischen Gesellschaft am Hochschulstandort Höhr-Grenzhausen stattfindet. Neben dem traditionellen keramischen Kunsthandwerk haben sich hier auch die Keramikindustrie und zahlreiche Bildungs- & Forschungseinrichtungen rund um das Thema Glas & Keramik etabliert.

Die Wertschätzung und Bedeutung der Deutschen Keramischen Gesellschaft für den Werkstoff Keramik und die hier ansässigen Institute des Bildungs- und Forschungszentrum Keramik e.V., kurz BFZK, sind europaweit einzigartig. Dies beruht insbesondere darin, dass praxisnahe Forschung (FGK, ECREF und Hochschule Koblenz), die Gründertätigkeit (CTC), die Lehre an der Hochschule, der sowie an der Berufsbildenden Schule eng miteinander verknüpft sind und so ein kontinuierlicher Austausch stattfindet. Ein wichtiger Verbund von Ausbildungs- und Forschungseinrichtungen, die sich mit dem Werkstoff Keramik in seiner gesamten Vielfalt auseinandersetzten. Jede dieser Einrichtungen trägt zum europaweit einzigartigen Schwerpunkt der Keramikindustrie bei, dies stellt einen maßgeblichen Beitrag für die Zukunftsfähigkeit unserer Stadt dar.

Entsprechend deren Leitbild prägt die Deutsche Keramische Gesellschaft „DKG", die Netzwerke der keramikorientierten Verbände durch Innovationen und öffentliche Wirkung, verknüpft industrielle Bedarfe und wissenschaftliche Entwicklungen zu Werkstoffen und Verfahren, veranstaltet regelmäßig Gemeinschaftliche Projekte, Tagungen, Symposien, Seminare und Weiterbildungen. Für den Standort Höhr-Grenzhausen und die gesamte Westerwaldregion ist diese Arbeit ein wichtiger und maßgeblicher Beitrag zum Fortbestand unserer Traditionen und der wirtschaftlichen Entwicklung. Das wissen wir hier in Höhr-Grenzhausen sehr zu schätzen, denn wir haben es uns ebenfalls zur Aufgabe gemacht, den Dialog um die Keramik stets zu fördern und zu unterstützen.

Ich danke allen Beteiligten für Ihr großes Engagement und wünsche der Deutschen Keramischen Gesellschaft eine erfolgreiche Tagung mit interessanten Vorträgen und Gesprächen.

Mit herzlichen Grüßen

**Thilo Becker**
Bürgermeister der Verbandsgemeinde Höhr-Grenzhausen

# Greeting from Mayor Thilo Becker to the 99th Annual Conference of the German Ceramic Society

Welcome to Höhr-Grenzhausen in the Kannenbäckerland, a cultural landscape with the largest clay deposits in Europe. I am very glad that the 99th International Scientific Ceramics Conference of the German Ceramic Society is being held at the Höhr-Grenzhausen university location. In addition to the traditional ceramic arts and crafts, the ceramics industry and numerous educational and research institutions in the field of glass and ceramics have also become established here.

The appreciation and importance of the German Ceramic Society for the material ceramics and the institutes of the Bildungs- und Forschungszentrum Keramik e.V. (BFZK) located here are unique in Europe. This is due in particular to the fact that practical research (FGK, ECREF and Koblenz University of Applied Sciences), start-up activities (CTC), teaching at the university and at the vocational school are closely interlinked and thus a continuous exchange takes place. An important network of training and research institutions that deal with ceramics in all its diversity. Each of these institutions contributes to the ceramics industry, which is unique in Europe and makes a significant contribution to the future viability of our city.

In accordance with its mission statement, the German Ceramic Society "DKG" shapes the networks of ceramics-oriented associations through innovation and public impact, links industrial needs and scientific developments on materials and processes, and regularly organizes joint projects, conferences, symposia, seminars and further training courses. For the Höhr-Grenzhausen location and the entire Westerwald region, this work is an important and significant contribution to the continuation of our traditions and economic development. We appreciate this very much here in Höhr-Grenzhausen, as we have also made it our mission to constantly promote and support the dialog surrounding ceramics.

I would like to thank everyone involved for their great commitment and wish the German Ceramic Society a successful conference with interesting presentations and discussions.

Yours sincerely

**Thilo Becker**
Mayor of the municipality Höhr-Grenzhausen

# Wo alles beginnt …

SIBELCO

**WesterWaldCampus, HS Koblenz**

**Festung Ehrenbreitstein**

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**Hochschule Koblenz**

**Keramikmuseum Westerwald**

**IKKG, Hochschule Koblenz**

# LECTURES

# Process optimisation to save energy using chemical additives beyond traditional applications

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While the use of deflocculants in the liquid preparation of fine ceramics has been practised for decades, the situation in plastic moulding is still different today. Particularly in the structural ceramics industry, the use of chemical auxiliaries to influence the body properties is the exception rather than the rule.

In addition to the use of tailored dispersing agents, lubricants and pressing aids also offer the possibility of optimising body properties to reduce the energy requirement in the production process. For this purpose, the entire process must be considered, since saving water and consequently drying energy is only the most obvious but not the only way to improve energy efficiency.

The presentation will show how the use of additives in the production process can save water and energy whilst simultaneously improving quality.

# Application of secondary raw materials

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Discussions towards the economical use of building materials in the future are increasing. Reuse of materials is therefore strongly encouraged, partly by National governments. The pressure to produce less waste is also increasing, and the costs for dumping/incineration of waste increase every year.

A lot of research is being conducted to reuse (previous) residual flows from various industries. When waste is reused as a raw material for a new product, it is referred to as a secondary raw material. In a broad sense, a number of interesting applications are already known, and many industries appear to be working on this.

TCKI, as being a foundation of the Dutch, Belgium and some German manufacturers of ceramic products (e.g. mainly street pavers, masonry bricks, roof tiles, wall and floor tiles) for more than 68 years, is also increasingly being asked to investigate all kinds of secondary raw materials for their possible applicability in the ceramic industry. This includes, for example, (combustion products of) residual flows such as fly ash, household waste digestate, all kinds of trass/glass powder and an increasing number of exotic species.

TCKI follows a fixed strategy during research. It is being investigated whether the material can potentially serve as a replacement for clay, sand or sanding, as an additive or as a combination of these. Test bricks are also made with variation in the amount of secondary raw materials added. After drying and firing test bricks, both their visual and physical/chemical properties are determined. Pitfalls, but also new opportunities are explained in more detail. If there is potential (sometimes after some improvements), the customer can be guided to make contacts with the ceramic industry for any follow-up.

# Digitisation of ceramic surfaces using optical 3D-profilometry

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The surface structure of a floor tile is a key factor for its product properties. Slip resistance, cleanability and durability are significantly influenced by the surface, with shape, topography and roughness being characteristic features. A tile with a surface profile characterised by deep, narrow valleys or grooves is more difficult to clean than a completely smooth surface. This seemingly logical assumption does not necessarily have to be recognisable to the naked eye and certainly cannot be quantified without metrological aids. Optical 3D profilometry makes it possible to digitise the ceramic surface and thus precisely analyse the surface topography. The resulting key figures on roughness and surface topography can then be compared with a wide range of product properties and analysed for correlations.

Knowledge of the surface topography thus enables explanations and predictions about product performance, as well as the analysis of defects. In addition, 3D profilometry is an ideal tool for optimising ceramic surfaces for specific applications, for example through targeted surface design by tile pressing tools.

The state of Rhineland-Palatinate, Ministry of Economics, Transport, Agriculture and Viticulture, has funded the DigiKerO project. In the lecture we want to demonstrate the versatility of optical 3D profilometry for (ceramic) surfaces, highlighting the initial project results.

# Synthesis of a new oxide precursor with low oxygen content and viscosity for the PIP method applied to ZrC.

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Zirconium carbide(ZrC) is one of the famous Ultra high-temperature ceramics (UHTC) materials and is a widely used material in the space and defense field due to its unique properties such as high melting point, high thermal conductivity, and high fracture toughness. One of the densification methods for the practical use of ZrC is the polymer infiltration pyrolysis (PIP) method, which is a useful method for manufacturing complex shapes. However, a suitable liquid polymer precursor is necessary for densification using the PIP method. Therefore, oxide polymer precursors for ZrC have been extensively studied due to their yield stability in air and facile synthesis methods.

Generally, oxide polymer precursor has been synthesized through sol-gel reaction with zirconium alkoxide and carbon source. In particular, the carbon source contains several hydroxyl functional groups for sol-gel reaction with zirconium alkoxide. However, it is difficult to control the molecular weight of the product if many hydroxyl groups participate in the sol-gel reaction, which increases the viscosity of the product significantly. Furthermore, as the oxygen content inside the precursor increases, the ceramic yield decreases because oxygen inside ZrC must be removed through carbothermal reduction. Therefore, new synthetic strategies are required to increase ceramic yield and reduce the viscosity of the precursor.

In this presentation, we will introduce the new oxide precursor for ZrC using both sol-gel reaction and radical polymerization. The carbon source used in our study does not contain oxygen and acts as a solvent, reducing the viscosity of the ceramic precursor and facilitate a stable infiltration process.

# Dosing of gas and combustion air for CO2 reduction – a comparison

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In the energy-intensive manufacture of ceramic products, a wide variety of strategies for reducing energy consumption and the associated $CO_2$ emissions are currently being discussed. As long as $CO_2$ neutral substitute fuels are very expensive or difficult to obtain, it is economically and ecologically mandatory to optimise the firing systems of existing kilns through technical modifications or retrofitting.

The use of preheated combustion air, which is taken from the cooling zone and fed to the burners, has long been recognised as a measure to increase the energy efficiency of a combustion system. Another approach is to minimise the consumption of burner air by using a more precise dosing strategy than was previously the case. Depending on the initial situation, but particularly in systems that are operated with a high excess of air, there is considerable potential for savings.

The presentation introduces the innovative dosing of combustion air using solenoid metering valves. The combustion air dosing technology provided for this purpose works according to the same principle as the already known pulse dosing valves for gas. The air valve is synchronised with the gas pulse with a time offset before and after the gas pulse.

The presentation uses reference projects to compare the technology of air dosing by means of solenoid valves with the use of preheated combustion air.

# New measurement set-ups for the validation of simulation predictions in thermal process optimization

**FRIEDRICH, Holger Dr. | KONSCHAK, Alexander Dr. | ZIEBOLD, Heiko | SHARBA, Shadi Dr.**

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The ambitious climate targets set by the EU, as well as economic benefits, require the improvement of thermal processes in the ceramics industry. This includes both minimizing heat losses and understanding the heat transfer from the kiln and its atmosphere to the firing material and vice versa.

Simulations are an important tool in this process optimization. The underlying calculations require precise input data for the materials and processes under consideration, which are dependent on temperature and, in the case of the product, also on the progress of the firing process.

To generate reliable material data and validate simulations, new test rigs have been set up and verified at HTL. One rig is used to measure the heat transfer coefficient during drying and debinding to better describe the convection that prevails at low temperatures. A second one is used to determine the radiation transfer during firing at high temperatures. A third set-up allows the measurement of the thermal conductivity of high efficiency insulation materials in a large-scale electric kiln. The new test rigs will be presented with examples of measurement results and the possibilities for improving the energy footprint of thermal processes will be described.

# Continuous layer deposition for the Additive Manufacturing of ceramics by Layerwise Slurry Deposition

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Powder bed technologies are amongst the most successful Additive Manufacturing (AM) techniques. The application of these techniques to most ceramics has been difficult so far, because of the challenges related to the deposition of homogeneous powder layers when using fine powders.

In this context, the "layerwise slurry deposition" (LSD) has been developed as a layer deposition method enabling the use of powder bed AM technologies also for advanced ceramic materials. The layerwise slurry deposition consists of the layer-by-layer deposition of a ceramic slurry by means of a doctor blade, in which the slurry is deposited and dried to achieve a highly packed powder. Not only very fine, submicron powders can be processed with low organics, but also the dense powder bed provides excellent support to the parts built. The LSD technology can be combined with binder jetting to develop the so-called "LSD-print" process.

The latest development of this technology shows that it is possible to print ceramic parts in a continuous process by depositing a layer onto a rotating platform, growing a powder bed following a spiral motion. The unique mechanical stability of the layers in LSD-print allows to grow a powder bed several centimeters thick without any lateral support. The continuous layer deposition allows to achieve a productivity more than 10X higher compared to the linear deposition, approaching a build volume of 1 liter/hour.

# Small-pored SiC substrates and their application as Diesel particulate filters with high PN efficiency

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Diesel particulate filters (DPF) are a component of every Euro VI or Stage VI exhaust system. Depending on the design of the engine calibration and the regeneration strategy, DPFs must be able to store different amounts of soot and withstand the resulting temperatures and thermal gradients in the event of an interrupted active regeneration. For applications with high soot loads of around 8 g?L-1 and difficult regeneration conditions, silicon carbide (SiC) ceramics are used as a filter substrate. Dinex is a manufacturer of complete exhaust systems, including the design and manufacture of cannings. The product portfolio also includes associated catalysts and its own SiC filter substrates. The product portfolio includes highly porous SiC materials1, which are produced by a reaction forming process. A mixture of metallic silicon with graphite is extruded as a honeycomb, converted to ?-SiC at T = 1450–1600 °C and then converted to ?-SiC in a high-temperature step2. The small-pored SiC material3 with a pore size of 7–10 ?m exhibits a sufficiently high separation rate after just one conditioning cycle (WHTC) on the engine test bench and can comply with the Euro VI emission limit value of 6?1011 particles ? kWh--1. The small-pored filter material was tested in an active regeneration test followed by a durability test and thermal cycles. The filtration efficiency was not impaired. The newly developed small-pore SiC substrate material therefore exhibits high thermal shock stability and durability.

# Material Development of Cerium Oxide Suspensions for Vat-Photopolymerization

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The importance of hydrogen as an alternative energy source is growing in times of climate change and energy transition. A possible approach for the regenerative production of green hydrogen using solar energy is being investigated in the publicly funded Redox3D project in collaboration with the DLR. In this project, the development and production of receiver-reactor geometries for solar-thermochemical hydrogen production is being driven forward. The functional ceramic cerium oxide is used as a high temperature redox material for these reactors.

First results of material development for the production of cerium oxide ceramics via vat photopolymerization (VPP) are presented. The ceramic material cerium oxide is not widely used and there is almost no information in the literature about the additive manufacturing of cerium oxide via VPP. Since there are no commercially available cerium oxide suspensions for the VPP process, they had to be developed from scratch. Viscosity measurements were carried out to characterize the suspensions. Dispersants were used to reduce the viscosity of the suspensions, allowing a significant increase in the solid content. After the additive manufacturing process, the organic components must be removed from the parts in a three-stage thermal post-treatment. The thermal behavior of the parts was investigated using dilatometry and TG analysis. Based on these results, the thermal post-treatment was optimized to achieve dense sintering of the ceramics.

# Micro Particle Jetting: A novel AM technology for oxide and non-oxide ceramics

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In the last decade of ceramic processing, a number of additive manufacturing (AM) technologies have evolved. Each of the different technologies may have its benefits and drawbacks regarding productivity, resolution, wall thickness, thermal postprocessing or powder characteristics.

The team of D3-AM is developing a novel AM technology: Micro Particle Jetting (MPJ). With MPJ it is aimed to enable the 3D printing of oxide and non-oxide ceramics, where other AM technologies may reach their limits.

The process is based on inkjet printing. Water-based suspensions are applied with a self-developed print head, which allows the processing of powders with particle sizes up to 60µm. Bright colored as well as dark materials can be shaped into components with low/high wall thicknesses (1-30mm) reaching a resolution of ~150µm. The combination with a support material enables overhangs and internal channels.

Two materials have successfully been developed and processed so far using MPJ. The focus was put on aluminum oxide as well as sintered silicon carbide (SSiC). For both materials dense samples were fabricated reaching relative densities >99% and >98%, respectively. Highlighting SSiC, it is a material of interest in various industries due to its mechanical and chemical stability at elevated temperatures, resistance against thermal shock, thermal conductivity, and its hardness close to diamond. Limited work has been reported regarding additive manufacturing SSiC, resulting in a dense and fine-grained microstructure.

Micro Particle Jetting may open the path to additive manufacture oxide or non-oxide ceramics using environmentally harmless water-based suspensions with low limitations in materials selection and component size.

# Ontologies and data pipelines – a field report from the development of multilayer ferrite inductors

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Digitalization is a current and prominent cross-cutting topic in ceramics and materials science in general. Many research initiatives and levels of significance are associated with this term. The Initiative Platform MaterialDigital (PMD), for example, aims to create a material data space filled with semantically linked data. The concept envisages that semantic relationships between the data are described as ontologies and that processing of data takes place via automated data pipelines. Various research projects from all areas of materials science are working on the implementation of this concept based on specific use cases.

In the project presented here, the use case is the development of multilayer ferrite inductors as passive microelectronic components. The inductors are fabricated by ceramic multilayer technology and co-firing of metallized tapes of NiCuZn ferrite and a dielectric base material. Investigations focus on the effects of fabrication technology on the permeability of the ferrite. A data pipeline is introduced that automatically processes the unstructured experimental data into structured, machine-readable and semantically linked data. It is shown how SPARQL queries are used to retrieve proper input values from this data to enable, for example, a reliable prediction of component inductance using multiphysics simulations. The concrete implementation of the data pipeline and a domain ontology will be presented using examples and challenges and advantages will be discussed.

# Membrane Reactors – Classical and Additive Manufacturing of Asymmetric Ceramic Membranes

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The presentation covers setup of membrane-driven reactors and possible areas of application. It is focused on the ceramic membrane components as central component of the reactor setup. Membrane components consist of two structural parts: on the one hand there is a 20-100µm thin separation membrane made of special ceramics showing ion conductivity, on the other hand there is need for a supporting structure to brace the fragile membrane shell. So, membrane components forms a asymmetric ceramic group which has to manufactured. Including classical manufacturing methods (Tape Casting) and new Additive Manufacturing methods (3D Screen Printing) versatile approaches are covered producing these membrane assemblies. The presentation shows current work at Forschungszentrum Jülich/IEK-1 and at WZR ceramic solutions GmbH, which are consortium partners in the AMAZING project (Additive Manufacturing for Zero-emission Innovative Green Chemistry). The presentation concludes with an outlook of the potential of this emerging reactor technology as replacement for conventional emission-intensive production facilities.

# Laser-induced direct metallization of additively manufactured chromia doped alumina

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Laser-induced direct metallization (LDM) is a two-step metallization process capable to apply 10 - 15 µm thick and down to 50 µm fine metallic structures on 3D surfaces of oxide ceramics. It consists of an activation step in which the surface of the substrate desired to be metallized is selectively structured with a pulsed laser beam thereby changing surface morphology and chemistry. During the subsequent metallization step the substrate is immersed in an autocatalytic (often called electroless) plating bath in which metal is deposited selectively at the activated surfaces. The activation effectiveness and the coating properties are predominantly influenced by the laser and the substrate properties. This study investigates the laser activation of additively manufactured 2 wt.% chromia doped alumina activated with a picosecond pulsed laser with a wavelength of 523 nm. Samples were were manufactured via Digital Light Processing (DLP) and sintered with different holding times. The influence of the holding time and of the laser activation parameters on the autocatalytic metal deposition with copper was evaluated.
It is shown that with increased holding time the plating thickness declines and the roughness of the plated copper layers increases for all investigated laser activation parameters. The surface topography of the additively shaping parts showed no influence on the metallization effectiveness compared to injection molded samples.

Additionally, an additively manufactured and 3D metallized functionalised part with conducting paths and mounted LED is shown demonstrating the applicability of the process on tilted surfaces and the prospects of the technology to manufacture functionalized ceramic parts.

# 3D printed porous $SiO_2$ structures for $CO_2$ capture

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Porous $SiO_2$ plays an important role in a variety of applications in chemical process engineering, e.g. as a catalyst support, chromatography material or as an adsorbent. In most cases, a bulk of porous $SiO_2$ is used, the flow through which is not completely ideal. 3D printed and partially sintered structures allow control over the macroscopic level of hierarchical porosity, whereby the micro- or mesoporosity of the material should not be affected.

The paper presents the application of 3D printed polyethylenimine coated $SiO_2$ substrates using MEX material extrusion and DLP digital light processing for $CO_2$ capture and release. It is shown that while maintaining the high specific surface area of the $SiO_2$ body, mechanically stable monoliths could be produced that exhibit a massively reduced pressure drop compared to conventional powder spills with comparable $CO_2$ adsorption capacity.

# Ceramic multi-material 3D printing through vat photopolymerization

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This talk presents the status quo of multi-material additive manufacturing (AM) of ceramics based on lithography-based ceramic manufacturing (LCM), a technology belonging to the family of vat photopolymerization (VPP) techniques. Beside the introduction to the technological principles and the elaboration of current limitations and boundaries, the focus of this presentation will also be on the results and current challenges in terms of co-printing and co-sintering of different ceramic materials as well as ceramic and metals. Different material combinations have been investigated including hydroxyapatite (HA)/tricalcium phosphate (TCP), porous/dense alumina, porous/dense HA, alumina/zirconia-toughened-alumina (ZTA), and copper (Cu)/glass ceramic. In more detail, this contribution will showcase the use of this multi-material AM approach to combine ZTA sandwiched between pure alumina, yielding a characteristic strength higher than 1 GPa on the laminate multi-material system, compared to 650 MPa in the monolithic alumina. It will also present the outstanding thermal shock resistance of such AM produced multi-material components owing to the embedded compressive layers, which leads to a significant performance enhancement compared to the monolithic reference. This article also discusses the main issues and future possibilities of ceramic-ceramic and metal-glass ceramic multilayer fabrication by LCM technology. The initial results show that this technology holds great potential to path the way from classical single material structures to multi-material and functionally graded ceramics.

# Cordierite: Advancing Engineering Frontiers through Additive Manufacturing Excellence

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Cordierite, an esteemed aluminosilicate with the chemical formula (Mg,Fe)2Al4Si5O18, has been extensively researched since its discovery. Recognized for its remarkable wear resistance and extraordinarily low coefficient of thermal expansion (CTE) of around 2 ppm/°C at room temperature—lower than that of most metals and technical ceramics—cordierite emerges as a premier technical ceramic. Its allure extends to high-temperature electronics, photonic instruments, aerospace components, energy applications, and high-performance sensors, where temperature fluctuations could imperil measurement accuracy and safety. However, cordierite's material performance hinges heavily on its powder metallurgical processing, where powder treatment and composition significantly influence phase stability, posing challenges for ceramic synthesis and processing industries trying to yield top-notch products.

3DCeram achieved a significant breakthrough with its stereolithography (SLA) technology, utilizing a UV laser to cure a ceramic-dispersed photopolymeric slurry. Material extrusion (MAT) technologies have shown promise, enabling layerwise deposition of thermoplastic pellets, filaments, or ceramic suspensions. Both methods unlock novel shaping possibilities for cordierite's applications and enhance its performance. In 3DCeram's SLA technology, a specialized cordierite powder mixture tailored for space applications allows a further reduction of the CTE to -0.1 ppm/°C at 20°C, surpassing commercially available cordierite. This breakthrough opens up possibilities for high-volume production of intricate parts with exceptional properties, redefining its boundaries in modern engineering across various fields.

# Manufacture and properties of highly dense 3YSZ coatings

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Sintered ceramics made of 3 YSZ have a high fracture toughness due to the so-called transformation reinforcement. In this work, as part of an AIF project, it should be investigated whether thermally sprayed layers made of 3 YSZ also have such high toughness values. Both atmospheric plasma spraying (APS) and suspension plasma spraying (SPS) were used for this purpose. The aim was to produce layers with high density, fine grain size and a high proportion of tetragonal phase. Various mechanical tests were carried out on the layers, e. g. hardness tests but also bending tests on notched microbeams. These tests provided initial evidence of transformation toughening, although the measured toughness values fell short of expectations.

# Realizing sealing layers and refractory metal contacts on ceramic surfaces using diode laser array treatment

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One of the most significant challenges currently facing the modern ceramic industry is the need to enhance the energy efficiency of technological processes, particularly those related to thermal treatment. The conventional thermal treatment is not only energy-intensive but also results in unacceptable deterioration of certain ceramic materials, like in case of sealing of the highly porous surfaces of oxide-based ceramic matrix composites (OCMCs), or during the realization of refractory metal contacts. Therefore, this work is focusing on the establishment of laser-based approaches to resolve these issues.

For this purpose, the glass-containing pastes having sufficient laser energy absorption were formulated, their printing and the laser treatment were optimized. The innovative diode laser array operating in the continuous wave mode in the near infrared spectral range with a line-shaped beam was used. This ensured high-speed (dwell time in the millisecond range), energy efficient (electrical-to-optical efficiency 50-60%) selective heating of the printed layers. Using this approach, the OCMC sealing was demonstrated. For the sealing layer to be melted, a dwell time of 20–30 ms and an intensity in the range of 5–14 kW/cm$^2$ were required. As a result, a partial infiltration of the porous OCMC matrix at depths 10-40 µm was achieved keeping the material intact without thermal degradation of alumina fibers. This approach also enabled realization of low-resistance Mo-based layers on low-cost alumina substrates under ambient air. Laser radiation with intensity around 25 kW/cm2 was heating the metallic particles for a short time (1-3 ms), melting glass component in the structure, and ensuring good adhesion of the layer to the substrate.

# Free Flow Structuring – a slurry-based binder jetting technology process

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Among the different techniques for the Additive Manufacturing of Ceramics, Binder Jetting is the most promising method to economically produce large ceramic parts. Due to the commonly low sinter activity of the flowable feedstocks its applications for ceramics are limited to porous or melt-infiltrated parts. However, by using flowable slurries as a starting material, which are applied via slot-die coating in free flow, fine powder particles can be used. This allows to produce a more densely packed powder bed with significantly less distinct interlayer structure, good interlayer homogeneity, and higher sintering activity. Onto the powder bed, thermally or UV-curable binder systems are selectively jetted via inkjet printheads in order to define the part contours. In doing so, ceramic, metal or hard metal green parts consisting of fine powder particles with a high packing density can be obtained, resulting in dense sintered parts. This process which has been developed at the Fraunhofer Center HTL is called Free Flow Structuring (FFS). Dedicated FFS devices have been installed at the Fraunhofer Center HTL, which can be used to process a variety of feedstocks.

# Robocasting of aluminum-doped zinc oxide (AZO)

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Robocasting, also known as direct ink writing, is an additive manufacturing technique offering the possibility to shape various materials, e.g., ceramics or metals, into three-dimensional complex shapes. Highly filled pastes, which can be water- or solvent-based, are extruded through fine nozzles and deposited layer-by-layer. Another advantage of the robocasting process is the possibility of multi-material printing, facilitating the combination of different materials within a single print. This capability enables the fabrication of complex, heterogeneous structures with spatially varying properties. The rheological properties are decisive for the quality and shape retention of the final product.

In the present work, the study focuses on the investigation of a printable water-based paste to produce aluminum-doped zinc oxide (AZO). AZO is a widely used material class since it is highly electrically conductive and a low-cost alternative to e.g., indium tin oxide (ITO). Using this environmentally friendly paste, various structures were fabricated by robocasting, and the mechanical and physical properties of the manufactured ceramic were investigated.

This work additionally showed the capability of combining AZO with an electrically isolating material, ZrO2. Core-shell structures as well as layered multi-material samples are feasible using two extruders and specially designed nozzles.

# Manufacturing of ceramic-steel-composite materials via conventional extrusion and three-dimensional additive extrusion technology

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Extrusion is state-of-the-art in the manufacturing of ceramic materials such as thermal handling equipment, cellular structures for liquid and gas filtration, tiles and bricks. The extrusion process was also successfully transferred to a range of innovative materials e.g. metals or metal-ceramic composites in recent years. Here, the combination of powder metallurgical methods and the ceramics-derived extrusion process enables the fabrication of a certain range of complex shaped specimens that cannot be produced using other technologies.

Generally, mixing the raw materials with an aqueous plastification system provides a plastic paste at ambient temperature. The extrusion of these plastic pastes allows for the efficient production of a large variety of items. Both, the flexibility in materials and shape favour the demanding industrial application. The thermal treatment comprising drying, debindering if necessary, and the final consolidation (sintering) transfers the material into its final state. However, the geometry of the extrudate is limited since the paste is pressed through a rigid die with a constant cross section. Complex structures are excluded from manufacturing or require extensive post-processing. Here, combining the extruder with a 3-axis machine with computerized numerical control enables the three-dimensional (free) forming of the paste with an improved geometric flexibility.

The fabrication of metal-ceramic composite materials based on highly alloyed steels with certain ceramic components are in focus of the presentation. The classic linear extrusion and the three-dimensional extrusion address different future applications comprising engineering materials and high temperature components.

# Automating the Future: High-Throughput Production of Porous Alumina Ceramics

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The high-throughput (HT) method, characterized by automated sample preparation and analysis coupled with AI-driven data evaluation, is already well established in the pharmaceutical and chemical fields. However, its application in materials science, especially in ceramics research, remains limited. Key areas in ceramics research that would greatly benefit from the use of HT processing are the analysis of phase diagrams or the evaluation of the complicated relationship between microstructure and properties in porous ceramics. We present the first step toward automated processing of porous ceramics by the sacrificial templating method, using an automatic powder dispensing robot to improve accuracy and reduce manual work. The reliability of the system and the predictability of deviations were evaluated based on powder flowability. Porous alumina ceramics with varying porosities and pore geometries were successfully fabricated using different organic pore builders. Precise dosing enabled fine tuning of porosities, resulting in highly tunable mechanical and thermal properties. Our results highlight the significant potential of high-throughput methods in advancing porous ceramic research, offering opportunities for increased efficiency and precision in material characterization and development.

# Chemical Vapor Deposition of Phase Pure Thorium Dioxide Films from Volatile Molecular Thorium(IV) Precursors

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Thoria ($ThO_2$) has been identified as an excellent candidate for the use as a heterogeneous catalyst in the ammonia (NH3) synthesis from nitrogen ($N_2$) and hydrogen ($H_2$), as indicated by theoretical calculations.[1] In pursuit of an efficient method for generating $ThO_2$ coatings, volatile metal-organic thorium(IV) complexes have been synthesized and employed as single-source molecular precursors for the metal-organic chemical vapor deposition (MO-CVD) of $ThO_2$ thin films.

The high volatility and thermal decomposability of the precursors facilitate the production of homogenous $ThO_2$ thin films. Adjusting the substrate temperature during the deposition process enables the manipulation of the resulting morphology after post heating treatment.

[1] G. Wang G, E.R. Batista, P. Yang, 2023, Front. Chem. 10, 1051496.

# Experimental and numerical studies of densification, deformation and delamination of co-sintered multi-material composites

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Nowadays, the fabrication of multi-material components with desired geometries and tailored microstructural properties is drawing continuous attention. By laminating or additive manufacturing and subsequent co-sintering, multi-material composites that combine a wide range of favorable properties can be produced. Examples are metal-ceramic laminates and multi-ceramic composites, which effectively open the spectrum of material applications and provide a higher degree of flexibility than single materials. However, undesired deformation that triggers delamination, curvature, cracks or even catastrophic failure frequently occurs during the co-sintering process. To solve these issues, a thermo- mechanical model that predicts densification, deformation and delamination of multi-material components along the entire co-sintering process was developed. The multi-ceramic composite $Al_2O_3$/3Y-TZP and metal-ceramic laminate 17-4PH/3Y-TZP were selected to test and validate the developed model by experimental investigations. The developed model effectively describes deformation, curvature, and stress distribution in studied material combinations, as revealed by experimental studies.

# Using machine learning to classify pore types in ceramic replica foams

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Porous ceramics are promising materials for the energy transition, for use in lightweight structures, as support materials for catalysts or heat exchangers. The surface to volume ratio gives them an advantage over dense materials. The most commonly used industrial process is the replication process based on heterogeneous polymer foams or templates. Burning out the struts leaves hollow struts with the typical triangular structure of polymer foams. Using microtomography (µCT) measurements, the microstructure can be displayed as a stack of 2D cross-sectional images, which are used for evaluation. However, current software solutions cannot separate the different types of pores. Using machine learning, a neural network based on the Eff-Net architecture is employed. The necessary training network is generated by Liner.AI software using 2,800 training images of a 30 ppi $Al_2O_3$ foam with up to 10,000 training iterations and data augmentation. The recognition accuracy for the strut pores was over 87%, while that for the foam pores was 99%. This is then used in the next stage of the Tensorflow-based neural network to identify the strut pores in arbitrary ceramic replica foams. Here, 1200 images of another ceramic foam and a 30ppi PU foam are analysed. The network identified 16.86% material, 81.91% foam pores and 1.23% strut pores for the ceramic. For the PU foam only material (3.9%) and foam pores (96.1%) were identified. For the ceramic, the values obtained are consistent with the total porosity. In addition, the amount of coating on the replica foam can be deduced from the µCT images.

# Porous ceramics – why it's important to identify the representative volume-of-interest

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Porous ceramic foams are used in a wide field of applications as catalyst support structures, lightweight materials, filtration, energy or acoustic adsorption or energy storage materials. Beside this, porous ceramic scaffold for bone replacement are a promising material in future to ensure a faster medical healing.

In addition to determining the pore morphology, surface, connectivity and shape, the physical properties (thermal, mechanical, acoustic) are of crucial relevance for the applications mentioned. There is a difference here compared to dense ceramic materials, as the structural as well as physical properties are significantly shaped via the pores and porosity. Therefore, it is essential to determine the minimum volume, which allows a generally valid prediction for the entire structure. This so-called representative volume-of-interest (REVOI) can be determined by a combination of image evaluation based on µCT images and FE simulations in combination with physical measurements. Using examples of $Al_2O_3$ replica foams [1], porous $Al_2O_3$ ceramics via sacrificial templates [2] and 3D printed structures [3], the principle and necessity of the representative volume is explained.

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[3] Biggemann J., Köllner, D., Schatz, J., Stumpf M., Fey, T., Influence of µCT scanning resolution and volume on FEM-simulation of periodic 3D-printed porous ceramics, Materials Letters (2021), 303, 130529, 10.1016/j.matlet.2021.130529

# Insights into the Sintering Processes of Ceramics revealed by in situ High Temperature Raman Imaging

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Raman spectroscopy has proven to be a powerful tool for the investigation of various materials at room temperature, including minerals, gases, glasses and organic compounds. By combining Raman Microscopes with high temperature and high pressure setups, the in situ study of mineral reactions has become feasible. Here we present a novel approach using in situ hyperspectral Raman imaging to study the sintering process in silicate ceramics. This method allows real-time, spatially resolved analysis of solid-solid phase transitions at elevated temperatures, providing unprecedented insight into high-temperature reactions in multi-component systems. By eliminating the need to quench samples prior  analysis, our technique allows us to study of thermodynamic and kinetic phenomena during sintering. In our investigation of the CaO-$Al_2O_3$-$SiO_2$ system, samples were heated stepwise from 700 °C to 1200 °C at a heating rate of 10 °C/min and hyperspectral Raman images were acquired at each temperature step. The resulting images, generated using classical least squares fitting, based on reference spectra, provide insight into phase proportions and reveal the evolution of mineral fractions over time. Three application examples demonstrate the utility of our method in revealing the effects of quenching, tracking the migration of solid-solid reaction fronts at the micrometer scale, and estimating relative mineral fractions to obtain kinetic information.

# Coating of Fe2O3 Particles with CuO as well as Carbon by Pulsation Reactor and study the effect of thermal retreatment in Forming gas on coated Particles for Metal Air Batteries

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Iron-air batteries represent a promising alternative for inexpensive and environmentally friendly electrical energy storage. The presence of iron as starting materials were predominantly pure iron powder or iron oxides (magnetite, hematite) in addition to graphite as the conductive component. The coating of $Fe_2O_3$ fine particles with CuO particles with specific properties can be thermally synthesized by the pulsation reactor. The particles produced using this technology are thus subjected to rapid thermal treatment as it advances in the hot gas stream. Therefore, the process is particularly suitable for the production of powders with modified characteristics.

This work describes the characteristic properties of the CuO coated $Fe_2O_3$ particles with the addition of Carbon materials to improve the conductivity. During the coating process in the pulsation reactor, the characteristic process parameters such as temperature as well as composition and art of the coating materials, on properties of the produced particles were investigated applying different analytical methods. According to this work, it was also concluded that the PR technology could reach a wide range of fine particles with tailored properties in a continuous process.

The produced particles were successively thermally reduced using laboratory rotary furnace to increase the conductivity of the produced coated particles. Also, the effect thermal retreatment in Forming gas atmosphere on the properties of the coated particles were studied and optimized to select the best conditions for the production of active coated particles with specific properties for the application as metal air battery slurry.

# Modeling Microstructure-Property Relationships in ATZ/ZTA Ceramic Composites: Simulation, Machine Learning, and Optimization

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The properties of ceramic composite materials such as zirconia toughened alumina (ZTA) crucially depend on the composition of the microstructure. Various parameters, such as the volume fractions of the individual components, grain size ratios and interface fractions, have an influence on the macroscopic material behavior. By adapting the microstructure in a targeted manner, the ceramic can be tailored to the specific requirements of the application.

We present a simulation-based approach for modeling the relationship between microstructure and material properties. A microstructure generator first generates a 3-dimensional image of the ceramic structure. Using finite element simulations, the associated macroscopic material properties (e.g. thermal conductivity) of the actual structure are calculated. Validation and calibration of the simulation using characterized ideal samples ensures high reliability of the simulation results. The space of design parameters of the relevant microstructures is systematically scanned by automating the simulation.

The data obtained is used to train a probabilistic machine learning model (Gaussian process). The model is able to efficiently and accurately predict the corresponding macroscopic material properties for a given microstructure.
By applying an adaptive sampling strategy, the required number of training data points is greatly reduced and high data efficiency is achieved.

The model then serves as a surrogate function in a numerical optimization routine. This approach allows us to specifically tune and optimize the parameters of the microstructure to the desired properties.


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# High-resolution computer laminography as a powerful tool for the non-destructive testing of LTCC multilayer components

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The inspection of ceramic components, such as LTCC multiylayer components, after processing and sintering is a major challenge. Ultrasound based methods can be used to examine flat samples for defects that are not optically accessible. Since we are looking from the surface, defects are sometimes hidden underneath conductive tracks. X-ray tomography can also reveal defects hidden in depth, as we obtain a 3D model of the sample, but this requires a certain sample thickness. Therefore, high resolution computer laminography (HRCL) combines advantages of both techniques. The special set-up was developed at the Fraunhofer IKTS to examine printed circuit boards.

First, the principle of laminography is briefly explained. The magnification M is defined by the quotient of the distance between source and object (SOD) and source and detector (SDD). The smaller the distance between source and object, the higher the resolution. The X-ray tube is positioned vertically for this purpose. The planar object can pass under the tube and thus produce minimal SOD. For a complete image of the object, it is rotated. The resulting oblique radiations (1600 projections) are then reconstructed as a volume. This results in typical artifacts such as the capping artifact.

The authors present in this contribution the benefits of HRCL for LTCC multilayer components as inspection method by showing different HRCL resolutions. With the highest resolution in our test structures the authors reveal a porosity that was not previously expected. The summarized advantages are:

- No prior information necessary
- Non-destructive
- High lateral resolution
- Satisfactory resolution in normal direction
- Localization of features at different depths (3D) possible

# Modelling and simulation of debinding in ceramic green bodies

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In the production of ceramic parts, organic binders which are necessary for forming must be removed from the green body. During thermal debinding, the binder decomposes into gaseous reaction products which then must be transported from the interior to the surface through the available pore channels. This creates a gas pressure in the pores and, hence, stresses in the solid skeleton. Along with the thermal stresses associated with the external heating and the heat of reaction in the interior, these may damage the part and thus represent a limiting factor for the heating rate. As an alternative to costly and time-consuming trial-and-error cycles for finding optimal process parameters, numerical Simulation offers the possibility to design, e.g., the Temperature profile so that the process can be completed in a minimum time and thus savings in both time and energy can be achieved. The talk presents a general model for the debinding process that describes the relevant mechanisms, i.e., chemical decomposition and capillary-driven transport of liquid binder, pressure- and diffusion-driven transport of gaseous reaction products and deformation of the solid skeleton. The experimental determination of the relevant model parameters is described and examples for the computation of transient gas pressures and skeleton stresses along with the optimisation of the temperature profile are given.

# In-situ deflection measurement of B3B-strength testing through X-ray tomography and radiography

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Biaxial testing is one of the cornerstones of mechanical strength testing for brittle materials such as ceramics and glasses. Over the past two decades, the use of the Ball-on-Three-Balls-test (B3B) has increased due to the method's high accuracy and fast/simple execution. As there is no sufficiently precise analytical description for this load case, the strength of specimens is calculated using an empirical expression that is based on results obtained through Finite-Element-Analysis (FEA). It is available for a practically relevant specimen geometry range. In recent work, FEA has been utilized to assess the influence of non-linear effects, such as large specimen deflection, on the measured strength.

In order to validate the utilized FEA-model for these extreme cases, the experimental measurement of the specimen's displacement is necessary. Due to the design of the fixture for the B3B-test, common direct methods, such as digital image correlation or LVDT-measurements, are not feasible. Therefore, X-ray tomography was employed to directly track the displacement of the load and support balls in three dimensions. Furthermore, the ball displacement was also determined from two dimensional radiographs. The latter method significantly decreased the experimental time and allowed continuous measurements. Further validation was provided through indirect LVDT measurements of the whole testing setup. The experiments were performed on thin plates of high strength glass to emphasize the influence of non-linear geometric effects. Additionally, transformation toughened Ce-doped zirconia was investigated to assess the influence of quasi-plastic material behavior in the B3B-test.

# Knowlege Management in der sanitärkeramischen Industrie

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Im Kontext der sanitärkeramischen Industrie spielt ein effektives Wissensmanagement eine entscheidende Rolle bei der Verbesserung der Effizienz, Innovation und Nachhaltigkeit der Produktion. Der Vortrag stellt die Bedeutung von Wissensmanagementpraktiken in diesem Sektor vor, mit besonderem Fokus auf das neu eingerichtete Büro in Höhr-Grenzhausen. Als zentrale Anlaufstelle für Wissenstransfer und interne Schulungen soll das Büro den Austausch von Keramik-Know-how über die Landesgrenzen hinweg erleichtern. Durch Präsenzveranstaltungen, digitale Tools und kollaborative Plattformen sollen Mitarbeiter befähigt, Entscheidungsprozesse verbessert und kontinuierliches Lernen gefördert werden. Neben diesem Wissensaustausch wird auch die Informationsbeschaffung und -speicherung im Umfeld eines international produzierenden Konzerns thematisiert. Die Integration von keramikspezifischem Wissen über Werkstoffeigenschaften, Produktionsprozesse und Messverfahren trägt zum Gesamterfolg der Organisation bei. Durch strategisches Wissensmanagement kann sich die Sanitärkeramikindustrie an veränderte Marktanforderungen anpassen, die Produktentwicklung vorantreiben und den Herausforderungen des anthropogenen Klimawandels begegnen.

# Energieeinsparungen in der Silikatkeramik durch Optimierung des Rohstoffversatzes

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Das Thema der Nachhaltigkeit im Bezug auf die Verwendung von Primärenergie ist nicht erst seit den massiv gestiegenen Energiekosten ein Thema in der klassische Silikatkeramik. Neben dem Sintern sind auch die Rohstoffaufbereitung und die Trocknung energieintensive Herstellschritte, wobei Zusammensetzung, Aufbereitung, Trocknung und Wärmebehandlung miteinander eng korreliert sind. Hier gilt es neben der zu erzielenden Energieeinsparung dennoch nicht die wichtigen Produktparameter zu vergessen:

- Formgebungs-, Trocknungs- und Brenneigenschaften der Masse bei reduzierter Feuchte
- Erhöhung der Materialfestigkeit zur Steigerung der Bruchlasten
- Reduzierung des Trocken- und Brennbruchs
- Verbesserung der Frostbeständigkeit und Reduzierung des Materialeinsatzes
- Vermeidung von Haarrissen in Glasuren und Engoben durch angepasste Rohstoffzusammensetzungen sowie von Ausblühungen löslicher Salze.

Neben dem Einsatz von klassischen Prozesshilfsmitteln und Additiven soll dies hier vorrangig durch eine Optimierung des Rohstoffversatzes als auch der Prozessparameter erreicht werden. Von großer Bedeutung ist hierbei die Charakterisierung der Rohstoffe an sich und mit besonderem Fokus auf die Verarbeitungs- und Trocknungseigenschaften. Zum Abschluss des Projektes soll ein Modell vorliegen, welches es ermöglicht Energieeinsparungen durch eine gezielte Anpassung der Rohstoffversätze zu realisieren.

# The impact of hydrogenbased firing technology on silicate ceramic products

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The joint project "Development of an innovative hydrogen-based kiln technology for the production of ceramic materials (H2TO)" is part of the programme "Avoidance of climate-relevant process emissions - KlimPro" of the German Federal Ministry of Education and Research (BMBF) and is a multidisciplinary cooperation between a manufacturer of chamotte and clay products, the IZF Institut für Ziegelforschung e.V. and the Transferstelle Bingen (TSB), a division of the ITB - Institut für Innovation, Transfer und Beratung gemeinnützige GmbH, the Transferstelle Bingen (TSB), a division of ITB - Institut für Innovation, Transfer und Beratung gemeinnützige GmbH, KERATEK GmbH, Keramischer OFENBAU GmbH, Küppers Solutions GmbH and FGK Forschungsinstitut für Glas | Keramik GmbH. The aim is to demonstrate a concept for the implementation of a hydrogen-based tunnel kiln technology for an existing kiln plant, taking into account the local conditions, the investigation of the possibilities for local production and supply of green hydrogen, the development of a tunnel kiln technology with regard to the mutual influence of energy and process-related emissions for the production of ceramics, and the investigation and adaptation of the materials to the changed process conditions. The presentation will focus on the aspects of firing conditions using hydrogen as fuel on the quality of the ceramic products. The first results of the investigation at the FGK Institute on the influence on the phase development during ceramisation in a water vapour atmosphere and its influence on the physical and chemical properties of the products will be highlighted.

# Method development for real-time analysis and characterisation of mineral raw materials and residues

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Automated real-time characterisation of clay minerals and raw materials plays a crucial role in a wide range of industries. Clay raw materials are widely used in the ceramics, construction, and environmental industries. Accurate knowledge of their composition is essential to assess the quality of the materials. This in turn enables the optimisation of manufacturing processes and the development of new technologies. Fast and accurate analysis is fundamental to make the extraction of raw materials itself more targeted and efficient. It can ensure faster response times and increased resource efficiency. With this in mind, the FGK has invested in the development of infrastructure to use the latest analytical systems in research and industrial applications. Innovative methods such as Environmental Scanning Electron Microscopy (ESEM), Raman-Spectroscopy, Hyperspectral Imaging of drill cores and Laser-Induced Breakdown Spectroscopy (LIBS) are used. These methods will also be used in combination with new ways of data analysis and the application of machine learning based algorithms for the automated evaluation and classification of mineral commodities.

# Production of electrospun calcium zirconate fibres for use in refractory crucibles for melting titanium

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One way of producing ceramic fibers on a nanoscale is the method of electrospinning from specific precursor solutions. This contribution presents the production route of calcium zirconate ($CaZrO_3$) fibres using the electrospinning process and subsequent thermal treatment. Furthermore the influence of these fibres in refractory $CaZrO_3$ crucibles for the melting of titanium alloys on the thermomechanical properties of these crucibles is demonstrated.

Starting from methanol-based spinning solutions, an ethanol-based spinning solution was developed which enabled the small-scale production of fibre mats. After calcination at 800 °C, low amounts of the fibres produced in this way were added to $CaZrO_3$ compositions for the production of crucibles. The addition of commercial yttria-stabilized zirconia (YSZ) fibres was also tested to compare the effects of the different fibres. The chemical, physical and thermomechanical properties are presented and the results of the casting trials with Grade 5 titanium alloy are shown.

# Development and characterisation of Al2O3-C stopper materials with boron-free glazes

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Monoblock stoppers ensure the production of semi-finished or cast steel parts by enabling the control of the steel flow from the tundish or ladle into the moulds. To minimize their interaction with molten steel (and slag), the $Al_2O_3$-C monoblock stoppers are protected from oxidation by boron-containing glazes. In the case of self-glazing stoppers, the glaze will be formed by liquid portions, which occur and accumulate at the surface during a second heating to 1300 °C.
Boron is the most important part of the self-glaze, as it ensures a low glaze-forming temperature together with a high resistance against corrosion and thermal shock due to its low thermal expansion as well as high refractoriness of the batch. However, boron is harmful to the health and environment and should be omitted in future batches.
To develop boron-free monoblock stoppers with similar self-glaze forming behaviour and material properties like the boron-containing batches, potential self-glaze forming agents such as $CaSiO_3$, MgO, and $Na_2CO_3$ were explored during this study. Thermodynamic calculations (FactSage) and a DoE were employed. After carbonization at 1000 °C, the glaze (melt phase) formation temperature, oxidation resistance at 1300 °C, and RuL were target properties for the development of proper batches. As a result, at least two $Al_2O_3$-C monoblock stopper compositions were identified showing similar properties such as boron-containing batches. The glaze and the microstructure were investigated in SEM.

# 3D-Printed Metal-Ceramic Refractory Components for Corrosive Environments

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Fused Filament Fabrication (FFF) for manufacturing of refractory ceramics and metal-ceramic composites regarding their combination into multi-material functional parts was investigated. The aim was to combine the corrosion resistance of ceramics with the mechanical and physical properties of steel. The developed multi-material component was based on an AR78 alumina rich spinel filament and a metal-ceramic filament consisting of a mixture between AR78 and 316L stainless steel. The study involved filament production and evaluation, adaptation of 3D-printing parameters as well as selection of debinding and sintering routes with the help of comprehensive thermal analyses including DSC/TG and filament thermal stability tests. For the evaluation of mechanical properties of sintered 3D-printed materials the compression, three-point bending, and splitting tensile strength tests were carried out. Multi-material samples were successfully printed and sintered. The interface analysis was carried out using SEM/EDX. The multi-material sample with a metal-ceramic core and a ceramic outer shell successfully withstood 2h of a corrosive alkali salt-based atmosphere at 850 °C. The subsequent structure evaluation was performed using tomographic 2D images and SEM/EDX analyses. The 3D-printing for the successful combination of the two dissimilar materials has been proven to be a promising approach for future development of high performance functional refractory products.

# HalFoam – A Ceramic Foam Technology Platform

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Morgan Advanced Materials Haldenwanger GmbH has developed an environment friendly technology platform for the direct foaming of ceramic products.  These foams, made from alumina, fused silica, silicon carbide and zirconia, show unique thermal, mechanical and chemical properties.

With the decarbonization of industrial processes and the increasing importance of hydrogen applications, materials with an excellent behaviour under hydrogen atmospheres at high temperatures becoming indispensable. Specifically, we developed a fibre free aluminium oxide foam material HalFoam Alumina™.

With a high content of 98.5 % alumina, HalFoam Alumina™ shows outstanding resistance to corrosion and chemical degradation against hydrogen atmospheres and aggressive environments at a service temperature of 1.680°C.

Halfoam products exhibit a high specific mechanical strength and a low thermal conductivity. Applications benefit from this through higher mechanical resilience and lower heat loss.

# Development and characterization of MgO and TiO2 reinforced Steel Ceramic Composites for application with molten aluminum alloys

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The incorporation of Steel Ceramic Composites (SCC) for aluminum refractory applications can be very beneficial due to exceptional properties and increased functionality of composites. However, it is hampered by the well-known reactivity of liquid aluminum. Prolonged contact of molten aluminum or aluminum alloys with steel-based products leads to their damage by the rapid dissolution of steel elements.

The development of SCCs capable of withstanding the long-term contact with liquid aluminum alloys required thorough understanding of the interaction phenomena occurring between the composites and the melt. The crucial and most sophisticated aspect of the composite corrosion process is the corrosion initiation caused by the contact with the liquid metal. This urged comprehensive investigations of all contributing factors, including the composite surface treatment or the impact of chemical and electrochemical corrosion driving forces occurring between both materials.

For the analysis of the initial corrosion stage novel DSC-aided corrosion tests and high temperature electrochemical investigations were developed and successfully applied. The corrosion resistance of SCCs was investigated using wettability measurements as well as finger immersion and crucible corrosion tests. Presented results addressed the structural analyses of developed composites using SEM/EDS/EBSD and X-Ray diffraction methods. The evaluation of aluminum alloy solidified after the corrosion tests was carried out by means of automated feature analysis (AFA) using PSEM ASPEX.

The developed pre-oxidized MgO reinforced SCC exhibited superior corrosion resistance, being capable of withstanding more than 168 h of contact with liquid aluminum alloy.

# Keep it simple: Kelvin Cells via Liquid Crystal Display-Stereolithography Printing

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Ceramic scaffolds for bone tissue engineering are an emerging field in the topic of materials science. Properties such as interconnected pore networks with high tortuosity and tailorable pore shapes combined with appropriate strength are particularly important. However, this direct imitation of human tissue structures is difficult to achieve using conventional processes for cellular ceramics such as freeze-drying, sacrificial templating or gel casting. Here we explore the direct printing of complex parts with high porosities via LCD based stereolithography (SLA). The network studied were Kelvin cells, showing a periodic pattern of 2x2x6 unit cells with a thin and fine structure and strut thicknesses down to 0.20 mm. Alumina samples were printed with a powder mass percentage of 53% and 70% investigating two different ceramic resin compositions. Ultrahigh porosities between 89.5% and 97.2% and a maximum compressive strength of $1.84 \pm 0.17$ MPa were reached due to the dense struts of the structure. LCD-based ceramic stereolithography proved to be a promising candidate for rapid and cost-effective fabrication of highly porous and complex ceramic structures.

# Characterization of steel-ceramic composite material based on recycled MgO-C refractory bricks

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Aluminium is commonly produced through the Hall-Héroult process, which involves electrolyzing a melt of dissolved aluminium oxide in molten cryolite. In order to reduce carbon footprint of this process, inert corrosion-resistant anodes can be used instead of consumable carbon anodes. Additionally, utilizing recycled materials in the manufacturing of such anodes can further reduce the carbon footprint.

A composite material, comprised of recycled MgO-C refractory brick material mixed with 316L stainless steel (with 40:60 volumetric ratio), was studied in as-sintered state as well as in pre-oxidized states after pre-oxidation under air at 800° C, 900° C, and 1000° C. These thermal treatments enhance chemical resistivity, to a level suitable for application in cryolite environment at elevated temperatures. Oxide based surface phases formed during oxidation thermal treatment were investigated with help of XRD and EBSD analyses. Electrical conductivity was measured at both room and elevated temperatures. Influence of $TiO_2$ doping in amount of up to 3 vol.% on electrical conductivity was also evaluated for each pre-oxidation thermal treatment route. Appliance tests of cold isostatically pressed electrodes based on the studied material were carried out in a laboratory scale Hall-Héroult cell.

# Processing and Modification of metallurgical slags for solar-thermal absorptance, transport and storage media

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The use of ceramic solid particle technology in thermal energy storage (TES) integrated concentrated solar power/ thermal (CSP/T) plants offers high solar to electricity ratio and enhanced storage densities thanks to their high operational temperatures and wide temperature ranges. Metallurgical slags with similar composition to the state-of-art bauxite particles can be utilized as a sustainable and economical secondary raw material to prepare solid particles. In this study, ferrous and non-ferrous metallurgical slags will be assessed as secondary raw materials for the preparation of solid particles as heat absprtance and storage medium. The effect of chemistry, crystal quality and phase composition will be related with CSP related functional properties such as heat capacity, solar absorptance and high temperature stability. Beyond their use in particle form, their potential use as high temperature process components will be also discussed.

# Fiber-Reinforced Zirconia-Toughened Alumina Ceramic Matrix Composites by Material Extrusion-Based Technology

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Material extrusion-based additive manufacturing becomes interesting to fabricate oxide ceramic matrix composites. Herein, 0–30?vol% alumina fibers are added to zirconia-toughened alumina powder mixture and extruded into filaments. Shrinkage and mechanical properties of filaments and 3D-printed samples are investigated. Thermomechanical analysis is conducted on filaments with and without fiber content indicating lower shrinkage in the direction of fiber alignment during the sintering process. The flexural strength of the extruded filaments and printed bars is measured through a 4-point bending test. Filaments containing 15?vol% fiber exhibit the highest flexural strength of 110?MPa, with additional fiber content leading to a reduction in flexural strength. Using Weibull calculation, it is observed that printed bars without fibers result in significantly lower bending strength in comparison to the filaments because of the presence of printing failures. Bars with 10?vol% fibers, printed with 0° infill orientation achieve the same mechanical properties as the filaments, even though in microcomputed tomography gaps between printed lines and voids between raster lines can be observed. These results demonstrate that fiber reinforcement of ceramics offers a great potential to avoid the reduction of mechanical properties by printing defects.

# Ceramic injection molding of 2Y-TZP and 3Y-TZP

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Partially stabilized tetragonal zirconia with 2 mol% of $Y_2O_3$ (2Y-TZP) has been introduced to the market as a zirconia ceramic grade with particularly high fracture toughness and strength. Due to its low $Y_2O_3$ content the transformation toughening mechanism is highly pronounced, which results in improved mechanical properties of sintered parts. For this study thermoplastic feedstocks with two different grades of zirconia powders were made; one with 2 mol% $Y_2O_3$ (2Y-TZP) and another with industry standard 3 mol% $Y_2O_3$ (3Y-TZP). Cylindrical samples were made by injection molding, followed by solvent debinding, thermal debinding and sintering. Bending strength was measured with a ball on three balls biaxial bending strength method. A different behaviour of 2Y-TZP and 3Y-TZP powders during the compounding of the feedstocks will be shown and a comparison of bending strength, hardness and microstructure of the two materials will be presented. Injection molding of 2Y-TZP could be used for producing mechanical or luxury ceramic parts where highest possible strength and fracture toughness is needed.

# The study on the heterogeneous bonding formation for compound aerogel

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Aerogels, characterized by numerous pores and a high specific surface area, find wide applications in fields requiring high specific surface areas, such as catalysis. By combining two metal oxide precursors, heterogeneous bonds are formed uniformly at the atomic level, enhancing reactivity. In this study, a composite aerogel of titania and silica was synthesized to improve the pore structure and increase the reactivity of titania aerogel. Unlike silica aerogel, synthesizing and controlling the reaction parameters of titania aerogel pose greater challenges. The reaction times of each alkoxide solution are disparate, with the hydrolysis and condensation of Ti precursors occurring more rapidly. Conversely, silicon alkoxide hydrolysis and condensation proceed at a slower rate due to the lower positive charge of Si atoms compared to Ti atoms, resulting in a smaller surface area for the obtained titania aerogel. Owing to the rapid reaction rate and difficulty in controlling the titanium-based precursor, the porous structure of titania aerogel is relatively weak, leading to high aggregation in the network structure. In this study, we obtained a silica-titania composite aerogel without phase separation by minimizing the difference in sol-gel reaction rates and achieving a uniform sol. Subsequently, we conducted a comparative study between the silica-titania composite aerogel and the titania aerogel.

# Challenges and opportunities to improve the strength of 3D-printing ceramics

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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 and reliability of these systems is the initiation and uncontrolled propagation of cracks in the brittle ceramic parts. Novel design concepts 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 "damage tolerance". Moreover, by orienting (texturing) the grain structure, similar to the organized microstructure found in natural systems such as nacre, crack propagation can be controlled within the textured ceramic layers.

In this contribution, the potential of employing lithography-based ceramic manufacturing (LCM) process to design multi-phase layered 3D-printed architectures is presented, which can contribute to the fabrication of future ceramic components with enhanced damage tolerance. Several design strategies are presented and analysed under typical loading conditions, such as contact damage or thermal shock. The fabrication of complex 3D ceramic-based multi-material parts with tailored microstructures is discussed, as a new pathway for designing ceramics with outstanding mechanical strength and reliability.

# Sequential Mechanical Flexure: A Key to the Coupled Evaluation of R-Curve Behaviour and Subcritical Crack Growth

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For the mechanical design of ceramic components, the fracture sistance is a design-relevant and material-specific feature. In common technical ceramics, the fracture resistance can increase as a function of the crack length, which is termed R-curve behaviour. It reflects the capacity of the material for intrinsic and/or extrinsic toughening during stable crack extension. Another design-relevant material-specific property is the sensitivity towards subcritical crack growth. That is a time-dependent phenomenon and commonly estimated by two crack growth parameters. Both phenomena can be evaluated from basic experimental data (load, deflection, and time), recorded during sequential flexure experiments on through-thickness V-notched beam samples. The present study aims for a review of such experiments in terms of their premises, preconditions, advantages, and limitations. The main focus is on the graphical and calculatory data handling and the data interpretation, which are demonstrated exemplarily.

# Damage-tolerant Ceramics by Ultra-High Dislocation Density

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Dislocations in ductile ceramics promise metal-like toughening while unlocking functionality, e.g., electrical conductivity, thermal insulation and ferroelectric properties. Previous studies have been limited by the small dislocation-rich volumes and/or low dislocation densities reached, whereas Brinell ball scratching offers crack-free, arbitrarily large plastic zones, serving as a simple and effective method at room temperature. Using MgO as an example, we tailor extremely high dislocation densities up to ~$10^{15}$ $m^{-2}$ , which is comparable to severely deformed metals. After the plastic zones are characterised by chemical etching, electron channelling contrast imaging (ECCI) and scanning transmission electron microscopy (STEM), we demonstrate that the crack initiation and propagation in these plastic zones with high-density dislocations can be completely suppressed.

As the residual stresses introduced during the scratching processes might play a critical role in the failure mechanisms, we analyse them using high-resolution electron backscatter diffraction (HR-EBSD). The residual stress is then removed by annealing while the dislocation density is retained. With residual stresses being mostly relieved, the cracks are not completely suppressed any more, but the pure toughening effect of the dislocations is clearly visible.

# Development of cost-efficient ceramic tools for friction stir welding using additive manufacturing

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Friction stir welding is a modern joining process that is used to join metal materials without a melting process. In this process, the workpieces to be joined are heated by friction and then mixed together under pressure, creating a strong metallurgical bond.

Joining with ceramic tools is an innovative welding technique that is characterized by its versatility and its advantages in terms of temperature resistance and wear resistance. Friction stir welding tools made of ceramic are therefore ideal for high-temperature applications and enable the joining of difficult-to-weld materials such as aluminum alloys and offer advantages such as low heat exposure, high strength of the welded joints and environmental friendliness by avoiding filler materials and harmful welding fumes. Due to these advantages, friction stir welding is often used in the aerospace, automotive, shipbuilding and other industries where high-strength and lightweight joints are required.

The aim of the presented project is to design ceramic tools in a material- and cost-efficient way, so that they represent an alternative to the commonly used metal tools. The focus of tool production is on additive manufacturing. Material selection, feedstock development and the determination of suitable pressure parameters are essential for the implementation of the project.

# In search of sustainable solution synthesis routes for (photo) electrocatalysts in H2 production and CO2 reduction

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Solution-based syntheses all involve a liquid phase. Sol-gel and precipitation (hydro- or solvothermal) routes, each encompass a whole family of methods, differing in reactants, precursors or mineralizers, growth modifiers, and process parameters such as T, p etc. This large parameter space allows for flexible control over composition, structure, and morphology, determining catalytic performance e.g. in water splitting and CO2 conversion.

Each method has its pros and cons in sustainability: i) Energy efficiency is a plus point for low temperature routes such as hydro/solvothermal routes; ii) use of water as the solvent avoids noxious solvents; iii) citrate routes can be considered biobased, as citric acid is fabricated by microbial fermentation. Such considerations impact atom and energy efficiency and thus the sustainability of the syntheses.

Hydrothermal routes were employed for Mo-based sulfide powders with various compositions, exhibiting electrocatalytic behavior towards water splitting, in the best case outperforming the plain MoS2 benchmark. Thin film production is achieved by spin-coating of complex oxides like copper bismuth oxide, copper tungsten oxide and various copper iron oxides, for photoelectrochemical reactions, achieving interesting photocurrent densities.

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# Highly efficient nanocarriers with a dual therapeutic approach against triple-negative breast cancer

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Up to date, triple-negative breast cancer is responsible for more than 15 % of new breast cancer cases per year. Lacking hormone expression of targeting receptors, TNBC shows aggressive heterogenous tumor biology with a high risk of reoccurrence and metastasis and, therefore, therapeutic options for patients are limited.  This demands new materials for with tailored functionalities.

In this study, a targeted dual-purpose therapeutic nanocarrier is developed by integrating tailored functionalities and payloads into one nanocarrier through covalent conjugation strategies. The nanocarriers demonstrated an outstanding radiochemical yield of > 98 % and serum stability in human serum during 3 h ($^{68}$Ga) and 120 h ($^{177}$Lu). In vitro studies with FA-DOTA@m$SiO_2$ carriers demonstrated a 43% cell internalization suggesting specific targeting of folate receptor in TNBC cells. Apoptosis assays showed combined delivery of radiations and DOX induced significant cell death to TNBC cells earlier at different time points. Our data suggests that dual-functions nanocarriers has great potential in targeted delivery of drug doses for TNBC tumor treatment (rare disease) and points out further studies to evaluate its preclinical therapeutic efficacy.

# PTCR behavior of lead-free BNBT-based thermistor ceramics

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Semiconducting ceramics with a positive temperature coefficient of resistance (PTCR) behavior are used as passive components for self-limiting heating devices. Lead free PTC ceramics based on compositions of the $BaTiO_3$-rich side of the BNBT system $[Bi_{0.5}Na_{0.5}]xBa_1\text{-}xTi_{1+n-y-z}Nb_yMn_zO_3$ were prepared using the mixed oxide route. An increase of the Curie temperature from 125°C for x = 0 up to 190 °C for x = 0.2 for specimens sintered in air was observed. In order to obtain semiconducting behavior at room temperature, niobium was used as a donor dopant. For y = 0.0005 – 0.0025, low room temperature resistivity (~1000 Ohm*cm) was found. Larger donor concentrations show increased resistivity without any PTC behavior. Additional acceptor doping with manganese leads to significant increase in the resistivity jump (up to five orders of magnitude for z = 0.0004) near $T_C$. Variations of the stoichiometry have significant effect on the microstructure and thus for the PTC-behavior for samples sintered in air with x > 0.03. The obtained results enable tailoring of the PTCR response of BNBT materials by selecting the composition, dopant concentrations, stoichiometry and sintering conditions.

# Database-driven high-throughput solid-state synthesis and characterization of BiFeO3-BaTiO3 ceramics for energy applications

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Solid-state synthesis of functional ceramics is a well-established technique on both laboratory and industrial scale. However, compositional engineering using solid-state synthesis is labor-intensive and therefore prevents generation of large sets of training data for machine learning software where data quality and reproducibility is of utmost importance. Recent advances in automated powder dispensing systems and automated characterization methods provide the opportunity to transfer these to the field of functional ceramics research. Based on the lead-free piezoelectric BiFeO3-BaTiO3 (BF-BT) binary system, we investigate the applicability and robustness of a solid-state high-throughput engineering approach to increase data point density in phase diagrams by compositional variation of the starting materials. Synthesis parameters are subsequently optimized and validated by a machine-learning algorithm. We demonstrate that dosing accuracies with a molar error of less than 0.1 mol% can be achieved, resulting in a consistent and repeatable sample stoichiometry. The functional properties and crystal structure are evaluated as a function of calcination and sintering temperature with the dataset subsequently used for training a machine learning model. Especially for researches who have not yet been in contact with a high-throughput ecosystem, we address basic questions regarding viability and applicability of solid-state high-throughput synthesis to functional ceramics development.

# Investigation of radiation-converting ceramic tapes for energy-efficient illuminated signage systems

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Previous LED-based illuminated advertising systems severely limit the possible colour space by using monochrome LEDs. In addition, these systems use polymer-based colour filters. These filters absorb a large proportion of the light and age due to the ambient UV radiation limiting their endurance to a few years. RGB LEDs on the other hand can be used to create any colour impression but require a great technical effort to make large-scale signage visually appealing. In a joint project with partners from industry and research, a new system of near-UV LEDs and radiation-converting ceramic tapes was developed to create long-lasting and energy-efficient signage. The aim was to use UV or blue radiation (365-465 nm) to create customized phosphor systems as a starting material for ceramic converter tapes that emit red, green or blue light when excited. The working group for Functional Ceramics of the FGK focused primarily on the development of these converter tapes. For this purpose, the phosphors used were integrated into ceramic tapes by means of the tape casting process. In addition to optimizing the casting slip, the main focus was on the thermal process chain, which was individually adapted for each phosphor in order to obtain a ceramic tape with high density and defined thickness in the range of a few hundred microns. The tapes were analysed regarding their microstructure and their optical properties and a functional demonstrator was successfully built.

# Enhanced Piezoelectric Properties of Sol-Gel BCZT and Surface Modification

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The sol-gel process is one of the various methods used to produce BCZT. It offers precise control of the composition, low temperature production, and fine particle size. Here, the composition $Ba_{0.85}Ca_{0.15}Zr_{0.1}Ti_{0.9}O_3$ is prepared and the resulting powder is shaped in various ways before the physical and functional properties are investigated.

Since the piezoelectric properties of uniaxially pressed and injection molded samples differ significantly, the powder prepared by the sol-gel process was investigated in more detail. An additional surface modification step with stearic acid, required for the injection molding process, is responsible for the difference in results. The two different powders were investigated by surface chemistry ATR measurements. The difference for the piezoelectric coefficient $d_{33}$ (Berlin-Court) shows an increase of 218 pC/N due to the surface coating with stearic acid. Therefore, $d_{33}$ values of up to 288 pC/N can be achieved with the modified powder. Further surface and chemical analysis was performed to obtain a complete understanding of the coating process and to transfer the effect to other possible sol-gel systems.

# sol-gel synthesis of pyrochlore Zn2V2O7 for electrocatalytic conversion of dinitrogen into ammonia

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Molecular nitrogen is the most earth-abundant source for ammonia synthesis, which plays a significant role as feedstock in the chemical industries for various applications including energy carriers, fertilizers and polymers. Despite more than 100 years of industrial processes for nitrogen fixation (Haber-Bosch, Kellogg), the catalytic conversion of nitrogen to ammonia remains an energy-intensive (high T, P) process, demanding advanced concepts for nitrogen activation. In this context, this work focuses on the electrochemical synthesis of ammonia with its potential as a green fuel due to its high energy contents (18.6 MJ/kg), low storage costs and combustion without greenhouse gases. In order to drive the sluggish reaction kinetics of dinitrogen activation, suitable electrocatalysts are highly desirable. For this purpose, the aim is to investigate the sol-gel synthesis of various bimetallic oxides such as zinc pyrovanadate to study their nitrogen reduction efficiency. The synthesis was performed by careful co-hydrolysis of vanadium(V) triisopropoxide oxide and Zinc bis[bis(trimethylsilyl)amide] precursors. In this type of pyrochlore structure, zinc provides the structural stability while vanadium centre enables catalytic sites for the facile activation of thermodynamically stable dinitrogen molecule. With this approach, the zinc pyrovanadate electrocatalyst achieved the remarkable ammonia production yield rate and faradaic efficiency. This study will extend the use of sol-gel processing of mixed-metal oxides as the next generation of electrocataylsts.

# Synthesis of microstructural architectured NMC core/shell cathode powder

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NMC ($LiNi_XMn_YCozO_2$) cathode materials with a nickel content exceeding 80%, exhibit a remarkable discharge capacity of 200 mAh/g at 4.3 V [1]. However, increasing Ni content can involve rapid capacity fading, short cycle life, and poor thermal/structural stability. These drawbacks stem from the increased reactivity of Ni with surface oxygen during charge-discharge cycles, as well as larger Li/Ni cationic mixing, which can deteriorate the electrochemical performance. In order to overcome these issues, different approaches to develop NMC materials with controlled core/shell structured morphology have been proposed [2]. For instance, high Ni content ensures high specific capacity, while Mn-rich shell provides the improved structural and thermal stability.

In this work, NMC core/shell particles have been synthesized via easy process-controlled oxalate-assisted co-precipitation method. To achieve the formation of core and shell with different compositions two-staged synthesis approach has been employed. To prevent interdiffusion between the core and shell, a thin $WO_3$ layer has been applied to the surface of the Ni-rich core particles. SEM, EDX, XRD techniques has been used to study the compositional, morphological and structural relations within core/shell particles. It has been shown that the formation of the R3m structure can be achieved for both NMC90 and NMC622 compositions at 850 °C. In-situ Li-infiltration approach results in the formation of NMC structures with a relatively high I(003)/I(104) ratio. Additional Li introduction via mechanical mixing leads to even higher I(003)/I(104) value, however in turn, causes the $Li_2CO_3$ formation.

[1] 10.1016/j.jpowsour.2013.01.063
[2] 10.1016/j.jpowsour.2019.227395

# Development of BNT-based leadfree PTC heating ceramics with scalable processing

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Electroceramics for heating applications utilize the anomalous increase in resistance of some ferroelectric materials during their phase transition from a polar crystal structure to a non-polar one and thus to the paraelectric state. The prototype, doped barium titanate $BaTiO_3$, shows this transition at a Curie temperature $T_C$ at 120 °C, in this case from the tetragonal phase to a cubic phase. The resistance jumps several orders of magnitude, and the semiconductor becomes almost insulating. These so-called PTC ceramics are used in electric cars as electric heaters, but contain large amounts of lead.

Our development of a leadfree alternative material is based on the well-known substitution of Bi and Na on the A side of $BaTiO_3$. We achieved a phase transition above 180°C with a large increase in resistivity, even at high voltages. This required optimized sintering parameters under reducing conditions. The form of manganese dopants has a large influence on the homogeneity and structural integrity of the ceramics. To facilitate a later industrialization of these leadfree ceramics, we studied their scalable and economical processing in-depth. This includes sintering of the pressed ceramics in stacks as well as steps to allow water-based or solvent-free milling. We will present our results and characterizations based on XRD, SEM, and electric measurements. Finally, we will offer a glimpse at possible new forming methods to reduce the necessity of heat exchangers.

# Study on CaCu3Ti4O12/NaCl Humidity Sensor Employing Aerosol Deposition Process

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The ambient humidity profoundly affects human life, industry, agriculture, food storage, and perceptual comfort. Monitoring and controlling environmental humidity is crucial. Therefore, the development of high-performance and highly sensitive humidity sensors is imperative. This study introduces, for the first time, the utilization of the natural properties of NaCl ions and their strong reaction with water, as well as the polarity response of water, in the preparation of CCTO ($CaCu_3Ti_4O_{12}$))/NaCl humidity sensors. In the treatment of NaCl, we employed four different methods: grinding and ball milling for 4 hours, 24 hours, and 48 hours, respectively. The obtained powders were combined with CCTO to form composite powders. Benefiting from NaCl's assistance, we achieved outstanding sensitivity and excellent linearity. Notably, this is an amazing result in the case of CCTO /NaCl humidity-sensitive sensors, achieved through a simple post-annealing process of the aerosol-deposited films at room temperature. Here, we utilized environmentally friendly and cost-effective NaCl, surpassing other expensive doping treatments. Reaffirming the feasibility of aerosol deposition in humidity sensor applications and highlighting CCTO as a promising candidate material for innovative humidity sensors.

# Enhanced Capacitance Density and Leakage Current Performance of BaTiO3/BaTiO3-Ag Double-Layer Structure

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Recently, improved electronic component performance is required for high performance, multifunction, miniaturization and stable power supply due to the development of AI semiconductor devices. Ferroelectric materials are being used to enhance the dieletric properties of capacitors which are passive components that take up a lot of space in electronic components. However, there are limits to improving dielectric properties with $BaTiO_3$, a single ferroelectric material. Accordingly, research on improving dielectric constant with metal fillers through percolation theory is actively being conducted. Many studies have significantly improved the dielectric constant, but the performance of dielectric loss and leakage current needs to be improved. In this study, a composite film was fabricated with Ag, a metal filler, based on $BaTiO_3$, a ferroelectric material. Then, a buffer layer was fabricated using same base material, $BaTiO_3$, and a double-layer structure was fabricated as a composite film through an aerosol deposition process. Measurements and comparisons with the properties of earlier research were made of the film's microstructure, crystal structure and enhanced dielectric and electrical properties.

# Amorphization and hydrogen permeability of carbon-doped TiZrN coatings by laser ablation

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In many metal materials used for hydrogen storage, hydrogen embrittlement occurs due to the presence of hydrogen in the material. To counteract this, fine ceramic coating materials such as TiN, TiC, and BN are being investigated as hydrogen permeation barriers. Along with this research, amorphous carbon, known for its high mechanical properties, chemical inertness, and low aggressiveness against materials, is also gaining attention as a potential hydrogen barrier material.
Our study focuses on the reduction of hydrogen permeability of carbon-doped TiZrN coatings by investigating the effects of laser output on amorphization and surface roughness in terms of lattice distortion and bonding state. The crystal structure and lattice constant of coatings, calculated by Rietveld refinement, increased from 3.612 Å to 3.964 Å. XPS and Raman analysis were conducted to identify the bonding state of the doped carbon, and the sp2/sp3 and IG/ID decreased by 26% and 59%, respectively. This indicates that amorphous carbon is formed due to high thermal energy and internal stress. The variation of surface roughness measured using AFM, and the Ra value decreased from 12.913 nm to 7.127 nm after carburization. Hydrogen permeability decreased by 78% at 573K, and diffusion mechanism of amorphous carbon with hydrogen permeability will be discussed.

# Reduction-Induced Structural Change in Lanthanum Manganites

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In recent years, there has been a great deal of interest in new devices for energy conversion. Especially perovskite oxides have become increasingly important in this regard, due to their chemical stability and high electrical conductivity. In order to ensure electrical conductivity, the presence of B-site cations with multiple valences, such as Mn, is required. The special properties of manganites are mainly due to their unusual defect chemistry, which is caused by their ability to absorb oxygen. Additionally, among different A-cations, La provides the highest catalytic activity, which is ascribed to its large electrical conductivity. The resulting $LaMnO_{3+?}$ has an excess of oxygen of ?, manifesting in La and Mn vacancies.

This work examines the effects of reducing the rhombohedral crystal structure of $LaMnO_{3+?}$-based perovskites by simultaneously modifying the crystal lattice through an A-site deficiency or substitution with Sr. Here, we were interested in the structural transition triggered during high temperature treatments at 300, 500 and 700 °C in a 5 % $H_2/N_2$ atmosphere. It was demonstrated that a phase transformation from rhombohedral to orthorhombic occurs upon reducing the B-site ions and removing oxygen from the lattice even at 300 °C. The sub-stoichiometric preparations released a greater amount of oxygen than their stoichiometric equivalents. In contrast, adding Sr has a stabilizing effect and inhibits this transition. Ultimately, at 700 °C the perovskite degrades.

The findings present an approach to investigate the reducing potentials of Mn ions in the $LaMnO_3$ perovskite system under different conditions and the resulting structural modification to improve their application as an energy conversion system in the future.

# Investigation of Carbon-Bonded Alumina Samples with Concentrated Carbon Binder Surface for Copper Melt Filtration

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The foundry industry's development has led to an increase in the purity requirements for metals. When considering the impurities of metals, a distinction is made between gases (e.g. hydrogen and oxygen), trace elements and non-metallic inclusions. Non-metallic inclusions influence the mechanical properties of metals detrimentally and so process steps removing inclusions are of great importance. Filtration with ceramic foam filters is used since the 1960s for the reduction of non-metallic inclusions. The aim of this study is to investigate the effect of different coatings consisting of coked coal tar pitch on the performance of bulk samples and the suitability of coated ceramic foam filters for copper melt filtration. The coated bulk samples were subsequently characterized with regard to bending strength, surface roughness, pore size distribution, residual carbon content and wetting behavior in contact with a copper melt. The surface and cross-section of the samples were characterized by optical microscopy and scanning electron microscopy. Compared to bulk samples without coating, the coal tar pitch coating had no negative influence on bending strength. The sessile drop experiments showed that substrates coated with coal tar pitch had a higher contact angle compared to samples without any coating. Furthermore, carbon-bonded alumina foam filters were coated with the coal tar pitch. These filters were tested by means of sandcasting trials with a copper melt.

Keywords: carbon-bonded alumina, copper filtration, wetting behavior

# Cold sintering of solid electrolytes for Li-ion and Na-ion solid-state batteries

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Li-ion and Na-ion based all solid-state batteries (ASSB) are a very promising but simultaneously challenging approach for electrochemical storage devices. The ionic conductivity in ASSB has to be realized by a solid electrolyte instead of a liquid. In contrast to liquid filled cells the wetting does not occur, so that the conductive paths must be realized by grain-to-grain contacts. Conventional sintering of solid electrolytes typically requires temperatures between 800 and 1400 °C. Apart from the energy consumption these temperatures are leading to reactions with the active cathode material [1]. To avoid this undesirable reaction during conventional sintering of composite cathodes, the sintering temperature has to be reduced extremely. For LATP ($Li_{1.3}Al_{0.3}Ti1.7(PO_4)_3$) electrolyte, the sintering aids and the cold sintering process are successfully demonstrated. To further decrease of temperature to a target of < 300 °C, a novel cold sintering approach was investigated by simultaneously applying high pressures of 600 MPa. With this approach highly densified solid electrolytes with moderate ionic conductivity have been achieved [2].

In this study, the influence of cold sintering parameters (temperature, pressure, sintering additives) is evaluated, and the parameters are optimized for two materials. For Li-ion electrolyte, the cold sintering of LATP is investigated. Next generation of batteries with Na-ion electrolytes is addressed by Nasicon ($Na_{3.4}Zr_2Si_{2.4}P_{0.6}O_{12}$). For Nasicon, the high ionic conductivity of 0.27 mS/cm by adding NaOH and cold sintering at T = 370 °C without any heat post-treatment was achieved.

References:

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# Titanium dioxide varistors for low voltage applications

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It was possible to produce ceramic low voltage varistors with a breakdown voltage < 100 V/cm and an energy absorption >100 kJ/kg by adjusting the doping and the grain boundary phase of titanium dioxide ceramics.

These varistor materials are specifically designed to protect low-voltage applications, typically up to voltages of several hundred volts. Titaniumdioxide is an electric insulator. Doping with small amounts of $Nb_2O_5$ (< 0.2 mol%) can generate a moderate electrical conductivity of titanium oxide. The varistor behavior depends on the grain boundaries and the grain volume conductivity and the electronic barrier between. The grain boundaries are modified by other additions like $Y_2O_3$, $SiO_2$ and other oxides for the titanium dioxide ceramic.

The paper presents effects of material composition, sintering parameters and structural modifications on V/I characteristics of the material. It will be shown that the all parameters determine the breakthrough voltage value, the nonlinearity of V/I and the capacity of energy absorption. The modification of the ceramic material helps to adapt those materials for low voltage applications as for  electronic circuits or protection against electrical charging in sensitive processes. Particularily, if theres are requirements which combine electrical insulation and continuously discharging, those materials will be helpful. In opposite to established ZnO varistors $TiO_2$ can already work at voltages < 1 or 2 V even with dimensions of the bulk in the range of several millimeteres. Therefore they may be applied for mechanical issues as reliable component and insulator and as discharging unit in the same time.

The development is still ongoing considering other potential candidates, too.

# Bioactive glasses meet herbal medicine: advanced biomaterials for bone regeneration

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Bioactive glasses (BG) are promising biomaterials for bone tissue engineering due to their ability to form a hydroxycarbonate apatite layer on their surface when they are in contact with biological fluids. Additionally, BGs stimulate new tissue formation via the activation of gene expression modulated by the release of ions during the degradation process [1]. The use of traditional herbal medicine or phytotherapeutic agents in combination with BGs is gaining attention to obtain advanced biomaterials that stimulate the regeneration of tissues and simultaneously prevent bacterial infection [2]. In this study, the dissolution products from different BG compositions were combined with Manuka Honey (MH) and the synergistic effects were evaluated in terms of biological response towards osteoblast-like cells and bacteria. Moreover, antibacterial assays with E. coli and S. aureus showed significant improvements in the antibacterial effects. In a following study [3], BG scaffolds were produced via the foam replica technique and dip-coated with polymer solutions containing MH as biologically active compound. The bioactivity, mechanical properties, release behavior and antibacterial effect of coated and non-coated scaffolds were investigated. There was no effect of the coating on the osteoconductive behavior of the scaffolds, suggesting the potential use of such coatings on BG scaffolds for bone tissue engineering applications.

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# Development of bioactive glass containing multiphasic bioceramic injectables for dental applications and the influence of an adaptive ultrasound treatment

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The rise in dental infections necessitates advanced synthetic bone repair materials as alternatives to natural bone. Composite hydrogels, incorporating bioactive glass, show promising results for bone regeneration. Our study focuses on synthesizing ultrasound assisted metal doped bioactive glasses with osteoinductive, antioxidant and antibacterial properties and developing an injectable system with enhanced visco-elastic properties using a polymeric matrix of chitosan, collagen and alginate. Various parameters including gelation, injectability, hydrophobicity/hydrophilicity, swelling, degradation, and bioactivity were evaluated for the hydrogels. Our synthesized hydrogels exhibited promising characteristics such as enhanced cell proliferation and attachment, warranting consideration for future preclinical trials. Notably, antibacterial activity against both S. mutans and S. aureus was observed, underscoring the hydrogels' resistance to bacterial colonization. Overall, based on these comprehensive findings, it can be inferred that the developed bioactive glass injectable holds substantial potential as a minimally invasive biomaterial for the treatment of dental infections, owing to its antibacterial properties and capacity for bone regeneration.

# Setting performance of apatite-forming calcium phosphate cements modified by vancomycin or gentamicin

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Calcium phosphate cements (CPCs) are established for bone repair. Modification with antibiotics is a promising approach to prevent or treat bone infections by local drug administration [1].

In this study, three different apatite-forming CPCs based on clinically approved cements were mixed with either pure Aqua ad iniectabilia, or solutions containing 40 mg/ml gentamicin respectively 50 mg/ml vancomycin. Cement hardening was studied by Imeter (automated Gillmore needle), while the change in quantitative phase composition during setting was assessed by in-situ X-ray diffraction (XRD), combined with Rietveld refinement and G-factor (external standard) method [2]. Cements hardened at 37 °C for 7 d were further characterized.

Imeter measurements showed that setting times of all three cements were not affected by vancomycin, but significantly increased by gentamicin. Accordingly, in-situ XRD proved that dissolution of the starting compounds and especially formation of the hydration products was strongly influenced by gentamicin. Despite its effect on the setting reaction, gentamicin did not significantly affect the quantitative phase composition and apatite crystallite size after setting for 7 d. Two cements formed only apatite as hydration product, while octacalcium phosphate was additionally detected in the third one.

In conclusion, the study proved that no effects on cement setting need to be considered when vancomycin is added. However, the considerable retarding effect of gentamicin must be compensated. Applicable cements might be achieved for instance by increasing the amount of accelerator ($Na_2HPO_4$).

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# Chemically Engineered Nanocarriers for Tumor Specific Localization and Drug delivery

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Low solubility of the molecular drugs fetches poor efficacy and systemic toxicity. Transporting and/or encapsulating the drug molecules via nanocarriers promise long blood circulation time. Fusion of molecules on the surface of mesoporous carriers facilitate overcoming intrinsic physiological barriers of clearance through innate immune system and ensure safe delivery of therapeutics to tumor. We have developed several nanocarriers for the encapsulation of molecular drugs and inhibitors through covalent functionalization strategies using small linkers and natural molecules such as citric acid. Stimuli responsive polymers on carrier particles assisted drug storage and controlled release. Surface ligands were quantified using electrokinetic sonic amplitude based approach. Data confirmed the preferential accumulation of carriers into tumor without effecting the healthy organs. The approach was extended to chemically engineered nanoassembly by co-conjugating anticancer drugs and radionuclides which showed enhanced therapeutic effect to tumor cells. The minimum off-target and effective ligand-driven transport of therapeutics to tumor illustrate the potential of our site-specific approach.

# Properties of multiple rare earth oxides co-stabilized YDyGdSmNd-TZP ceramics

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TZP starting powders containing 0.6 mol% each of yttria, dysprosia, gadolinia, samaria and neodymia stabilizer were fabricated by a wet chemical route by coating monoclinic zirconia with rare earth nitrates and subsequent calcination. The powders were consolidated by hot pressing in the temperature range between 1250-1550°C for 1h at 60 MPa pressure. The materials were characterized with respect to microstructure phase composition and mechanical properties. The materials combine high fracture toughness of 9-12 MPa $m^{0.5}$ over the whole sintering temperature range with moderate hardness and attractive strength up to 1100 MPa. XRD showed that stabilizer re-distribution takes place during sintering, an initial highly tetragonal containing little or no stabilizer is successively eliminated and a stabilizer saturated tetragonal phase is progressively formed. The volume fraction of cubic increases with sintering temperature while its stabilizer content increases. Above 1500°C a small amount of plate shape aluminate phase is formed from the alumina sintering aid and rare earth oxide.

Due to their transformation induced plasticity and high LTD resistance multistabilizer TZP materials with tailored stabilizer recipes are interesting new materials for dental implants and restorations.

# Mechanical properties of 3D-Printed Ceria-Stabilized Zirconia via Direct Ink Writing

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Ceramic dental implants are gaining ground as a solution for tooth loss. While 3Y-TZP ceramics offer excellent strength and aesthetics, their vulnerability to low-temperature degradation (LTD) in the mouth is a concern. This research proposes ceria-stabilized zirconia (12Ce-TZP), known for its superior hydrothermal stability, as an alternative material solution.

Direct ink writing (DIW) is an AM process entailing micro-extrusion of highly concentrated zirconia pastes through a narrow nozzle deposited in a continuously spatially controlled filament in a layer-wise fashion. To ensure an easy flow through the nozzle during printing and sufficient yield stress to support layer stacking after deposition, DIW pastes need to have an adequate shear-thinning flow and specific viscoelastic properties. Defect-free printing followed by a proper drying procedure and adequate debinding and sintering cycles allows to obtain fully dense monolithic prints.

In this work, a water-based hydrogel (Pluronic F-127) was explored as a carrier for ceria-stabilized zirconia powder to manipulate the paste rheology while maintaining colloidal stability. The effects of the dispersion and mixing techniques on paste properties were investigated using particle size distribution, zeta potential, and rheology analysis. Scanning electron microscopy, micro-computed tomography, and density measurements were used to evaluate the printing defects in sintered Ce-TZP samples. Biaxial flexure testing and hardness measurements were performed to assess the mechanical properties of high-density printed Ce-TZP discs.

Optimizing the mixing technique significantly enhanced the mechanical properties of the DIW zirconia. These improved properties rival or even surpass those observed in conventionally processed parts.

# Additive Manufacturing of Ceramics for Dental and Biomedical Applications

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Additive manufacturing (AM) of ceramics has emerged as a promising technology with transformative potential in the field of dental and biomedical applications, as it offers new design and material possibilities and reliable production of patient specific applications.
In dentistry, ceramic AM promises the fabrication of complex geometries with high precision, allowing for the production of minimally invasive veneers that closely match the natural tooth structure. These veneers offer superior aesthetics and durability, while preserving tooth integrity and minimizing patient discomfort.

Furthermore, AM techniques have revolutionized the field of bone regeneration by enabling the fabrication of customized scaffolds with tailored architectures. These scaffolds facilitate cell attachment, proliferation, and differentiation, promoting enhanced bone regeneration and integration.

This presentation will delve into the specific challenges and opportunities associated with ceramic AM of dental restorations and scaffolds for bone regeneration. Topics of discussion include material selection, process optimization, mechanical properties, biocompatibility, and clinical translation. Insights from ongoing research efforts will be shared, highlighting recent advancements and future directions in this rapidly evolving field.

# Recycling of YSZ Dental Blanks

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Ceramic dental restorations made from yttrium-stabilized zirconium oxide (YSZ) offer biocompatibility along with excellent mechanical and optical properties. However, the production of these restorations carries a significant carbon footprint. The extraction of raw materials, including zirconium oxide and yttrium oxide, and their subsequent processing are energy-intensive activities that generate highly contaminated waste water, which can sometimes be radioactive. Zirconium oxychloride (ZOC), a precursor for various high-performance bio- and technical ceramics such as dental restorations, implants and luxury goods, is predominately produced in China through a complex process. In the next production step, yttrium is integrated, and the resulting calcined YSZ undergoes multiple grinding steps before being spray-dried, with or without binders, to create ready-to-press (RTP) powder. For dental restorations, the RTP powder is pressed, debinded and pre-sintered to form "dental blanks" sold to dental labs for CAD/CAM machining. Dental technicians mill individual crowns or bridges out from these blanks, which are then sintered at temperatures between 1400-1600°C and further customized. However, approximately 80% of this high-quality material remains as waste after milling. The key question is whether this valuable residue can be reused, and if so, for what purposes. The team at TIAG is currently investigating the potential for recycling this material to reduce waste and improve sustainability in dental restoration production.

# Microarchitecture orchestrates biology of bone substitutes

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By the use of additive manufacturing of ceramics, libraries of diverse microarchitectures can be tested for osteoconductivity and bone augmentation capability and improve our understanding of the biology fo osteoconduction and bone augmentation and its dependency on microarchitecture.

For the production of scaffolds, we applied the CeraFab 7500 from Lithoz, a lithography-based additive manufacturing machine for ceramics. As in vivo test model, we used a calvarial defect and a bone augmentation model in rabbits.

In lattice microarchitectures, the optimal distance between rods is 0.8 mm. For periodic minimal surface architectures, the largest sphere fitting into the design should not exceed 1.53 mm. Moreover, the triply periodic minimal surface architecture of gyroid and diamond is superior to primitive. Evaluation of early time points by expression profiling showed that a decrease of the filament dimension and distance from 1.25 mm to 0.5 mm by otherwise identical material, porosity, microporosity and transparency yields in enhanced early vascularization of the defect and differentiation of osteogenic cells in the defect at 10 days and in high osteoconductivity and bony bridging at 28 days. Dependent on the diverse types of microarchitectures, the best microarchitecture for osteoconduction and bone augmentation might be different.

Conclusions
In essence, additive manufacturing enables the production of personalized bone tissue engineering scaffolds with the optimal microarchitecture for osteoconduction and bone augmentation to yield in optimal outcomes of clinical procedures involving bone substitutes in cranio-maxillofacial surgery, dentistry, and orthopedics.

# Automated Colorization of Dental Ceramics

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The current state of the art in the fabrication of aesthetically demanding ceramic restorations are individually designed restorations with customised colouring that can achieve shades, colour gradients and gradations of translucency. Although advanced techniques (additive manufacturing / 3D printing) are currently developed, investigated, and discussed, subtractive procedures and manual or semi-automated moulding processes are dominant today. In order to achieve optimal optical results, colour- and translucency-graded preforms are increasingly being used, which are then given their final colour in further steps, typically manually, after the milling or shaping process. In an innovative approach, dental ceramic restorations based on feldspar glass ceramics as well as on pre-coloured stabilized zirconium oxide qualities with graded translucency (depending on the yttrium oxidecontent) are individualised in a fully automated digital printing process.

In collaboration with the industrial partner bredent, which played a key role in developing the technological implementation of the printing process, the FGK's Functional Ceramics working group developed the required inks based on colouring inorganic ions and investigated their interactions with each other and their influence on colour, translucency and the other relevant dental ceramic properties, in particular mechanical strength. The aim was to achieve the best possible aesthetic design result while at the same time being cost-effective and fulfilling the dental ceramic properties required by the relevant standards.

# Leveraging the Design of Bone Grafts Manufactured using LCD stereolithography

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Additive manufacturing of bio-ceramics using LCD stereolithography allows the creation of ceramic parts with unprecedented resolution for various medical applications. However, the potential of this technology can only be leveraged by exploring complementary methods to enhance the microstructure of the bulk and the morphology of the surface of sintered parts. Thus, this contribution demonstrates the efficacy of particle templating in creating tailored porosity within ceramic structures, with no discernible decrease in compression strength observed at a loading concentration of 2.5%. This controlled introduction of pores holds promise for enhancing biological integration without compromising mechanical integrity. Furthermore, our research highlights the effectiveness of surface treatment using the piranha solution in reducing the stair-step effect inherent in additive manufacturing processes. This reduction in surface irregularities mitigates stress concentration sites, thereby lowering the potential for delamination crack formation. In addition, live/dead staining, cell proliferation and cytotoxicity tests were conducted on the selected materials. Overall, our findings contribute to the advancement of ceramic-based bone implants by addressing both structural and surface quality considerations critical for their successful clinical application.

# 50 years „Hermsdorfer Biokeramik“ - The past, the present, the future

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Ceramics have been used successfully in the field of joint endoprosthetics since the 1970s.

While alumina ceramics were primarily used in the early days, zirconia ceramics and dispersion ceramics made of zirconia and alumina also played a major role later on. Since the 2000s in particular, artificial femoral heads and ceramic inserts for acetabular cups made almost exclusively from these mixed ceramics have been used on the market. Due to the significantly better mechanical properties such as strength, fracture toughness and wear, initial clinical problems of pure alumina ceramics such as implant fracture and increased abrasion have been almost completely avoided.

As a result, the range of indications for the use of ceramic joints has been continuously expanded, so that in most markets in the field of hip arthroplasty, the metal heads that were mainly used until a few years ago have been strongly displaced.

Furthermore, the use of the new high-strength ceramic materials makes it possible to substitute metallic implant components made of CoCrMo-based alloys with ceramic implants.

Based on the more than 50-year history of "Hermsdorfer Biokeramik", the lecture will provide an exemplary review of the development stages of ceramic implants. The materials and implants currently used will be characterised and an outlook given on innovations in the materials sector and possible new implants for the treatment of further indications in the coming years.

# Opportunities for artists to work with ceramics on a large scale

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The lecture looks into the possibilities for artists to work with ceramics on a large scale, with a focus on possibilities in Europe. The opportunities for artists to work with ceramics are usually limited to the size of standard pottery kilns. Technical capabilities for firing artworks that use a human figure as the measurement are rare. Working with clay on a large scale is quite different from hand - sized artifacts and changes the artist's approach. The lecture explores Artist in Residencies, commercial workshops and industry supporting artists.

# EKWC: Fifty years of working with artists, architects and designers, through an open source approach, innovating traditional ceramic knowledge

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The EKWC is an international artist-in-residence and centre-of-excellence for ceramics. For over 50 years, artists, designers and architects from all over the world have worked here to experiment with clay. The experiments result in both special works of art and technical innovations. The works developed here are shown in museums from New York to Tokyo. What makes EKWC special is the combination of world-class facilities, the presence of consultants with internationally leading technical knowledge and the openness to freely share recipes, processes and innovations.

The centre is located in the former dyeing and tannery of the Royal United Leather Factory in Oisterwijk, the Netherlands. A monumental building that was once the largest leather factory in Europe. A place where history, inspiration and making are combined for more than a century.

The mix of facilities, knowledge and contacts offer growth opportunities. Not only for skilled ceramicists, but also for other disciplines. Since the early 1990s, more and more non-ceramicists have registered for a working period. The resulting experiments, technical developments and dynamic ensured that the centre occupied an increasingly relevant position in the field of ceramics; indirectly the EKWC influences the (international) world of art, design and architecture.

Experienced artists and young talents work side by side at EKWC. Over the years, the institute has received many talents and renowned names for a working period, such as Betty Woodman, Tony Cragg, Anish Kapoor, Kimpei Nakamura and Jun Kaneko.

In our lecture the EKWC talks on how the collaboration of artist and our staff drives innovation in the field of ceramics through our residency program and open source approach.

# Greek Vases: Manufacturing and Paintings

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This presentation aims at spotlighting a very specific group of fine ceramic products from Ancient Greek. Greek potters made every effort, in order to create highly artful and aesthetic products, which were decorated with geometrical and figurative paintings before being subjected to a secondary firing cycle.

Ancient resources do not reveal much of the science and the engineering of the production of such elaborate products. However, vases themselves do show images of the entire value chain, starting from the digging of clay, to the forming, painting, and firing of the vases. Ancient written sources refer to prayers addressed to the gods, in order to bless each firing cycle, showing that failures during firing were quite common. Different types and forms of vases were used for the various purposes.

Typically, Greek Vases have predominantly been studied by archaeologists. This talk, though, wishes to present some of the beauty and the technology of Greek Vases to the technical ceramic community. In Germany and Europe, there are large collections of the finest vases to be adored in a multitude of museums.

# Vom Töpferort zum Bildungs- und Forschungszentrum. Höhr-Grenzhausen im Wandel der Zeit

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Bereits 1851 wurde in Grenzhausen eine Gewerbe- und Zeichenschule für das Kannenbäckerland angeregt, damit das Handwerk nicht länger nur vom Meister zum Gesellen weitergegeben, sondern auch wissenschaftlich begleitet wurde. Seit jedoch die preußische Regierung die Lehre der Keramik zum schulischen Curriculum erhob, nahm die Verwandlung der Dörfer Höhr und Grenzhausen von einem Töpferort zu einem Forschungsstandort richtig Fahrt auf. Welche Weichen in diesen 173 Jahren gestellt wurden und mit welchen Problemen man sich damals und heute konfrontiert sah, ist das übergreifende Thema dieses Vortrags. Besonderes Augenmerk wird dabei auf die Position der Frauen, die Internationalisierung sowie die Gewichtung von Technik, Handwerk und Kunst gelegt.

# Ceramics, Refractories and Composites: Approaches for Sustainability and Strategic Sovereignty

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The challenges of today´s world such as scarcity of energy and resources, turbulent political situation as well as environmental aspects demand for a re-thinking in view of strategical sovereignty in Europe. There is an urgent need to strike new pathways, towards recycling and upcycling as well as towards development of new advanced materials and technologies enabling to respond quickly to changing environments. The presented paper depicts selected approaches to address such challenges in the field of high temperature materials. Recent examples include novel concepts for electrification of the ceramic, cement and metal processing industries using new developed electrodes based on refractory composite materials and/or using hybrid heating systems such as microwave plasma torch, concepts for non-premixed combustion of ammonia in porous inert media additive manufactured from composite ceramic materials as well as innovative concepts for recycling and upcycling of carbon bonded refractory materials.

# Multi-layered materials for electrical machine cores by Selective Powder Deposition and pressure-assisted sintering

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The high efficiency targeted in new electrical machines demands superior fabrication freedom compared to conventional processes in terms of design and materials selection. Traditionally, electrical machine cores are manufactured by stacking laminated sheets of electrical steel (FeSi) coated with an organic insulation to impede the flow of eddy currents. This manufacturing route restricts the Si content to less than 4 wt% to ensure adequate workability. However, higher Si content steel, i.e. Fe-6.5wt%Si, represents an optimized grade due to its zero magnetostriction and higher electrical resistivity, which further reduces the eddy current losses. In this regard, indirect additive manufacturing technologies offer the possibility to fabricate complex geometries and to process brittle materials such as Fe-6.5wt%Si and ceramics.

This work addresses the manufacturing of metal-ceramic multi-material components using an indirect powder bed-based AM technology named Selective Powder Deposition (SPD) followed by pressure-assisted sintering for powder consolidation and part densification. Layers of FeSi and ceramic powder with matching coefficient of thermal expansion and elastic properties were alternatively deposited in a graphite die in order to build a multi-layered part. Dense and crack-free laminates were obtained upon consolidation using spark plasma sintering. Good adhesion between the FeSi and ceramic layers was realized thanks to the mechanical interlocking given by SPD. Moreover, complete insulation of the metal layers was achieved. The resolution and compatibility of the layers along with the crystallographic texture of the magnetic material were assessed by microstructural characterization techniques.

# Functional Ceramics for sustainable energy storage and conversion

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Specifically designed ceramic materials are essential for sustainable energy storage and conversion applications in batteries, capacitors, solar cells, piezoelectrics, and (photo-) electrocatalysts. Given the evolving landscape of energy generation, storage, delivery, and consumption, innovative technologies and approaches are crucial for developing long-term sustainable energy systems. To enhance energy security and mitigate negative health and environmental impacts, next-generation energy sources like solar, wind, tide, and wave energy offer promising avenues for utilizing chemical energy from renewable sources, despite their intermittent availability. Battery storage systems are emerging as key solutions to address this challenge. Targeted material synthesis through chemical strategies can enhance the functional performance of materials. Atomic-level preorganization of (nano)structured functional ceramics using specific synthesized molecular complexes, which integrate all material-dependent elements into a single molecular structure, shows promise in improving materials' performance in sustainable nergy conversion and storage. Unique synthetic strategies and methods for next-generation catalytic metal oxides or chalcogenides demonstrate exceptional control over materials' composition, morphology, and phase formation.

# Chlorophyll-modified TiO2 Nanofibers for Photocatalytic Degradation of Methylene Blue Dye

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Methylene blue (MB) is a ubiquitous cationic dye extensively utilized in the textile industry, notorious for its presence as a wastewater contaminant. In this context, the photocatalytic degradation of environmental pollutants is of paramount interest for sustainable development.

Hence, this study endeavors to evaluate the photocatalytic efficiency of an innovative solution based on green leaf extracts (GL)-functionalized electrospun titanium dioxide (anatase) nanofiber sheets for the degradation of MB via visible light irradiation. Our methodology involved the fabrication of electrospun $TiO_2$@PVP nanofiber sheets, subsequently subjected to calcination at 500°C for 5 hours to yield anatase nanofibers. The X-ray diffraction analysis confirmed the formation of the anatase structure, desired for higher photocatalytic efficiency. SEM analysis revealed that the average diameter of the anatase nanofibers was 400 nm. Subsequent functionalization of the anatase nanofibers was achieved through incipient wetness impregnation using green leaf (GL) extracts containing chlorophyll a, chlorophyll b, and pheophytin as photocatalysts, with a catalyst dosage of 1 g/L.MB degradationConfirmation of the GL component's presence on the nanofibers sheet was obtained by UV-VIS and FTIR measurements. Dye degradation analysis was carried out in a photocatalytic reactor using a solar simulator as the irradiation source. The UV-VIS measurement of GL@anatase nanofiber sheets after 420 minutes of visible light exposure showed a 94% photocatalytic degradation of 10 ppm MB solutions. Our findings underscore the efficiency of GL-functionalized anatase nanofibers in the elimination of MB dye from wastewater.

# Re-use of recycled calcium zirconate for the manufacture of titanium alloy products by investment casting

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Sustainable production, especially in the manufacture of titanium castings using investment casting, is becoming increasingly important in terms of energy saving and resource conservation. This contribution presents the results of a study on the reuse of recycled CaZrO3 material from investment casting moulds (lost mould) from titanium component production for the manufacture of new CaZrO3 investment casting moulds.

In addition to the mechanical machinability (milling), the chemical evaluation of the recycled material and the properties when reused in slurry formulations, the quality of the titanium components produced in the investment casting moulds made from recycled material was also evaluated. Finally, a strategy was developed as to how and where this recycled material can be used.

# Electrophoretic Deposition of protective coatings for cost-reduced Solid Oxide Cell Interconnects

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Solid Oxide Cells (SOCs) are on their way to an industrial level in the field of hydrogen-technologies, and increasing research activities are directed towards sustainability and economic viability. One of the most relevant SOC-components in this field is the ferritic stainless steel (FSS) interconnect (IC).

The evaporation of Cr (as fundamental element in FSS) leads to a strong degradation of the air-electrode (Cr-poisoning) and thus presents the main degradation mechanism related to the IC. Along with excessive corrosion that results in the formation of a resistive chromia scale, these issues provide strong motivation for the development of protective coatings. The SoA solution in Jülich utilizes a specialty high Cr-containing steel (Crofer22 APU or H) with a plasma sprayed Co-based protective coating. The high performance of this system comes at the cost of the overall sustainability and cost-efficiency of the ICs, and thus the entire SOC system. A key approach towards economic viability and sustainability of SOCs is therefore the assessment of the use of commercial steel ICs, combined with a coating with reduced environmental impact. Electrophoretic Deposition (EPD) is a promising candidate for this application as a cheap and flexible coating method to apply thin ceramic coatings on steel. In this work, alternative materials for both base IC and coating are compared with SoA materials in their suitability for SOC-ICs, while being evaluated by means of microstructural properties and performance, such as corrosion behavior and area specific resistance. Therefore, EPD is chosen next to Atmospheric Plasma Spraying (SoA) and the implementation of real IC structures brings the development one step closer to operation level.

# Optimizing GDC electrolytes for solid oxide cells: Influence of rheology on microstructure formation

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Gadolinium-doped ceria (GDC) is a promising substitute for 8YSZ in solid oxide cells offering potential benefits as a fuel electrode. Yet, interdiffusion at the active interface between YSZ electrolyte and Ni-GDC electrode decreases performance. Thus, adopting a GDC electrolyte with a Ni-GDC electrode is assumed to enhance performance by mitigating interdiffusion.

However, incorporating GDC into a fuel electrode-supported cell is challenging. Particularly, achieving a dense microstructure of the electrolyte during the critical co-sintering of multiple layers necessitates a complete understanding of each processing step. Therefore, cell production was systematically examined, focusing on fabrication of fully screen-printed three-layer electrolytes.

Pre-treatment of the GDC showed a significant influence on the sintered structure. Hence, the impact of powder pre-calcination at various temperatures on sintering behavior was investigated. Powder characterization included particle size distribution, specific surface area measurements and scanning electron microscopy. Using rheology, novel screen-printing pastes were prepared and analyzed. Dispersion stability, pseudoplasticity, viscoelasticity, and time-dependent behavior (thixotropy) were investigated. Subsequently, full cells were produced. Cell bending after co-sintering of the electrolyte was quantified. Cross-sections showed appropriate microstructures, while performance tests of these cells are pending.

# Grain boundary conductivity and blacklight sintering of BaZrO3-based proton conductors

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Acceptor-doped $BaZrO_3$ is one of the most researched materials for use as an inorganic proton conductor with the disadvantage of long sintering times at high temperatures (> 1600 °C, 24 h). Coupled with BaO evaporation at these high temperatures, it is difficult to produce stoichiometric, dense, and large grained ceramics.

The first part of this presentation focuses on the influence of B-site doping with varying charge or size mismatch on the segregation behavior to the grain boundary. Y and Sc, Y and Al, and Y and Ti were chosen as the dopant combinations for this study besides a pure Y doping. The segregation behavior of the different dopants at grain boundaries was then analyzed with S/TEM and EDS, while the ionic conductivity was measured by EIS. By using ions with different ionic sizes and valencies, it is possible to evaluate the impact of these factors on segregation. This information can then be used to engineer the grain boundary segregation for higher conductivity.

The second part focusses on a new high heating rate sintering method as a promising alternative to conventional sintering: blacklight sintering. It uses a high-powered UV light source to heat ceramics extremely fast leading to short sintering times. This technique was applied to sinter $BaZr_{0.8}Y_{0.2}O_{3??}$ (BZY20) and $BaZr_{0.8}Y_{0.1}Sc_{0.1}O_{3-?}$ (BZY10Sc10) in under four minutes. Even though optimization in regards to the homogeneity of the microstructure is needed, the proton conductivity is already comparable to conventionally sintered samples. Hence, blacklight sintering is a promising technology with the potential to sinter $BaZrO_3$ much faster at lower energy input.

# Molecular layer deposition modified pore size and hydrophobicity of ceramic membranes

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Membranes are used at large scale to purify surface or wastewater and are increasingly applied for organo-solvent nanofiltration (OSN). However, large waste streams are still treated with traditional energy-intensive technologies like distillation. Here, polymeric membranes suffer from swelling [1], which can change pore sizes significantly due to solvent-membrane interaction. In contrast, ceramic membranes are hydrophilic and more robust, yet nanofiltration membranes are challenging to fabricate commercially [2].

In this study we utilized Molecular Layer Deposition (MLD) for modifying high-porosity $Al_2O_3$-based ceramic membranes with pore size of 20 nm, by coating the membrane surface with titanicone-type hybrid layers grown by MLD. Objectives were to 1) narrow the membranes' pore size and pore size distribution, and 2) to investigate the hydrophobicity of MLD layers obtained from $TiCl_4$ and three different organic co-reactants, being heptanol, 3-aminopropyltriethoxysilane (APTES), and n-propyltrimethoxy-silane (n-PTMS).

For the first time, the stability of the MLD layer was investigated by putting the deposited membranes into four solvents, selected as per polarity. The hybrid layer exhibited stability against the hexane (non-polar), no change in  water contact angle (WCA) (114°), and no degradation was recorded after 24 hr. Furthermore, with ethyl acetate, acetone, and water, only 1.1% WCA change was recorded. The hybrid layer membrane was highly stable in aggressive solvent conditions. These results will enable a wide range of non-swelling ceramic OSN membranes with tuned surface properties.

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# Manganese Difluoride (MnF2) Coating for Molecular Approached Anode Protection in Anode-free Lithium Metal Batteries

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Rechargeable lithium-containing batteries are present in nearly all electronic devices used daily by a large share of the world's population. The concept of "Anode free" lithium batteries (AFLB) offers the possibility to work with the extremely high theoretical charge capacity of metallic lithium of 3862 mAhg ?1 together with one of the lowest redox potentials available of -3.04 V vs SHE, all without using actual lithium as an anode and thus increasing safety and reducing catastrophic failure risk.

In the present approach, a molecular single-source precursor for MnF2 is designed, characterized, and deposited as a thin layer of MnF2 on copper foil by plasma-enhanced chemical vapor deposition (PE?CVD), which is further used as a current collector in AFLB. Electrochemical measurements show a strongly prolonged rechargeability and scanning electron microscopy (SEM) verifies a more homogenous deposition of the lithium metal on the treated current collector compared to the bare copper one. An insight into the charge mechanisms is gained by electrochemical measurements such as lithium plating in contrast to intercalation behavior. This approach exemplifies the strong potential of AFLB and illustrates the need for further research on this topic.

# Effect of processing parameters on mechanical and microstructural properties of vacuum (pressure-) infusion fabricated oxide ceramic matrix composites

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Fibre reinforced all oxide ceramic matrix composites (CMC) are a growing market, presenting a range of opportunities for advanced material applications. However, to fully exploit the commercial application potential of oxide CMC and enable large-scale commercial application, innovative and improved fabrication technologies with serial production capabilities are needed.

Addressing this need, the development of a novel vacuum-(pressure-) assisted slurry infusion technology (IFOX) for oxide CMC has been a focus of recent work at DLR. This new technology is characterised by a continuous and automatable infiltration and drying process that can be applied to various types of fibre preforms and promises serial production capabilities of near-net shape oxide CMC components. An alternative tool setup and the effect of various material and process parameters such as pressure and time on the mechanical and microstructural properties were investigated. Results for fibre fabric reinforced alumina and silica materials will be presented and compared to the same materials fabricated by a vacuum-assisted slurry infusion (VASI) process using a vacuum-bag setup. A comprehensive understanding of the advantages and limitations of each approach was achieved, offering valuable insights for future advancements in oxide CMC fabrication.

# Cyclic Testing of C/C-SiC Sandwich Structures and Interfaces

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In a new design approach, sandwich structures made of ceramic matrix composites (CMC) have been realized by using the liquid silicon infiltration (LSI) process. Due to their high specific stiffness and strength, low thermal expansion, high environmental stability and temperature resistance, as well as due to economic manufacturing processes, these so-called C/C-SiC sandwich structures offer a high potential for the application in dimensionally stable structures, like optical benches in satellites.

Carbon fibre reinforced polymer (CFRP) preforms for both, skin plates and core plates, were manufactured by autoclave technique using prepregs, based on a 2D carbon fibre fabric, preimpregnated with phenolic resin. Skin and core plates were individually converted to C/C panels by pyrolysis. Slit webs were cut out of the thin walled (0.6 mm) core plates and assembled to a grid core. Skin plates and grid core structure were joined to a sandwich structure, using an adhesive based on phenolic resin and amorphous C powder. Finally, this C/C sandwich was infiltrated with molten Si and both, the SiC matrix and the SiC joining area, were built up by a chemical reaction of Si and C, leading to a permanently joined C/C-SiC sandwich structure.

Sandwich and interface coupons were manufactured and tested in 4-point bending and tension, respectively. In order to demonstrate the mechanical stability, compliance tests with increasing load levels were performed. The results from testing and FEM simulation were correlated and it could be shown that the real structural behaviour was reproduced closely.

The manufacture of C/C-SiC sandwich structures as well as the results from simulation and mechanical testing will be presented in detail.

# Funktionsweise und Anwendungen des Oxidkeramischen Hybridrohrs / Functionality and application of the oxide ceramic hybrid tube

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The oxide ceramic hybrid tube is an innovative product created by combining a core of monolithic ceramic with an outer layer of oxide ceramic fibre-reinforced CMC (OCMC). The manufacturing process ensures a strong bond between the two layers, resulting in a unique sandwich structure that combines the best properties of both materials.

The monolithic ceramic core is characterised by high gas tightness, temperature resistance and abrasion resistance. These properties make it ideal for applications where robustness at high temperatures is of crucial importance. The outer layer of OCMC contributes to damage resistance and thermal shock resistance, which means that the hybrid pipe can also withstand extreme temperature fluctuations and external stresses.

This combination of properties makes the hybrid tube particularly suitable for demanding applications, for example in chemical process engineering, where high temperatures encounter abrasive environments. Furthermore, the hybrid tube offers flexibility in the integration of additional functional layers that can provide specific properties such as electrical conductivity or catalysis.

The presentation will shed light on the functional principle of the hybrid tube by explaining how the combination of materials leads to a high-performance solution. In addition, various applications will be presented in which the hybrid tube enables new technologies or improves the efficiency of existing ones.

# Graded Resistivity in Ceramic Matrix Composites

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When it comes to electrical applications, CMCs are used as conductors or insulators with a fixed resistivity defined by the used fiber, matrix and production route. Therefore, electrical applications that need a graded resistivity could not be produced with CMCs so far. For electrical applications such as direct current switches CMCs with a wide range of conductive and insulating properties within the same material are necessary. During a switch off event a continuous resistivity increase in the switching distance reduces the electrical current while preventing an arc formation. As soon as the resistivity reaches 1012 ?·mm$^2$/m the current comes to a standstill and the power is successfully switched off. Graded CMCs are developed because they can withstand the large thermal shock loads during switching. To produce CMCs with graded resistivity a multi-layer material development is carried out. Every layer consists of a mix of short fibers, resin and fillers. The mix ratio is changed in every layer to change its resistivity. Multiple mixes are stacked in a mold and solidified via a hot-press cycle. After that a polymer infiltration and pyrolysis (PIP) cycle is carried out to convert the resin into ceramic matrix. This procedure is repeated until the open porosity is low enough to form a dense material. Afterwards a polishing procedure is applied to the contact surface to enhance the material durability and further reduce the risk of an arc formation. To verify resistivity a static conductive test and a dynamic load test is performed. For samples consisting of one mix a resistivity bandwidth from 101 Ω·mm$^2$/m to above 1012 Ω·mm$^2$/m was successfully produced. For graded samples the resistivity bandwidth accomplished ranges from $10^3$ Ω·mm$^2$/m to 109 Ω·mm$^2$/m.

# Development of oxidic reinforcing fibers at ISC Würzburg

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Over the past three decades, Fraunhofer Institute for Silicate Research (ISC) has worked intensively on the development of ceramic reinforcing fibers. Starting from the laboratory scale, both oxide and non-oxide fiber compositions have been developed. In the case of non-oxide fibers, these were developed on the basis of organometallic precursors for the production of SiC or Si-B-N-C fibers. For the development of oxide fibers, aqueous raw materials are used. In both systems, the processes were scaled up to a technical scale in the size of several kilograms with 500 filaments and 200 m continuous multifilament. Currently, further upscaling to pilot scale in the size of > 1 t/year is being carried out. In two current EU projects, oxide fibers are being further developed in the mullite and corundum systems. To increase high-temperature stability, additives such as Zr, Y, Mg, Ti etc. are to be investigated. The aim is to develop higher quality fiber types for use at temperatures > 1200 °C compared to the state of the art.

With the equipment and know-how of Fraunhofer ISC, customer-specific ceramic fibers with different chemical compositions, various diameters between 8 - 100 µm, different cross-sectional shapes, adjustable crystallinity and porosity, specific interphases, filament counts in the roving between 20 - 500 and textile packaging - roving, fabric, chopped fibers - can be developed.

# From SiC-fiber to Ceramic Matrix Composites – Development of Ceramic Matrix Composites with the newly available BJS Silafil F SiC-fiber

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BJS Ceramics and BJS Composites are two start-up companies, founded in 2014 and 2015, with the aim to create an all European source of ceramic SiC-fibers and its ceramic composites. With the newly announced availability of the first SiC-fiber from BJS Ceramics, called Silafil F, BJS Composites is now able to show the development of a new CVI based SiC/SiC-CMC material, using the fibers from BJS Ceramics. We will cover the highlights of fiber, fabric and composite development as well as the achieved physical properties.

# Mechanical, microstructural, and fretting wear behaviour of Al2O3–ZrO2-CNT based bimodal composite coatings

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In the current work, bimodal thermal barrier coatings (TBC) were deposited via atmospheric plasma spraying (APS) using $Al_2O_3$ as a matrix, reinforced with 20 wt% of $ZrO_2$ and 4 wt% of carbon nanotubes (CNT) over Inconel 718 substrate. The objective is to study the effect of bimodality and reinforcements on the mechanical and tribological behavior of $Al_2O_3$-based TBC. $Al_2O_3$–$ZrO_2$, $Al_2O_3$–$ZrO_2$-CNT, and micro-$Al_2O_3$ coatings are named as AZ, AZC, and $Al_2O_3$, respectively. The presence of partially melted and solid-state sintered nanostructured region (NR) with fully melted and re-solidified microstructured regions (MR) showed bimodal microstructure. Reinforcements lead to enhanced nano-hardness from (12.8 GPa) for $Al_2O_3$ to (14.7 GPa) for MR of AZ and (14.1 GPa) for AZC, which is attributed to a higher amount of t-$ZrO_2$ present in the coatings. NR reduces shear stress generation during fretting wear in AZ (293.8 MPa) and AZC (298.7 MPa), resulting in a more uniform surface and reduced wear rate. Additionally, the higher aspect ratio and lubrication effect of CNTs in AZC generates the least energy dissipation (92.9 J) and wear rate ($0.9 \times 10^{-6}$ $mm^3N^{-1}m^{-1}$). SEM and EDS analysis of worn surfaces in coatings revealed abrasive, adhesive wear is dominant in $Al_2O_3$ coatings due to the higher amount of material transfer from coating to $S_{i3}N_4$ body than AZ and AZC. Overall, the synergistic effect of bimodality and reinforcements leads to improved mechanical properties and reduced shear stress generation during wear making APS-AZC coating a potential material for wear and high temperature environment.

# Sequential infiltration of prepregs for the fabrication of oxide fiber ceramic matrix composites (OFC)

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The microstructural design of matrices for oxide fiber ceramic matrix composites (OFC) in order to enable damage tolerant fracture behavior is challenging. Depending on the characteristics of the starting powders, such as particle size or sintering behavior, its feasibility might even be limited to some extent. However, the usage of different materials might offer advantageous functional properties, such as thermal insulation or corrosion stability. In this study, we investigated the use of different intra- and interbundle matrices in one composite with the aim to combine favorable mechanical behavior and thermal insulation properties. A sequential infiltration process was used to manufacture OFCs with an alumina-zirconia matrix, which exhibits high damage tolerance, and a mullite-alumina matrix with favorable properties for thermal insulation applications. It was found, that the effect of the matrix combination on the mechanical and thermal properties as well as the microstructure of the OFC depended on the infiltration sequence. Thereby, the flexural strength of a composite with mullite-alumina matrix could be increased by 41 % when the prepregs were first infiltrated with the alumina-zirconia slurry. However, the favorable thermal insulation properties of the mullite-alumina matrix could not be maintained.

# Modern way of C/SiC manufacturing

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At present, carbon fiber reinforced ceramics, especially carbon fiber reinforced silicon carbide (C/SiC) is transitioning from a highly expensive military/space grade material to much more common industrial applications. An improved approach to the process chain, based upon the liquid silicon infiltration (LSI) process for producing tailored, cost effective near-net-shape C/SiC parts is shown in the upcoming presentation.

Preform fixation/stabilization is done by a chemical vapor infiltration (CVI) process under preform compression to archive good surface qualities and dimensions. Densification is then carried out by rapid chemical vapor infiltration (r-CVI) to archive sufficient density in less than 50 h. The r-CVI process differs from classic CVI methods by directing a gas flow of high purity precursor gas close along the preform geometry. This process offers the possibility to modulate carbon morphology in order to archive in-situ fiber protection against liquid silicon attack. The next step is an efficient siliconization process which is utilizing novel, reusable crucibles and siliconization aids based on pyrolytic boron nitride (pBN). The C/SiC parts do not bond to these aids and can be easily removed. Contact surfaces retain a good surface quality, while the aids can be reused without cleaning or machining. Therefore, labor and resources could be reduced vastly to produce near-net-shape C/SiC parts.

# O-CMC für industrielle Anwendungen

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Oxidische Ceramic-Matrix-Composites (O-CMC) bieten mehrere technische Vorteile für Anwendungen in industriellen Bereichen wie thermische, chemische und metallurgische Prozesstechnik. Im Vergleich zu etablierten Werkstofflösungen ist der Einsatz von O-CMC allerdings relativ teuer, was deren Wettbewerbsfähigkeit schmälert. In diesem Zusammenhang untersucht Rauschert O-CMC-Herstellungsverfahren, wie Gewebelaminierung für komplexe Bauteilformen im BMBF-Projekt DoMiGat und Kurzfaserspritzen im EU-geförderten Projekte InVECOF. Hierbei soll auch die Anwendbarkeit der damit erzeugten Bauteile in den benannten Industriebereichen erprobt werden. Die Präsentation zeigt Ergebnisse dieser Arbeiten.

# Understanding the role of gas phase reactions during surface siliconization of carbon-carbon composites

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Carbon-Carbon composites with densified Silicon Carbide surface (C/C-SiC) are well-known for their exceptional thermal and oxidation resistance. Reactive Melt Infiltration (RMI) or Liquid Silicon Infiltration (LSI) are employed to impart oxidation resistance to these composites by transforming the carbon matrix surface into silicon carbide. Successful infiltration yields dense-grey SiC, while unsuccessful process yields porous green SiC layer. Components from failed siliconization process possess lower thermal resistance, inducing high-temperature surface damage. Hence, understanding the causes of failed siliconization and their influencing factors becomes crucial for enhancing high-temperature performance of these composites. This study proves that gas-phase reactions occurring prior to silicon melting are the primary triggers behind the greenish SiC layer. Through siliconization experiments and Simultaneous Thermal Analysis, these reactions are linked to the specific-surface characteristics of silicon powder used and the amount of residual silicon post the gas phase reactions. Further siliconization experiments with minimized gas phase reactions verify the inference. Microstructural differences between gas and liquid reaction-formed SiC are investigated, leading to the proposed four-step reaction pathway explaining the formation of surface SiC layer on siliconized composites. These findings offer vital insights for optimizing the outcome of surface siliconization process.

# Nachhaltigkeit durch innovative C/C-Verbundwerkstoffe

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Ceramic fiber composites are innovative lightweight solutions for the most demanding tasks in industrial applications. Schunk offers customers both oxide and non-oxide materials from a broad portfolio and has recently further reduced the CO2 footprint of its own range of materials with a C/C material based on recycled fibers. Application examples illustrate the benefits of using ceramic composite materials with a focus on sustainability.

# International exposure in the ceramics curriculum at TU Darmstadt


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30 years ago, we all felt that international tensions were a matter of the past; it seemed as if big wars would not happen anymore. However, now, the political international networks have started to crumble into several chunks of different sizes. Here, the scientific networks should play a role to counteract this development. Scientists should work together across international boundaries and teach their students to do so. Specifics in culture, advantages in respective teaching concepts, and dangers looming in various political systems should be known to future leaders. Beyond politics and culture, the sustainability crisis demands joint international action and should bring us even closer together.

We will present strategies for facilitating international 3-month research visits for undergraduate students and propose ideas for collaborative M.Sc. research projects. We will also share insights from 3-month research visits of Ph.D. students, spanning countries from the US, UK, and Australia to Russia, Japan, S.-Korea, and China. This exchange should be mutually beneficial. Therefore, we will explore how to attract international students to German Universities, what they can gain from the experience, and address concerns they may have.
Lastly, we will delve into the opportunities for senior researchers in international collaboration. We will discuss the avenues provided by the Alexander-von-Humboldt Foundation and other funding sources, highlighting the benefits and potential impact of such exchanges on the ceramics field.

# From unpopular matter to smart subject: promotion of young talents and refractory research at TU Freiberg

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The imparting of knowledge as well as hard and soft skills to young PhD scientists by a close supervising as well as by workshops and training courses, are important instruments for acquiring not only scientific and technical but also social competencies in the environment of interdisciplinary research work. The German Research Foundation DFG has established long-term research programs such as the Collaborative Research Center 920, the Research Unit FOR 3010, and the Research Training Group GRK 2802 at the TU Freiberg, in which more than 60 PhD students explore basics framing multiple actual challenges in the field of refractory materials such as the manufacturing and interaction of ceramic foam filters with steel and aluminium melts for cleaner metal parts, electrically heatable refractory composites based on refractory metals and refractory oxides, and the recycling of MgO-C in new bricks the and upcycling of metal-ceramics as carbon-free electrodes. But also team and leadership competence questions were educated to the PhD students. For an interdisciplinary, international, and industrial-related education, all the research programs involve mentors from the industry, foreign universities, and three departments of Freiberg university (plasto-mechanics, fluid dynamics, iron and steel, and materials science), who guide the PhD students during workshops, internships, and bilateral discussions. The presentation will summarize key scientific outputs and will give insights into the tools and experience of more than 10 years of activities in focused research programs and structured training strategies of PhD students

# Sustainable promotion of young scientists in material science – strategies and challenges

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Innovative materials are integral to both present and future technologies. Sustainable progress in interdisciplinary research relies on the contributions of qualified young scientists. Mentorship programs and innovative strategies are key to uncovering new pathways for their advancement.

Tailored methods and adaptable strategies are essential for promoting young scientists, from PhD candidates to assistant or junior professors, and aligning them with evolving needs. These demands underscore the need for flexibility, as each stage of an academic career - be it PhD, post-doc, junior group leader, or habilitate - presents distinct challenges. Effectively promoting young scientists requires efforts to enhance the appeal of scientific careers, facilitate transitions into interdisciplinary fields, encourage international competitiveness and mobility, ensure equal opportunities, and recognize outstanding scientific achievements.

# Max-von-Laue Institute of Ceramic Materials (CerMaX)

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In 2018, the state government of Rhineland-Palatinate implemented research colleges, an instrument that aims to enable graduates of universities of applied sciences to pursue a cooperative doctorate together with a university within a transparent and structured framework. The Department of Glass Ceramics of Koblenz University of Applied Sciences and the Department of Mathematics/Natural Sciences of the University in Koblenz have succeeded in acquiring funding for a research college from 2018 to 2022 specializing in ceramics. This created an interdisciplinary context in which 12 graduates from both institutions worked on their dissertations.

On the basis of the completed and positively evaluated project, Koblenz University of Applied Sciences, the University of Koblenz and, as a new cooperation partner, the Research Institute for Glass I Ceramics GmbH have decided to set up a research training group from 2024, which will further intensify scientific cooperation and at the same time give graduates at the participating institutions the opportunity to do a doctorate. In addition, an accompanying network with external scientific fellows from universities in Italy, France and the USA as well as honorary fellows from various industrial companies offers the option of carrying out either partial or complete research work or research stays that significantly increase the scientific potential of the work.

Accompanying the academic cooperation, the doctoral students take part in a skills-building programme selected by the graduate centres of both universities and compiled for the needs of the research training group. Offers are also organised for PhD candidates for the transition to the next career stage.

# POSTERS

# Use of a rotary vacuum evaporator for ceramic granulation on the laboratory scale: influence of various parameters on the quality of the granules

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The present work evaluates the granulation process using a vacuum rotary evaporator followed by sieving, with the aim of correlating various parameters to achieve desired properties of the granules. It fills gaps in the limited literature and improves the understanding of this technique for Technical Ceramics. Objectives include the production of liquid phase alumina ceramics from a mixture of alumina, kaolin, chalk and talc, and understanding how raw material particle size distribution affects the quality of the granules. Critical process parameters and limitations have been identified. The results show that the process is suitable for laboratory scale investigations and produces granules appropriate for ceramic green and sintered pieces. In particular, it demonstrates the importance of the interplay between dispersant and binder in significantly affecting the process due to the surface chemistry of the particles. The conditions used resulted in pressed bodies with sufficient stability for demoulding and short-distance transport, although they remain fragile for machining or prolonged transport. The use of finer, well dispersed raw materials is likely to result in more homogeneous products, suggesting that ball milling during mixing may be critical for materials that tend to agglomerate. Acceptable mass recovery was only achieved when pressing relatively coarse granulated powders (below 1 mm), highlighting the need for precise control of dispersant and binder proportions to balance softness for densification and stiffness for stable pressed green bodies. This study advances the understanding of the vacuum rotary evaporation granulation process and provides insights into improving process efficiency.

# Coextrusion of Reaction-Bonded Carbides by Robocasting

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Coextrusion by robocasting is a suitable process for fabricating multi-material ceramic structures. Herein, the robocasting process is used to fabricate core shell structures, combined with subsequent liquid silicon infiltration (LSI). Thus, reaction-bonded silicon carbide (RBSC), reaction-bonded boron carbide (RBBC), and reaction-bonded silicon–boron carbide composites are produced. The LSI process offers the possibility to circumvent high temperatures and pressures used in traditional fabrication. Pastes with high solid loading and necessary carbon content enable the combination of robocasting and LSI. The impact of paste rheology on the structure of the multi-material core-shell samples is studied using scanning electron microscopy observations. A correlation between the difference in viscosity and the core geometry can be established. Crack formation in the material combination of RBSC and RBBC is found and compared with layered multi-material structures of reaction-bonded carbides. Residual stresses, which can be used to explain the crack formation, are investigated using Raman spectroscopy.

# Keep It Simple: Efficient Hybrid Methods for Ceramic Prototype Production

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Direct ceramic 3D printing processes are now well established, but due to cost and restrictions on solid parts and material selection, their availability and usability are limited.

A combination of material extrusion (MEX), VAT photopolymerization (VPP), and (hand) wax-based ceramic injection molding is a promising alternative to 3D printing for prototype and low-volume production of simple to more complex geometries. With this hybrid approach, reusable molds made of silicone or similar molding materials can be used independently of the ceramic feedstock.

The ceramic injection molding process allows the use of different feedstocks in the same mold, which is resource efficient and sustainable due to its up to 10-fold reusability. By focusing on the algorithmic description of components, the time from concept development to the finished sintered solid component is significantly reduced. Case studies on the production of heat shields and crucibles for refractory applications and ceramic nozzles for non-abrasive ceramic FDM printing will demonstrate the potential of this process combination.

# Influence of crystalline fraction on fracture toughness of lithium disilicates glass-ceramics

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The assessment of fracture toughness (KIC) of glass-ceramic materials is still an experimentally challenging issue and little is known of how microstructure affects this property. This work aims to correlate microstructural characteristics to KIC values by mathematical regression in lithium disilicate glass-ceramics (LS2). Complex LS2-based materials are the most relevant commercial GCs in dentistry. To standardize, stoichiometric LS2 glass was melted (1400-1450°C) and cast into 4x25x50 mm rectangular molds. The pieces were crystallized in different protocols to ensure variations in crystalline fraction and crystal size. The nucleation was conducted at 456 ± 2 °C for 12-312h and the crystal growth at 560 ± 2 °C for 0.75-2.50h. Fracture toughness was determined by the Chevron Notch Beam method (ASTM C1421-18), using 3-6 specimens for each condition. Crystal sizes and fractions were measured using optical microscopy and the fraction was quantitatively measured by X-ray diffraction (XRD). The crystal size varied from 3 to 20 µm and the crystallization degree from 0.1 to 96 vol%, resulting in a toughness range from 0.8 to 3.5 MPa.m1/2. Large crystal sizes and fraction resulted in microcracking and porosity. Hence, a non-linear behaviour was observed beyond 75 vol% of crystallization, showing that these variables need to be considered for the mathematical model. Our KIC measurements are within the literature for similar compositions, using different measurement techniques.

# Chemical Vapor Deposition of Phase-Pure Uranium Dioxide Thin Films from Uranium(IV) Amidate Precursors

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Homoleptic uranium(IV) amidate complexes have been synthesized and applied as single source molecular precursors for the chemical vapor deposition of UO2 thin films. These precursors decompose by alkene elimination to give highly crystalline phase-pure UO2 films with an unusual branched heterostructure.

# A strength testing method for additively manufactured ceramics

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3D-printed components exhibit structured surfaces as a consequence of the additive manufacturing process. For the stereolithographic manufacturing process, the structure's geometry and periodicity depend on the angle between the building direction and the respective surface. Therefore, the strength of ceramic 3D-printed components may depend on the orientation in which tensile stresses act with respect to the building direction.

In order to provide material data for the design of components, the strength characteristics have to be routinely assessed for various processing conditions and/or as means of quality control. Such investigations are laborious and costly if standardized methods and specimens for ceramics are used. In a recent the project, a novel test specimen was designed and investigated. It allows manufacturing of a sample set of sufficient size for statistical strength evaluation within a single print job with the LCM-procedure (CerAM VPP).

The basic principle of the test procedure as well as the learnings from a round robin trial are presented. Specimens were manufactured by four partners in three different specimen configurations. Thermal post-processing and testing was conducted at a single partner to minimize other processing variation. Ultimately, the geometry and strength of more than 2000 cantilevers were analyzed. This yielded plenty of data to assess the geometrical consistency as well as differences in strength for and between each partner. It is shown that through the introduction of an automated geometry evaluation, a large amount of strength and geometry data can be obtained with comparatively small effort.

# Magnetic Saturation as Coating Quality Indicator of WC-Co Tools

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Tungsten carbide (WC) work tools are known for their high precision and are favored in high wear applications. These tools may be coated with polycrystalline diamond films to improve their wear resistance further. However, they need to pass quality assurance step before the coating procedure to avoid faulty tools production and monetary loss. In this study, we aim to justify the use of magnetic saturation (MS) as a quality indicator for the samples' coating compatibility. The samples are divided into two categories: high (HMS) and low (LMS) magnetically saturated samples with 11 µT $m^3$/kg being the threshold value. The coated WC-Co samples are characterized based on: depletion zone, edge quality and diameter reduction. A KOERZIMAT 1.097 MS is used for magnetic saturation measurements, a Scanning Electron Microscope (SEM) is used for depletion zone and edge morphology analysis, and, lastly, the samples' diameter is measured before, during and after the coating process using a laser micrometer. The rods used are WC-%6Co with a mean WC grain size of 1.2 µm. From our measurements, we conclude the following observations: HMS samples undergo deeper etching, suffer from fracturing edges and a notably reduced diameter. NMS samples, however, have a shallower depletion zone, a relatively straight edges and a moderate diameter reduction. Hence, the magnetic saturation value is indeed a sufficient indicator to detect failure-prone samples.

# Suitability of the Impulse Excitation Technique (IET) to determine the Young's modulus of 2D macroporous ceramics

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The presence of defects or pores in a ceramic leads to a lower effective Young's modulus compared to the dense material. For the development of porous ceramics with precisely adjusted elastic properties, an exact determination of the Young's modulus is required.

Therefore, we investigated the suitability of the impulse excitation technique for measuring the dynamic Young's modulus of two-dimensional non-homogenous ceramics with low porosity ($P < 19$ %). It was shown that for rectangular samples the measurement is sensitive to the geometric pore position, as added holes outside the nodal lines of the fundamental flexural vibration could not be detected respectively had no influence on the result. Pores in the inner part of the sample led to a decrease of the Young's modulus that is in good agreement with empirical and analytical models as well as comparable values from the literature. For the investigated interval of porosity range, the influence of pore size and geometric position on the reduction of the Young's modulus was determined.

# Development of multifunctional high-temperature final coatings for ceramic tiles using hybrid metal precursor technology

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The poster presents the development of a multifunctional modification of the factory surface finish for use on unglazed ceramic tiles in a cooperation project between the FGK and n-tec GmbH. Through targeted crystallization, a possibility was developed to equip the tile surface with the functions of photocatalysis and catalysis as well as antibacterial properties. The innovative approach of the development is that no further process steps such as an additional coating application and no additional thermal post-treatment are necessary, as is the case with previous commercial systems. The modified surface finish can therefore be easily integrated and applied in an established production process to upgrade functionality without generating additional energy costs and emissions.

# Copolymerization in UV-curing suspensions: suitable for slurries in the VPP process?

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In the case of light-curing slurries, many components work together to generate layer-by-layer curing. The initiator - i.e. the component that ensures the polymerization reaction - must be carefully selected. Depending on the wavelength of a VPP printer, various initiators are available. It is important to choose an additive that has a maximum absorption in the corresponding wavelength range.

Light sources with a wavelength of approx. 460 nm are installed in some established printers. In most cases, the initiator "camphorquinone" is selected. Although exposure takes place in the area of the absorption maximum, the polymerization rate is quite low.

Coinitiators can accelerate the polymerization process and thus significantly improve the rate of polymerization. Numerous coinitiators are discussed in the literature. Aromatic amines in particular are very effective in combination with camphorquinone. Depending on the monomers, the coinitiator and the ratio of initiator to coinitiator, the polymerization rate can be increased threefold.

In the context of ceramic 3D printing, it is still questionable whether the coinitiators will prove their worth.

# High temperature wear resistant coatings for austenitic stainless steel

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Cermets are promising coating materials for steel components that are subjected to harsh processing conditions during operation at high temperature. In an austenitizing furnace for an industrial hot stamping process, the coatings should reduce corrosion and wear of the components. Cermet coatings were developed as part of the EU project HIPERMAT and funding was provided from the European Union's Horizon 2020 research and innovation program under Grant agreement 958196. Cermet coatings consisting of CoNiCrAlY and a MAX phase were investigated and compared with the established cermet coating material NiCr-Cr3C2. The coatings were applied on austenitic steel substrates using High Velocity Oxygen Fuel (HVOF) spraying. The coated samples were characterized by XRD, SEM, and EDS and the thermocycling resistance was tested from 500 to 1000 °C. High temperature wear tests were carried out on coated samples under laboratory conditions at 930 °C and components of an industrial furnace were also coated and tested directly during the hot stamping process.

# Determination of atomic positions and lattice parameters in barium titanate for calculations of energy function coefficients

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Barium titanate (BT) is a ferroelectric ceramic and a promising candidate for a variety of applications due to its excellent dielectric, ferroelectric, and piezoelectric properties. BT belongs to a large family of perovskites with the general formula ABO3. Barium titanate undergoes a phase transformation from the ferroelectric tetragonal phase to the paraelectric cubic phase at a temperature of 130 °C.

To describe this phase transition, the Landau-Ginzburg-Devonshire theory (LGD) can be employed. This theory is a particular example of Landau theory, with the Gibbs free energy representing the state function of the ferroelectric, and the temperature, stress, and polarization as independent variables. The Landau-Devonshire-Ginzburg theory, now widely accepted for describing ferroelectrics, is a mean-field theory that describes the thermodynamic properties of bulk ferroelectric materials.

In our work, Rietveld refinements of X-Ray data are using to determine the atomic positions of the respective ions in the crystal and the corresponding lattice parameters, that allows the polarization calculation. Furthermore, the experimental determination of the Curie temperature can be obtained at which the temperature-dependent permittivity measurement reaches its maximum. The remaining coefficients of the energy function can be calculated under zero stress conditions, these calculation methods permit the determination of all coefficients associated with the energy function.

# Development of a processing route for lead-free positive temperature coefficient of resistance ceramics based on barium titanate-bismuth sodium titanate

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Barium titanate-bismuth sodium titanate (BT-BNT) is a suitable candidate for lead-free positive temperature coefficient of resistance (PTCR) ceramics. PTCR ceramics are used, for example, as self-regulating heating elements. In the application, the Curie temperature TC plays an important role. TC describes the transformation temperature of the crystal lattice and thus the transition from ferroelectric to paraelectric properties, which determines the operating point of the PTCR ceramics. The BT-BNT solid solution was selected to extend the application possibilities of pure BT by increasing its TC from 130°C.

The main challenge is the processing of the powders through a mixed oxide route with a stoichiometric weight of bismuth and sodium $Ba_{1-x}(Bi_{0.5}Na_{0.5})xTi_{1.017}Nb_{0.003}O_{3+z}$ (x = 0.1 - 0.2) and the subsequent selection of appropriate sintering parameters to generate functional PTCR properties. The obtained results demonstrated that the grinding parameters and the heat treatment of the powders, coupled with the variation of the sintering temperatures, had a significant influence on the resulting microstructural and electrical properties.

The investigation of the influence of different processing parameters on the properties of the BT-BNT solid solution revealed a significant influence on the PTCR effectiveness and stability. This provides valuable information for the development of lead-free PTCR ceramics with optimized properties for applications in electronic devices.

# Synthesis and Characterization of Noval Ni(II) Complexes in Fabrication Nickel Oxide Thin Films via Chemical Vapour Deposition for Photoelectrochemical Water Splitting

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Solar-driven photoelectrochemical (PEC) water splitting stands as a promising avenue in harnessing renewable solar energy for the production of hydrogen gas, offering an environmentally sustainable approach. Nickel oxide emerges as a compelling choice due to its abundance, cost-effectiveness, and non-toxic nature. it is an ideal catalyst as photoelectrode in a water-splitting application due to Its stability in an aqueous electrolyte solution. In this study we delve into the synthesis and characterization of novel developed Ni(II) complexes based on tetra and bi-dentate ligands with a tailored design aimed at optimizing the chemical vapor deposition (CVD) process for the production of nickel oxide (NiO) thin films. Three noval Ni (II) complexes have been successfully synthesized and then characterized through various analytical techniques such as Single Crystal X-ray diffraction analysis, NMR Spectroscopy, FT-IR spectroscopy, UV/Vis Spectroscopy, and ESI-Mass Spectroscopy. These complexes have been used as precursors in CVD processes to fabrication NiO thin film by Plasma enhanced-CVD, and Magnetic assisted-CVD. The deposited NiO thin films have been characterized in terms of their thickness, morphology, and crystallinity (i.e. X-ray diffraction technique, Scanning Electron Microscopy, and Atomic Force Microscopy). Moreover, for a understanding of the efficiency of these syytems, we invastigated the photocatatytic activity of the generated thin films. Our results reveal that the NiO thin films exhibit notable efficacy and stability in catalyzing hydrogen evolution reactions.

# Exsolution of Metal Nanoparticles from Mesoporous Perovskite Oxides

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The design of highly efficient and durable catalysts by exsolution has become very promising owing to the exceptional stability and strong anchorage of the finely dispersed catalysts on the oxide support [1]. In this work, perovskite oxide ($La_{0.2}Sr_{0.8}Ti_{1-x}M_xO_3$, M = Ni, Co) is doped with different amount of active metals – Ni and Co, which are subsequently precipitated from the matrix of the support to the surface during heat treatment. Temperature programmed Reduction was carried out to observe the oxygen release from the perovskite during the heat treatment which is one of the main driving force in the exsolution process. In principle, the assessment of oxygen release as function of porosity, nature and amount of M-dopant provides profound insights into the development of the exsolution process.

Further understanding of the exsolution process, was carried out by performing some in-situ measurements such as in situ ASAX and TEM [2], to adequately monitor the physiochemical processes involved in the size evolution of the nanoparticles in real time. The analysis of the SAXS data revealed nucleation and growth events at different time scales which corresponded well to the structural changes of the perovskite matrix and the reduction of the metal species monitored by in situ XRD and XANES spectroscopy, respectively.

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# Mixed ionic electronic oxygen transport membrane materials for solar-thermic syngas production beyond 1000 °C

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The establishment of a technical carbon cycle to address climate change highlights the urgent need for renewable syngas production, driving investigation into solar-thermic carbon dioxide decomposition as a promising solution. This process, operating above 1000°C, yields carbon monoxide crucial for syngas generation, along with excess oxygen that requires removal. Oxygen transport membranes offer a potential solution. However, their viability hinges on the use of mixed ionic electronic conductors capable of withstanding extreme temperatures over prolonged periods. This presentation delves into the critical aspect of material selection for oxygen transport membranes, offering insights into current advancements and methodologies for evaluating feasibility. Specifically, we address challenges inherent in ceria/zirconia and calcium titanate-based materials, emphasizing their long-term thermal, mechanical, and chemical stability. These properties are intricately linked to ionic conductivity and non-stoichiometry, crucial factors determining the success of oxygen transport membrane technology. Through a thorough examination of these challenges, we aim to enhance our understanding of material requirements and contribute to the development of more resilient and efficient solutions for renewable syngas production.

# Investigation of Carbon-Bonded Alumina Samples with Concentrated Carbon Binder Surface for Copper Melt Filtration

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The foundry industry's development has led to an increase in the purity requirements for metals. When considering the impurities of metals, a distinction is made between gases (e.g. hydrogen and oxygen), trace elements and non-metallic inclusions. Non-metallic inclusions influence the mechanical properties of metals detrimentally and so process steps removing inclusions are of great importance. Filtration with ceramic foam filters is used since the 1960s for the reduction of non-metallic inclusions. The aim of this study is to investigate the effect of different coatings consisting of coked coal tar pitch on the performance of bulk samples and the suitability of coated ceramic foam filters for copper melt filtration. The coated bulk samples were subsequently characterized with regard to bending strength, surface roughness, pore size distribution, residual carbon content and wetting behavior in contact with a copper melt. The surface and cross-section of the samples were characterized by optical microscopy and scanning electron microscopy. Compared to bulk samples without coating, the coal tar pitch coating had no negative influence on bending strength. The sessile drop experiments showed that substrates coated with coal tar pitch had a higher contact angle compared to samples without any coating. Furthermore, carbon-bonded alumina foam filters were coated with the coal tar pitch. These filters were tested by means of sandcasting trials with a copper melt.

# Functional Ceramics for Sustainable Energy Conversion

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The developments of modern human life have been hardly connected to the energy produced by fossil fuels. Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress. However, with the rapid depletion of conventional energy sources and increasing energy demand, worldwide energy consumption has continuously grown. In response to the urgent need for climate change mitigation, ceramic and inorganic semiconducting materials have emerged as crucial players in renewable energy conversion processes, including solar-driven reactions like photocatalytic water splitting for green hydrogen production, CO2 reduction, and piezo/electrocatalytic activation of small molecules (N2, CO2). Additionally, these materials are essential components in energy storage systems such as rechargeable batteries. Innovative material processing techniques, including field-assisted (magnetic/electric) methods for both gas-phase and solution-based synthesis, besides specially designed molecular precursors, are enhancing the performance of next-generation sustainable energy technologies. This presented work will present detailed methods for generating novel and precisely engineered ceramic materials with tailored properties.

# Novel Heteroleptic Complexes of Zirconium and Hafnium as Precursors for Chemical Vapor Deposition of Metal Oxide and Nitride Coatings

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The foundry industry's development has led to an increase in the purity requirements for metals. When considering the impurities of metals, a distinction is made between gases (e.g. hydrogen and oxygen), trace elements and non-metallic inclusions. Non-metallic inclusions influence the mechanical properties of metals detrimentally and so process steps removing inclusions are of great importance. Filtration with ceramic foam filters is used since the 1960s for the reduction of non-metallic inclusions. The aim of this study is to investigate the effect of different coatings consisting of coked coal tar pitch on the performance of bulk samples and the suitability of coated ceramic foam filters for copper melt filtration. The coated bulk samples were subsequently characterized with regard to bending strength, surface roughness, pore size distribution, residual carbon content and wetting behavior in contact with a copper melt. The surface and cross-section of the samples were characterized by optical microscopy and scanning electron microscopy. Compared to bulk samples without coating, the coal tar pitch coating had no negative influence on bending strength. The sessile drop experiments showed that substrates coated with coal tar pitch had a higher contact angle compared to samples without any coating. Furthermore, carbon-bonded alumina foam filters were coated with the coal tar pitch. These filters were tested by means of sandcasting trials with a copper melt.

# Breaking the conventional picture: how an ultra-high dislocation density changes the fracture of oxides

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The duality of strength and brittleness/toughness has limited the use of structural materials for millenials. While metallurgy hinges greatly on this apparent tradeoff utilizing dislocation engineering, ceramics are mostly considered brittle and small defects can already lead to catastrophic failure. In some ceramic systems, however, dislocations as line defects can easily glide and multiply once they are introduced, even at room temperature. While this has been known since the 1950s, there has been a lack of methods to introduce a high homogeneous dislocation density on a macroscopic scale without cracking until recently.

With dislocation densities of up to ~$10^{15}$ $m^{-2}$ in MgO engineered via cyclic Brinell scratching, as will be showcased in this poster, the potential of dislocation-based toughening effect can finally be investigated on a broad length scale. After characterizing the plastic zones by chemical etching, electron channelling contrast imaging (ECCI) and scanning transmission electron microscopy (STEM), we found complete crack suppression during Vickers indentation on the dislocation-rich sample compared to the reference. To further investigate the crack-dislocation interaction in detail, double cleavage drilled compression (DCDC) samples were manufactured from MgO single crystals, where the stable crack growth was captured in situ in a scanning electron microscope (SEM), highlighting the crack tip interacting with dislocation-rich barriers in the crack path.

Further, notched micro-cantilevers were fabricated from dislocation-rich and reference MgO using a focussed ion beam (FIB). The fracture of these cantilevers with different crystallographic crack planes shows a change in the failure mechanism.

# HWH COMPETITION

# Influence of Y2O3 doping on the aging behavior and mechanical properties of ATZ ceramics

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Alumina-Toughened-Zirconia (ATZ) samples with a composition of 80 wt% $ZrO_2$, 20 wt% $Al_2O_3$ and a $Y_2O_3$ content between 2 and 3 mol% were prepared by mixing pre-stabilized zirconia powders and characterized regarding their mechanical properties and aging stability.
To evaluate the effect of composition modification, studies were carried out on sintered density, grain size, hardness and fracture toughness, as well as an analysis of the microstructure using scanning electron microscopy. It was found that a reduction in stabilizer content leads to a reduction in hardness and an increase in fracture toughness. The sintered density and grain size do not change significantly with Y2O3 content.
The phase composition was determined through X-ray diffraction of sintered tablets. The sintered bodies were aged for up to 150 h in an autoclave to determine the materials' aging behavior. Reducing the $Y_2O_3$ content to 2 mol% increases the transformability of the tetragonal phase and thus leads to a reduced aging resistance. It has been shown that the use of a very fine-grained material (grain size approximately 0.25-0.30 µm) can prevent this effect to a large extent, since below a critical grain size hardly any aging-induced phase transformation occurs.
The determined Avrami exponent indicates a rapid nucleation process at the surface, followed by one-dimensional grain growth into the volume.
The research indicates, that ATZ ceramic with 2 mol% $Y_2O_3$ is a promising material for load-bearing implants, due to its high aging stability and increased fracture toughness compared to 3 mol% $Y_2O_3$–stabilized ceramic.

# MAX phase composites with adjustable coefficient of thermal expansion for precision glass moulding

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Precision glass moulding is a manufacturing process for glass lenses. Tungsten carbide (WC) is currently used as the moulding material. The significantly lower coefficient of thermal expansion (CTE) of WC compared to optical glass increases the risk of glass breakage. A new moulding material must be developed to reduce the thermal expansion difference between the mould and the glass. Field-assisted sintered MAX phase composites appear to be suitable candidates for targeted adjustment of the CTE. A reinforcing phase has been added to the MAX phase Ti3SiC2. Silicon carbide (SiC) and titanium carbide (TiC) were used as the reinforcing phase. By varying the amount of the reinforcing phase, the CTE of the composites can be controlled. A mixing rule was developed to produce MC-Ti3SiC2 composites with a CTE similar to that of the most commonly used optical glasses. In addition to the CTE, the thermal conductivity was also investigated as a function of the carbide content, as the thermal conductivity has a large influence on the cycle time of precision glass moulding. After sintering, the MAX phase composites have to be machined to obtain a geometry corresponding to the glass lens to be produced. In order to machine the composites by ultra-precision grinding, a fully compacted, fine-grained and homogeneous material is required. The microstructure was characterised using light microscopy, electron backscatter diffraction (EBSD) and scanning transmission electron microscopy (STEM).

# Hydrogen corrosion of refractories of the system $Al_2O_3$-$SiO_2$

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In order to reduce $CO_2$ emissions, currently a change is taking place within the steel industry towards hydrogen-based steel production routes. Consequently, the requirement for sustainability of refractories is being extended to include chemical resistance to hydrogen. The aim of this study is to characterize the corrosion mechanism occurring in an exemplary cement-bonded $Al_2O_3$-$SiO_2$ refractory, which simulates a hydrogen-induced attack under high temperature conditions. Furthermore, the impact of graphite on the hydrogen-induced corrosion of the refractory is a focus of the study. Hydrogen exposure is performed at $T = 1400°C$ in two furnaces, which differ primarily in their lining material, either alumina or graphite. After hydrogen attack, scanning electron microscopy and powder X-ray diffraction are used to provide microstructural information which are verified by thermochemical equilibrium calculations. The occurring corrosion mechanism is represented as a sequence of formation and transformation of mineralogical phases. In addition, the analysis results reveal a significantly distinct corrosion attack in presence of graphite. Two thermodynamically calculated cases of reaction mechanisms are presented for extensive description. The first approach describes the removal of the corrosion products, thereby shifting the equilibrium towards the side of reaction products. The second mechanism clearly demonstrates that mixed gas atmospheres comprising $H_2$, $H_2O$, $CO$ and $CH_4$ enhance hydrogen-induced corrosion compared to pure hydrogen atmospheres.

# 3D printing of porcelain structures using filament-based print heads

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The suitability of a commercial soft porcelain powder and a commercial thermoplastic binder for FDM/FFF printing was investigated. The effects of solid loading and pre-calcination of powders on filament fabrication, printing properties and post-print treatment are analysed. The green filament flexibility, rheology, as well as the debinding kinetics, shrinkage during thermal treatment, including sintering and the flexural strength after sintering of the filaments have been carried out in this study. In addition, surface roughness and density have been characterised for different filaments, accompanied by microstructural analysis during the debinding process. A higher solid loading results in lower shrinkage and higher density, whilst reducing the flexibility of the green filament. However, the flexural strength is not affected significantly. Unfortunately, only filaments with the lowest solid loading of 45 vol.-% were printable, since slippage at the filament feeder-gear occurs at higher solid loadings. Using pre-calcined porcelain powder shrinkage during wick debinding could be significantly reduced.

# Dislocation-tuned functionality in single-crystal BaTiO3 and its temperature and frequency dependence

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#5

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Ferroelectric materials have driven electronic advancements due to properties like switchable polarization, high dielectric constant, and piezoelectricity. Controlling domain wall motion through methods like dislocation-based techniques is crucial to optimise these properties.

This work establishes a mechanical paradigm centred on dislocation-tuned functionalities in BaTiO3. The objective was to understand how dislocations influence the ferroelectric domain structure and dielectric and piezoelectric properties. BaTiO3 samples were subjected to high-temperature creep and plastic deformation, including an innovative notching technique to increase dislocation density.

Comparative analysis showed significant differences in dielectric and piezoelectric properties between deformed and undeformed samples. The Creep-1 sample exhibited increased dielectric permittivity and converse piezoelectric coefficient, highlighting strong electromechanical coupling.

A key finding was the anisotropic nature of dislocation-domain wall interactions. The [001]-oriented Creep-1 sample showed weaker pinning force and higher dielectric permittivity. The notched sample's dense dislocations acted as effective pinning sites, impeding domain wall movement and inducing new domain formation.

This study enhances the understanding of dislocation-tuned functionalities in BaTiO3, underscoring the role of dislocations in modifying ferroelectric properties and advancing the design and application of functional ferroelectric materials.

# Interlocking of ceramic structures – modularity for tailoring of piezoelectric properties

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Ceramic Structure Interlocking refers to the method of designing and joining ceramic components into a mechanically interlocked modular structure without the use of adhesives or additional fasteners. This technique has gained increasing interest in recent years due to its numerous advantages, including increased structural integrity or improved thermal and mechanical properties. Combining modularity with other material properties, such as electromechanical properties, can lead to new applications for specific requirements. A wide range of technical applications such as sensors, actuators and electrical transducers are based on piezoelectric ceramics. Piezoelectric ceramic-polymer composites have become increasingly important, especially in the field of piezoelectric transducers, as a single material does not always meet all application-specific requirements.

Building blocks (BBs) with a cylindrical interlocking structure were fabricated by SLA printing of positive structures combined with injection molding of lead-free BaTiO3. The BBs were bonded with various bonding materials, both conductive and non-conductive, to ensure electrical coupling between the BBs. The influence of the number of BBs, and therefore the number of bonding layers between them, on the piezoelectric properties was analyzed. Both types of bonding layers showed a decrease in piezoelectric properties with increasing number of BBs. However, no further decrease was observed after adding more than four BBs for both bonding materials. In comparison, the use of conductive bonding material allowed to maintain the piezoelectric properties with only moderate degradation, which can be used in energy applications.

# Indentation fracture resistance of silicon nitride measured on curved surfaces

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Ceramic balls made of silicon nitride have a high resistance against corrosion and abrasion making them ideal for bearing applications. However, their service life is often limited by surface spalling due to contact crack initiation and propagation. Hence, it is important to know the fracture resistance of the material. A simple method to determine this property is the indentation fracture method. Such experiments are conducted by placing a Vickers hardness indentation on polished cross sections of the balls. The investigated location is thus not the surface. The microstructure and residual stresses of the balls may vary in radial direction. Measurements on material from the ball interior may thus not reflect the properties of the surface, which is relevant for in-service performance. Using the ball surface directly for testing would also simplify the test execution significantly.

This work aimed to establish fracture resistance testing on spherical surfaces of bearing balls with different diameters using various indentation loads. These results reflect the local properties from the part of the balls relevant to their application. Additionally, insights into the properties of different parts of the balls were gained by comparing these results with values obtained from other radial locations of the balls: the subsurface, the centre of the balls and the surface of separately fabricated standard bend bars. Further, the microstructure was analysed to correlate with the measured properties.

# Synthesis and characterisation of palladium and palladium-silver membranes on porous ceramic supports

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Transitioning from fossil fuels to renewable energy sources requires the utilisation of hydrogen as a future energy storage solution. This includes economically viable technologies for the separation of hydrogen from gaseous mixtures and its conversion into various energy carriers, such as methane. For such applications, palladium membranes show considerable potential in membrane reactors as efficient hydrogen separators and catalytically active materials.

In this study, the synthesis of palladium and palladium-silver membranes on porous $Al_2O_3$ supports via Electroless Plating (ELP) was optimised. Membrane performance and surface structure were characterised through single gas permeation measurements and field-emission scanning electron microscopy.

Synthesis yielded pure palladium membranes with a maximum ($H_2/N_2$) separation selectivity of 131 and ($H_2/SF_6$) selectivity of 532 at hydrogen permeances between 2556.93 to 2995.28 L $m^{-2}$ $h^{-1}$ $bar^{-1}$ at 300 °C measurement temperature. Palladium-silver membranes with a maximum (H2/N2) selectivity of 35 and ($H_2/SF_6$) selectivity of 69 at a hydrogen permeance of 2441.97 L $m^{-2}$ $h^{-1}$ $bar^{-1}$ were obtained.

Initial results suggest that further optimisation of the ELP process can yield enhanced system stability and thus increase membrane performance.

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