Fraunhofer

Formnext 2021

News 2.2021

Fraunhofer Competence Field Additive Manufacturing

Editorial

The formnext special edition of the Fraunhofer Competence Field Additive Manufacturing NEWS 2.21 is in front of you, presenting the highlights of all exhibitors at the Fraunhofer joint booth in the new corporate design of the Fraunhofer-Gesellschaft and for the first time under the new name. Thus, the successful cooperation of more than twenty years of the Fraunhofer Additive Manufacturing Alliance is continued.

Exhibition highlights include the LIsec powder nozzle measurement system (Fraunhofer IWS), an additively manufactured combustion chamber for the sustainable use of hydrogen (Fraunhofer IPT), the smart gear with integrated RFID accelerometer (Fraunhofer IGCV), a hybrid component suitable for mass production made of die casting and 3D printing (Fraunhofer IWU) or pantographic structures with microscopic joints as programmable metamaterial (Fraunhofer EMI). These and other exhibits reflect the wide range of applications of 3D printing in aerospace, biomedical, automotive and energy technology.

formnext 2021 is also a welcome occasion for us to publish the Call for papers of the Fraunhofer Direct Digital Manufacturing Conference 2023 – expecting an exciting conference and take the opportunity to submit a paper yourself!

My colleagues and I look forward to a lively exchange with you directly during formnext or in the follow-up and wish you a successful visit to the trade-fair.

Dr. Bernhard Mueller
Spokesperson Fraunhofer Competence Field Additiv Manufacturing

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The Fraunhofer Direct Digital Manufacturing Conference (DDMC) is a cutting-edge forum for discussion on Additive Manufacturing.
Highlights of our biennial conference are:

- High-profile keynote speakers
- Numerous stage and poster presentations
- Industrial contributions
- Evening networking event in historic location
- Best Paper and Best Poster Award
- Conference proceedings with all full papers

DDMC 2022 has been postponed to 2023 to ensure another exciting live event
The conference will take place in Berlin.

To keep you updated in **2022**, we have planned a special webinar series

Bi-monthly live web meetings
Kick-off in spring 2022
Revisiting keynotes of DDMC 2020, including live statements from speakers

- Panel rounds with representatives from industry and Fraunhofer
- Scientific Comittee panel rounds and presentations

DDMC2023
Fraunhofer Direct Digital Manufacturing Conference

A Fraunhofer IPT

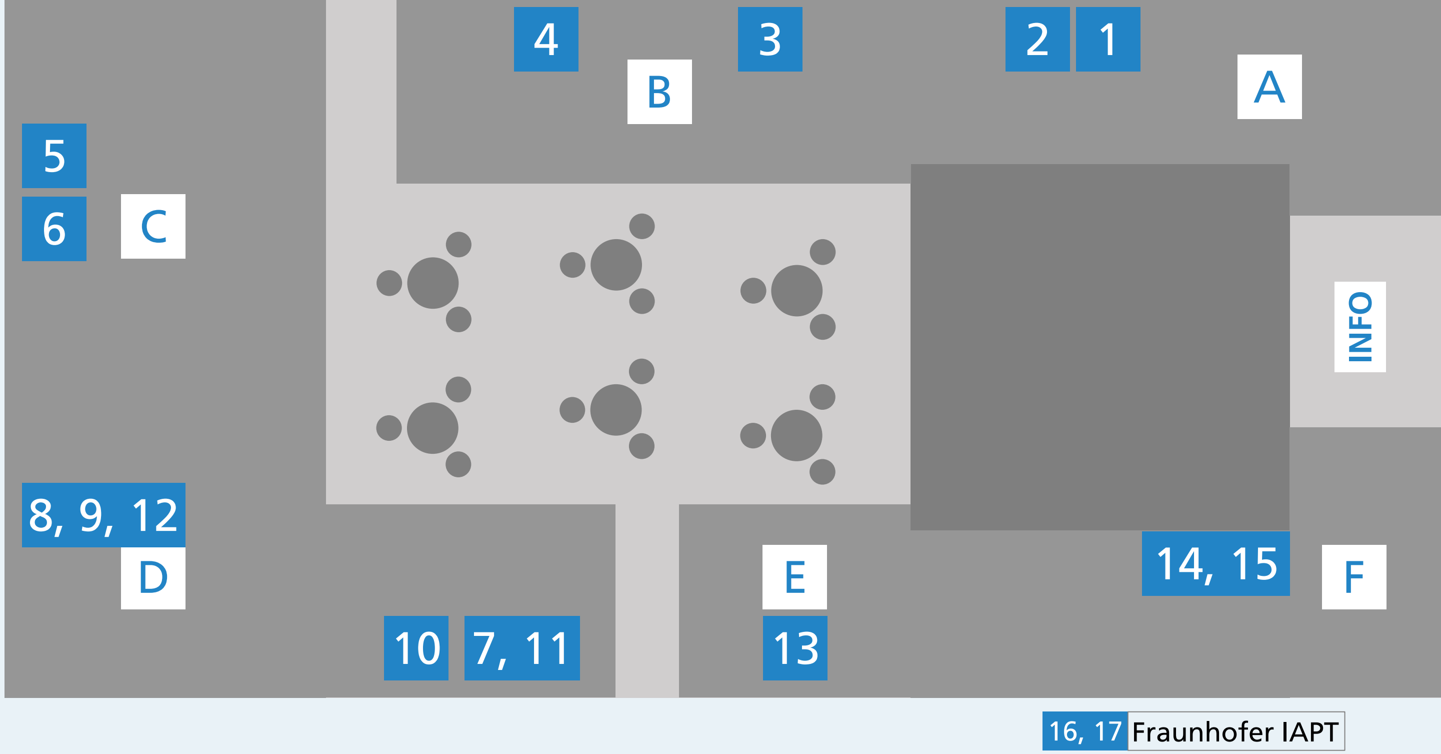
B Fraunhofer IFAM

C Fraunhofer ILT

D Competence Field Additive Manufacturing

E Fraunhofer IGD

F Fraunhofer IWS



Our Exhibitors

Office, Fraunhofer IWU, Dresden

Fraunhofer Competence Field Additive Manufacturing

The Fraunhofer Competence Field Additive Manufacturing intgrates 19 Fraunhofer Institutes across Germany and represents the entire process chain of additive manufacturing. This includes the development, application and implementation of additive manufacturing methods and processes. Many years of experience from national and international industrial contracts and research projects form the basis to develop customer-specific concepts and master complex tasks.

Fraunhofer IFAM, Dresden und Bremen

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

Fraunhofer IFAM offers the whole range of metal powder-based AM processes to provide thorough access to the various possibilities of additive manufacturing technologies. The comprehensively equipped additive manufacturing application center at Fraunhofer IFAM in Bremen comprises the complete process chain for LBM[1] and MBJ[2]. At Fraunhofer IFAM in Dresden, the Innovation Center Additive Manufacturing ICAM® brings together SEBM[3], 3D Screen Printing, FFF[4], Gel Casting, MoldJet® and LMM[5] under one roof.

Fraunhofer IGD, Darmstadt

Fraunhofer Institute for Computer Graphics Research IGD

Fraunhofer IGD is the internationally leading organization for applied research in Visual Computing. Numerous basic technologies are necessary to bring images, audio, video, and interactive 3D worlds to the viewer in high visual quality. Our visual displays create the opportunity of presenting complex and interdependent content through sensor data and simulations. Data and experience can be analyzed with the help of visual displays. Our goal is to keep more and more complex computer systems and increasing amounts of data manageable for humans, society and economy.

Fraunhofer Institute for Laser Technology ILT

Fraunhofer ILT, Aachen

Activities of Fraunhofer ILT cover a wide range of areas such as the development of new laser beam sources and components, precise laser based metrology, testing technology and industrial laser processes. This includes laser cutting, caving, drilling, welding and soldering as well as surface treatment, micro processing and additive manufacturing. Furthermore, the Fraunhofer ILT is engaged in laser plant technology, process control, modelling and simulation as well as in the entire system technology. We offer feasibility studies, process qualification and laser integration in customer specific manufacturing lines

Fraunhofer Institute for Production Technology IPT

Fraunhofer IPT, Aachen

Fraunhofer IPT creates system solutions for the networked, adaptive production of sustainable and resource-saving products and related services. Our focus lies in the areas of process technology, production machines, production quality and metrology, and technology management, and ranges from fundamental principles up to the digital transformation of production.

Fraunhofer Institute for Material and Beam Technology IWS

Fraunhofer IWS, Dresden

Fraunhofer IWS stands for innovations in laser and surface technology. The Dresden scientists offer one-stop solutions ranging from the development of new processes to implementation into production up to application-oriented support. The fields of systems technology and process simulation complement the core competencies.

[1]LBM: Laser Beam Melting
[2]MBJ: Metal Binder Jetting
[3]SEBM: Selective Electron Beam Melting
[4]FFF: Fused Filament Fabrication
[5]LMM: Lithography-based Metal Manufacturing,

»Hydrogen is the oil of tomorrow.«

Prof. Dr.-Ing. Harald Funke,
Professor for Gas Turbines and Aero Engines at the FH Aachen and project partner of the Fraunhofer IPT

Additively Manufactured Combustion Chamber for the Sustainable Use of Hydrogen

The Paris Climate Agreement, Flight Path 2050 and ACARE 2050 call for a rapid development towards emission-neutral mobility. Hydrogen (H_2) will play an important role in this. The problem, however, is that while hydrogen combustion does not produce carbon dioxide (CO_2), it does produce more nitrogen oxides (NO_x) than fossil fuel combustion. Thus, the hydrogen combustion process needs to be redesigned.

Exactly this – reduced NO_x values – is what the MicroMix (MMX) process delivers. Compared to conventional combustion processes with several large flames, the MMX process uses many small flames generating less NO_x. However, manufacturing a MMX combustion chamber presents production engineers with major challenges, for example, in terms of uniform distribution of the hydrogen and the tightness of the components.

How can a complex, integral design with reproducible internal structures be produced for the MMX process in a timely manner? The Fraunhofer IPT is pursuing the Additive Manufacturing approach: Using the Laser Powder Bed Fusion (LPBF) process, the institute can design the H_2 combustion chamber as an integral component and build up core elements fully aligned with each other, thus, making internal support structures and dead water areas superfluous. In addition, it has improved the flow of the flame rings by changing the outer geometry, integrated the supports for the spoke centering into the flame ring and aligned the air baffles with each other during design. In initial tests, the concept resulted in a higher tightness of the combustion chamber and improved distribution of the hydrogen.

The MMX combustion chamber, however, poses problems not only for additive, but also for conventional manufacturing, because further subtractive manufacturing steps are necessary, in addition to heat treatment and cutting off the build platform. In the next work steps, it is particularly important to develop a milling process that is specially designed for such filigree, loose-mounted air baffles and the tight tolerances for the gas outflow.

Through intensive collaboration and research into all manufacturing steps, the Fraunhofer team and its partners are on their way to make an important contribution to achieve climate targets and CO_2-neutral energy production.

Fraunhofer Institute for Production Technology IPT

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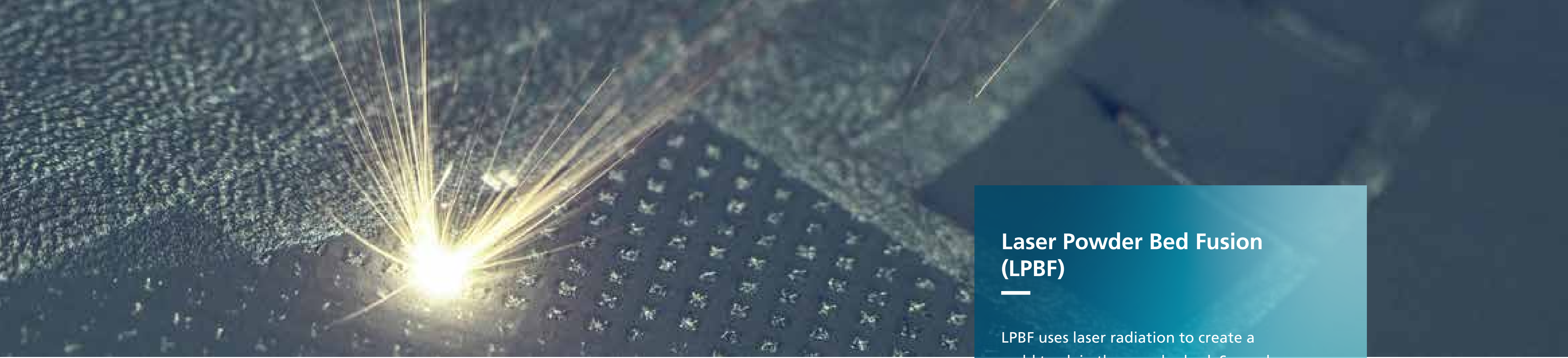

Additively Manufactured Grinding Wheel Provides Improved Cooling and Prevents Grinding Burns

Additive Manufacturing processes such as Laser Powder Bed Fusion (LPBF) offer the industry a far greater degree of freedom to design and produce components: Indeed, geometries that cannot be produced by conventional manufacturing processes, or only at great expense, can be produced simply and reliably with the aid of LPBF. The tool engineering sector can use this new design freedom profitably, for example, for weight reduction and the targeted guidance of gases or liquids.

Within the scope of a design study, a team from the Fraunhofer IPT recently developed and implemented concepts for additively manufactured grinding wheel bodies, concepts that make it possible to build channels in the grinding wheel to supply cooling lubricant directly to the contact zone between tool and workpiece. Effective supply of the coolant, thus, prevents thermal damage, known as “grinding burn”, to the material. Particularly in the case of wide grinding wheels or the production of grooves, sufficient cooling of the contact zone is not always ensured by conventional, lateral coolant supply.

As a demonstrator, a grinding wheel body consisting of seven segments was manufactured to test how efficiently cooling lubricant can be delivered to the contact zone. Each segment has a completely different internal structure: Not only does the form of the channel vary greatly, but so do the stable columns or grid structures. Furthermore, the internal structures are printed without support structures.

The possibilities opened up by the use of Additive Manufacturing processes are manifold and not limited to grinding wheels for tool technology. Therefore, the Fraunhofer IPT plans to further develop the use of Additive Manufacturing to redesign and improve tools for conventional – e.g. grinding and milling – and non-conventional manufacturing processes – e.g. electrochemical machining (ECM) – in order to increase their performance and improve their application behavior.

Laser Powder Bed Fusion (LPBF)

LPBF uses laser radiation to create a weld track in the powder bed. Several weld tracks next to each other result in a layer, several layers on top of each other result in a component. In this way, a 3D-printed metal component is created layer by layer from a CAD file.

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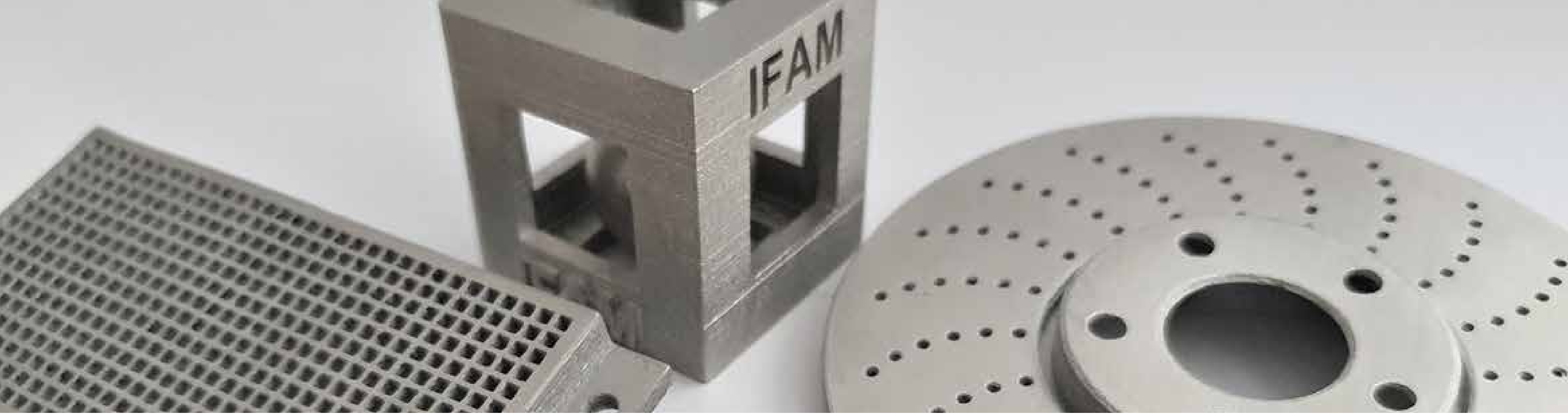

Sintered components produced with MoldJet®

New Processes for Filigree Components and high Productivity: LMM and MoldJet®

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Dresden has significantly expanded its portfolio in sinter-based additive manufacturing with the processes MoldJet® and Lithography-based Metal Manufacturing (LMM). The new processes round off the possibilities for filigree components (LMM) and for high productivity (MoldJet®) in particular. Both processes were presented for the first time at formnext 2019.

LMM is a stereolithography process for metallic components from the company Incus. In this process, a paste system consisting of metal powder, an organic carrier and a photosensitive polymer is selectively exposed layer by layer. After printing, the unexposed areas are removed and the components are sintered to form fully metallic structures. This way, LMM enables the most filigree 3D components with resolutions of 100 µm, which cannot be achieved with other processes.

With the MoldJet® from Tritone, the negative of the target component is first printed in layers from wax using an inkjet process. The open areas of the layer are then filled with a paste containing metal powder. The printed wax form serves as a support structure, so that overhangs can also be produced without difficulty. After printing is complete, the wax mold is removed and the green part is sintered to form a fully metallic component, as in LMM. The system technology used by Fraunhofer IFAM uses a turret system with six printing tables, which allows a very high productivity of up to 1600 cm^3/h.

Together with the existing technologies Fused Filament Fabrication (FFF), 3D screen printing, gel casting, and electron beam melting (EBM), Fraunhofer IFAM in Dresden offers its customers through the strategic cooperation with the manufacturing companies Incus and Tritone a wide range of metallic additive processes to specifically meet new industrial requirements. Together with the Metal Binder Jetting and Laser Beam Melting (LBPF) processes at Fraunhofer IFAM in Bremen, all relevant process technologies are available to partners.

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Components produced by Metal Binder Jetting before (left) and after (right) sintering.

Metal Binder Jetting - Extended Possibilities at Fraunhofer IFAM

During summer 2021, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Bremen commissioned a new Metal Binder Jetting facility. With 25 liters of build volume, this 3D printer enables the gap to be closed between prototype production in quantities of one and tool-based large-scale production.

In binder-based metal 3D printing, imprinting a binder into a metal powder bed creates cohesion among the powder particles. Layer-by-layer repetition creates a three-dimensional, so-called green part. This is removed from the powder bed after printing and then thermally post-treated in a sintering furnace. Here, the final step to the metallic component takes place in one debinding and sintering furnace cycle.

Compared to others such as laser-based 3D printing processes, metal binder jetting realizes significantly greater build speeds – at least ten times faster. In addition, the process allows for the processing of materials that were previously impossible to process with other 3D printing methods, such as metal alloys that cannot be welded at all or that weld poorly.

"The continuing interest in industrial 3D printing as a complement to conventional manufacturing processes has prompted us to invest in new printing technology here. The system 25 PRO, from the manufacturer ExOne, represents an ideal extension of our existing capabilities", says Claus Aumund-Kopp, Group Manager Additive Manufacturing at Fraunhofer IFAM in Bremen. Previously, three ExOne printers of the INNOVENT or INNOVENT plus type have been in operation at Fraunhofer IFAM in Bremen.

In addition to the operation of now four 3D printers for metal binder jetting, metal powder analysis and handling has been part of Fraunhofer IFAM's activities for decades. In order to be able to evaluate and process the raw material metal powder, various devices for powder analysis and preparation are available. The debinding and sintering furnaces required for the process are also operated. Fraunhofer IFAM thus has comprehensive technical equipment and expertise along the entire process chain of metal binder jetting.

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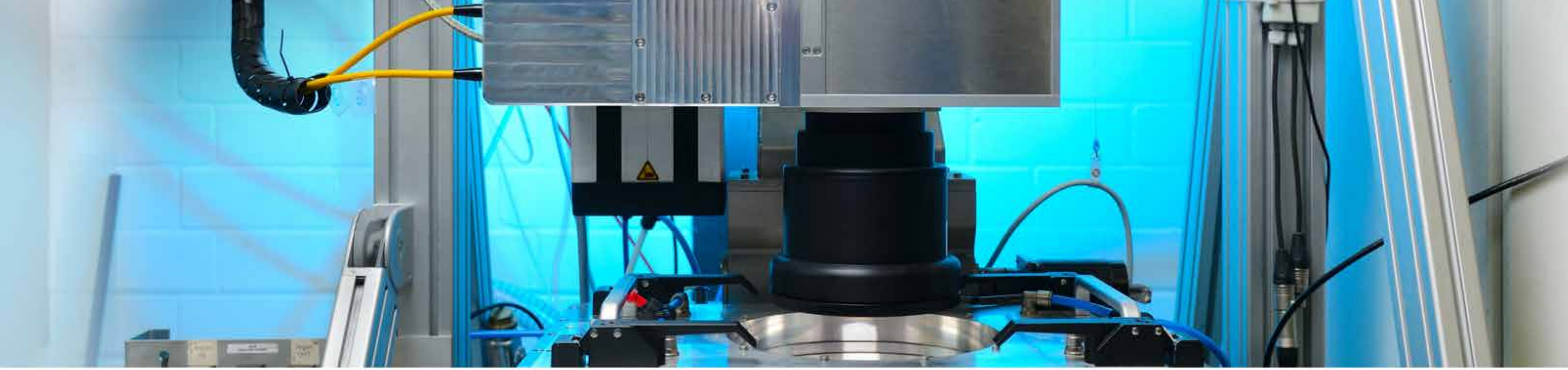

The developed dual fiber array allows the individual control of two single-mode fiber lasers that are deflected by a single galvanometer scanner

Enhancement of Productivity and Robustness through LPBF with Spatial and Temporal Laser Modulation

Additive manufacturing using laser powder bed fusion (LPBF) enables the production of functional components with almost unlimited geometric complexity thanks to the layer-by-layer manufacturing process. However, the comparatively low process productivity inhibits a broad industrial use of LPBF in production. The machines used for LPBF typically use a laser beam diameter between ds = 50 - 100 µm. With simultaneous use of large laser powers of up to PL,max = 1000 W, this leads to large maximum intensities and thus to a greater risk of component defects and process instabilities due to keyhole welding effects, increased formation of process by-products and local overheating. For this reason, the cost-intensive multiplication of laser scanner systems to increase the productivity of LPBF machines through parallelized processing is often resorted to in practice. In order to overcome the resulting restrictions of LPBF with regard to the achievable productivity and process robustness, as well as the range of materials that can be processed, the Fraunhofer Institute for Laser Technology ILT is researching approaches to temporal and spatial laser beam modulation for LPBF together with other research and industry partners as part of the BMBF-funded Research Campus for Digital Photonic Production DPP. The aim is to increase productivity per laser beam by at least 100 % while maintaining component quality, and to enable robust processing of new classes of materials using LPBF by adapting the laser beam diameter and laser intensity distribution, as well as complex multi-beam concepts and dynamic laser beam oscillation.

One approach addressed in the DPP is LPBF using a dual fiber laser array. Compared to conventional LPBF, two individually addressable single-mode fiber lasers are deflected by a single galvanometer scanner. Thanks to a multi-beam optical system specially developed at the ILT, the laser spots can be flexibly and dynamically adjusted in terms of their relative orientation. This results in additional degrees of freedom that can be used, for example, to minimize the necessary hatch vectors or to selectively preheat and postheat the remelted material. Meanwhile, the fundamental feasibility and potential of LPBF using dual fiber laser arrays could be demonstrated within the Fraunhofer lighthouse project futureAM and analyzed using high-speed images of the LPBF process.

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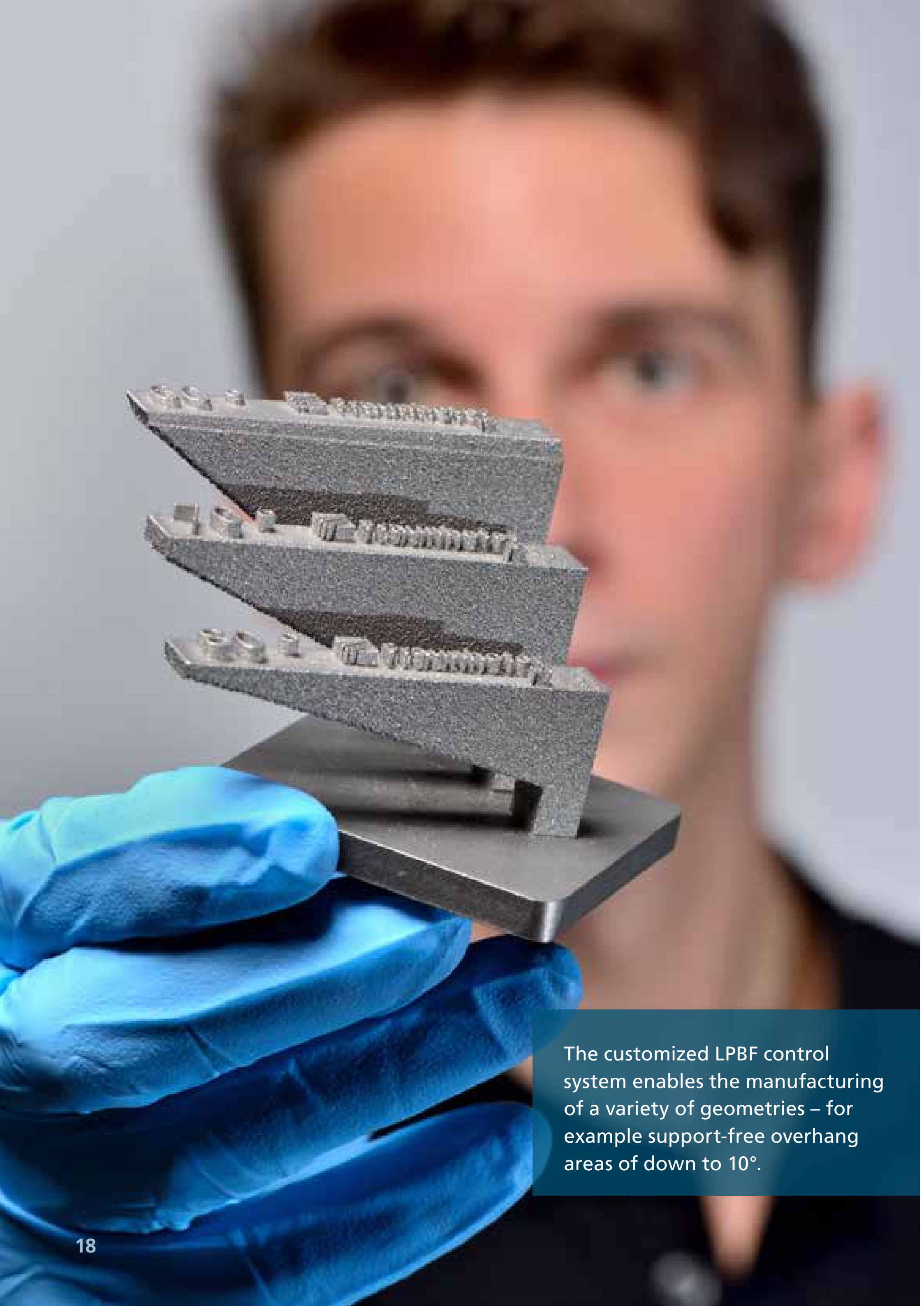

The customized LPBF control system enables the manufacturing of a variety of geometries – for example support-free overhang areas of down to 10°.

Tailored Laser Powder Bed Fusion

Geometry- and application-adapted LPBF process control opens up new possibilities for additive manufacturing

In Laser Powder Bed Fusion (LPBF), geometrically complex components are manufactured by remelting powdered material layer by layer. After applying a powder layer, the laser beam is moved across the areas of the powder bed that should be remolten according to a predefined processing strategy consisting of scan sequence and process parameters. However, the geometric characteristics of the component are currently only taken into account to a minor extent when selecting the processing strategy: This strategy is determined for the entire component, so that, for example, filigree and solid component areas are processed with the same strategy. This results in shape deviations, component distortion and restrictions in surface quality and productivity. In addition, the user has little influence on the quality of the component surface

At Fraunhofer ILT, a customized LPBF process control system is being developed which takes into account the component geometry to be manufactured and the user's requirements. To enable this, the necessary modifications are being made to the system and control technology to enable the LPBF process parameters to be controllable down to the level of individual scan vectors. Furthermore, software for component analysis was developed to enable geometry-specific assignment of the process parameters.

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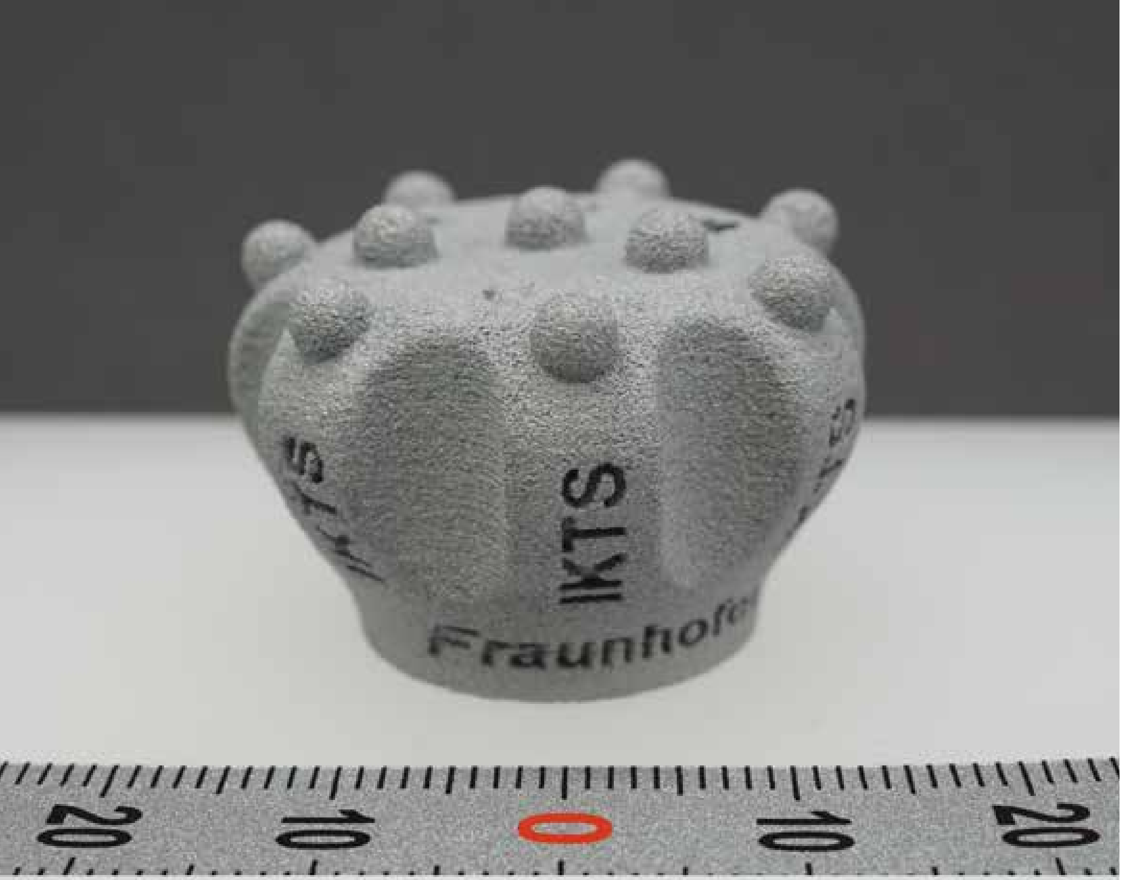

Hardmetal Components

Additively manufactured hardmetal components by BJT (above) and FFF (below).

Introduction of Additively Manufactured Hardmetals into Practice

Properties of additively manufactured hardmetals comparable with conventionally manufactured components

Hardmetals, which consists of tungsten carbide and cobalt, are also becoming increasingly important in additive manufacturing and are on the way of industrialization.

At Fraunhofer IKTS, various powder-based and filament- or suspension-based processes are being adapted and further developed with regard to the material system. The two technologies binder jetting (BJT) and fused filament fabrication (FFF) have proven to be particularly efficient. BJT has a very high productivity and building volume. The powder-based process produces green bodies with green densities below 40% of the theoretical density, which can be densified to 100% dense components by subsequent sintering. The realization of green densities above 50% is possible with FFF. The realizable resolution of the filament-based process depends on a correct deposition of the filaments. The manufactured components in both processes can be debinded and sintered using conventional furnace technology. This produces dense and pore-free components with material properties comparable to conventionally manufactured components. Hardnesses of over 1700 HV10 and fracture toughnesses of over 22.1 $MPa \cdot m^{1/2}$ can be achieved. By changing the material system in terms of metallic binder content and grain sizes, a wide range of properties can be achieved and thus many fields of application can be covered.

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

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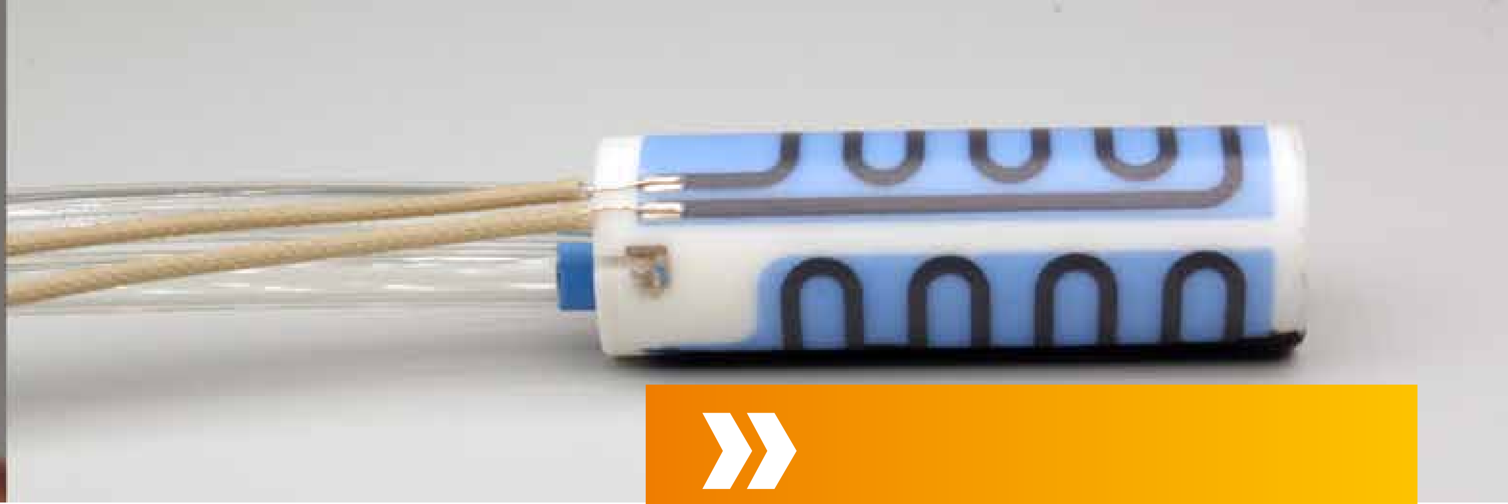

Sequential and Simultaneous Functionalization of Ceramic AM Components

»Our technology platform enables the manufacturing of highly robust components with integrated sensors or actuators!«

Dr. Lars Rebenklau,
Department Head, Systems Integration and Electronic Packaging

Material and property combination

Additive manufacturing is a »game changer«, especially for ceramic materials, which are difficult to machine due to their high hardness. Previously unknown component geometries can now be realized directly and functions such as cooling channel or mixer structures can be integrated.

By combining them with functional materials, the outstanding mechanical, chemical and thermal properties of ceramic materials can be extended even further, resulting in components with e.g. integrated electrical conduction structures, passive electrical components, sensors or actuators. Various manufacturing strategies are available for this.

In sequential manufacturing, the ceramic substrate is first shaped and sintered. In a second manufacturing step, the functional structures are then applied to the substrate surface and also thermally processed. The basis for this functionalization are the material systems of thick-film technology known in electronics technology. These also offer the advantage that additional electronic or sensory components can be fitted using various assembly and connection techniques. Furthermore, electrical integration into higher-level systems can be achieved by means of high-temperature stable contacting. As a result of the multi-stage processing, the sintering conditions can be optimally adapted to the different materials. Currently, the deposition of functional materials is only possible on accessible surfaces. Further developed techniques that circumvent this limitation are under development. The potential of this methodology has already been demonstrated for various thermal cycling processes (e.g. µPCR and heating-cooling systems for soldering processes).

In simultaneous manufacturing, the different materials are processed in one process and thermally co-processed together. This gives much more geometric freedom in the arrangement of the materials, but also significantly limits the available material portfolio. By combining different Si_3N_4 mixtures, ceramic igniters and heaters are currently being produced, but density or color gradients have also already been successfully realized.

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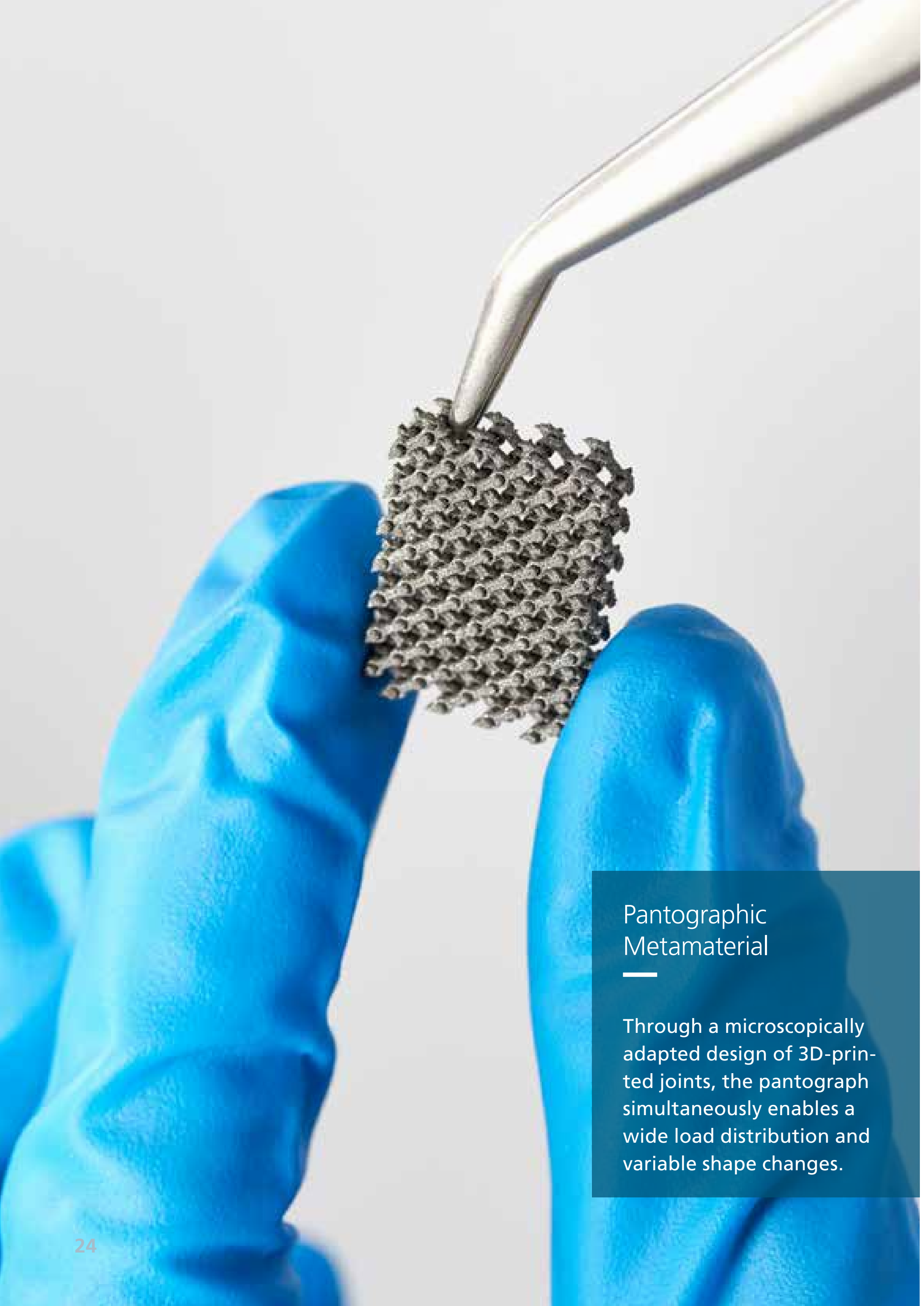

Pantographic Metamaterial

Through a microscopically adapted design of 3D-prin-ted joints, the pantograph simultaneously enables a wide load distribution and variable shape changes.

Comprehensive Solutions for Novel Materials

Pantographic structure with microscopic joints as a pro-grammable metamaterial

Fraunhofer EMI develops and researches new material solutions for previously inaccessible applications. It specializes in novel materials with complex geometries that cannot be produced using conventional methods.

Mechanical metamaterials have a structure with which the material properties can be selectively controlled. Additionally, complex and locally different functions can be integrated in programmable materials. In the Fraunhofer Cluster Programmable Materials, such materials are developed across institutes.

One example is the pantograph (see figure), which can perform a wide variety of reversible deformations using printed joints. The design freedom of the joints enables a programmed shape change that is not achievable with conventional materials. This shape changeability is no longer limited by the ductility limits of the underlying material and has also low-fatigue behavior.

Algorithms developed at Fraunhofer EMI increase the effectiveness of the simulation-supported design of such structures through a high degree of automation.

At Fraunhofer EMI, these materials can be produced with resolutions on the micrometer scale by laser powder bed fusion. The best possible process parameters for prototypes are investigated and implemented on the institute's own equipment, from filigree structures to larger components. Extensive analyses are used to create a deep understanding of the physical processes involved in 3D-printed materials.

Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI

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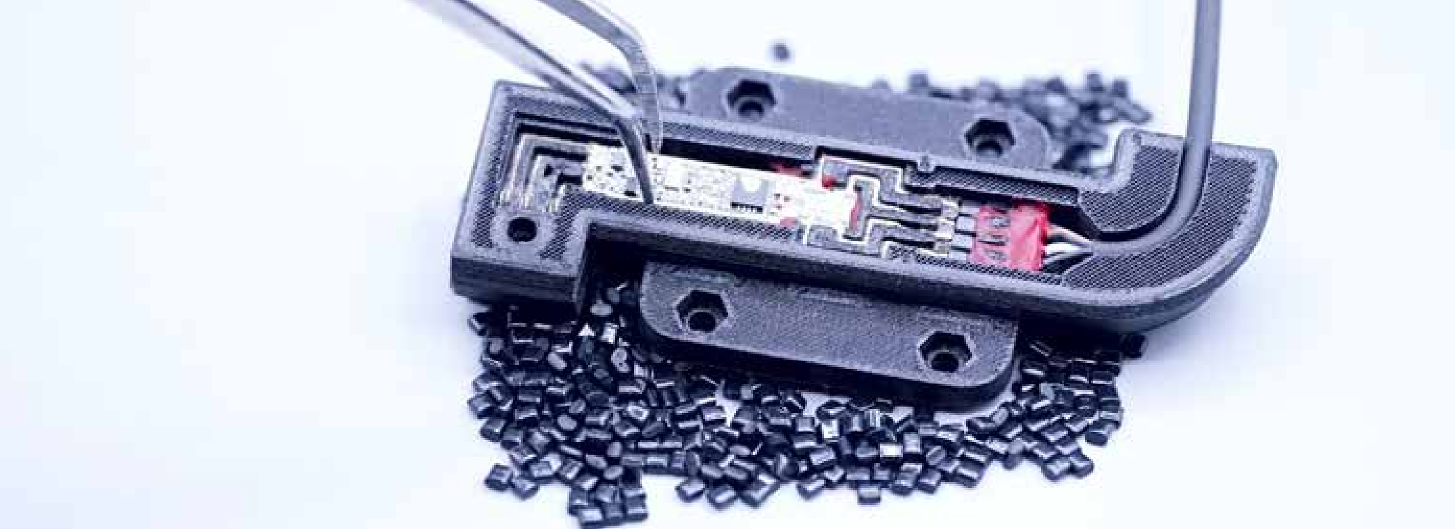

> **»Additive manufacturing has the potential to enable new products and business models. For this, functional integration will be a key element in future«**
>
> **Oliver Refle**
> Head of Department Additive Manufacturing

Functional Integration in Additively Manufactured Plastic Components

Printed curcuit boards and individualised sensors

Additive manufacturing (AM) processes for polymers offer the possibility to produce highly complex multi-material geometries. Fraunhofer IPA is conducting research on printing of technical and high temperature polymers and the integration of conductive elements and discrete components.

A central field of research in AM at the Fraunhofer IPA is the combination of polymer-based AM processes and (micro-)assembly technologies. This hybrid process combination enables the integration of discrete electrical or mechanical components into complex additively manufactured components and their connection with printed conductive tracks. The Fraunhofer IPA has built up extensive expertise in the development of corresponding manufacturing systems and processes on a laboratory and industrial scale and has demonstrated their usability in various applications.

Within the scope of laboratory tests, various jetting processes, such as piezo inkjet printing or dispensing, are used for the targeted application of conductive structures. Depending on the application scenario, conductive structures can be printed in high resolution with silver nanoinks using the piezo inkjet printing process. To obtain conductive elements with even higher conductivity, highly viscous conductive pastes can be precisely applied via jetting dispensing systems. Such conductive elements can be used as electrical connectors or functional elements for antennas or heat emitters.

The current research topic is 3D-printed individualised printed circuit boards (PCB). For this purpose, a hybrid machine setup was developed consisting of four process modules: (1) inkjet printing, (2) curing and sintering, (3) micro-assembly, (4) image processing systems connected via a common xyz-axis system. In this way, a hybrid manufacturing process can be automated and complex-shaped, individualised circuit carriers can be produced.

In parallel, Fraunhofer IPA investigated how industrial electrical components can be integrated into printed PBT housings to produce individualised proximity sensors. In a hybrid manufacturing process, housing elements were produced in the Arburg Plastic Freeforming (APF) process, electrical components were integrated and conductor paths were realised by means of contactless dispensing. It was shown that individualised sensors of industrial quality can be produced on the basis of this process route.

Within further projects, the possibility of integrating components and conductive tracks in AM parts made from SLA or SLS was also successfully tested at the Fraunhofer IPA.

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Sensor data, captured wireless and battery-free at the point of origin.

Smart Gear

with integrated RFID vibration sensor

Description and concept

The smart gear wheel is able to generate sensor data inside without batteries (passively, without additional energy supply) and send it wireless via the RFID frequency UHF (868 MHz) to an external receiver. The data can be recorded by means of a reader at a distance of approx. 10 mm. Measured values are relevant for making statements about the gearwheel/gearbox faults and for observing the gearwheel behavior. The integration of RFID sensor technology can solve challenges in the integration of electronics in the component, such as data transmission from a rotating component. Additive manufacturing makes it possible to integrate and use passive sensor technology inside the gear. In order to transmit signals in the required energy range despite the impermeability of case-hardened steel to frequency bands, an antenna was designed from the same material (20MnCr5) and its geometry-dependent transmission and reception properties optimized. It is additively assembled together with the gear wheel, is electrically isolated on the front side of the gear wheel and is conductively connected to the sensor system. By designing a curved antenna shape, the data from the eccentrically rotating sensor system can be acquired with a statically positioned reader. In order to be able to manufacture the antenna within a single building process, support structures are built from solid material. The cavities are then filled with insulating material so that the antenna and the sensor system are fixed in place and the support structures can be milled off. The invention can overcome the challenge of signal shielding metal. Additive manufacturing allows access to the interior of the component during the fabrication process and the simultaneous fabrication of multiple components within one build process.

Fraunhofer Institute for Casting, Composite and Processing Technology IGCV

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Optical measurment of 3D printed stainless steel reinforcement of die cast part (left), CastAutoGen demonstrators with EDAG concept car (centre), placement of aluminium adapter for power steering pump connector into the casting die (right)

CastAutoGen – a Hybrid Process Chain of Additive Manufacturing and Casting for Automotive Production

Additive manufacturing (AM) has been increasingly used in the industrial environment. However, long production times currently inhibit its use in large-scale series production. Combining well-established mass production processes with AM can be a solution to overcome this challenge.

To address these challenges, a novel hybrid process chain has been developed by the CastAutoGen consortium (Fraunhofer IWU and IWS, EDAG, Oerlikon AM Europe, Bohai Trimet, Audi and ZF) to combine the advantages of additive manufacturing with those of light metal die casting and implemented on a demonstrator from the automotive sector.

In the project, laser powder bed fusion (LPBF) as a suitable AM technology was combined with high pressure die casting (HPDC), one of the most common mass production technologies in the automotive industry, used for powertrain as well as for chassis and car body parts. Additively manufactured functional structures were successfully integrated into HPDC castings as cast-in features, representing different design variants and additional functions in a typical automotive die casting part – a "bracket engine auxiliaries".

The aluminum die-cast bracket has been equipped with a local stainless steel reinforcement, with a flexible adapter geometry made of aluminum to accommodate different design variants, and with a cast-in copper alloy heat exchanger for oil cooling purposes – directly integrated into the component. The 3D printed functional elements were integrated right during the diecasting process, placing them in the die before casting and by metallurgical bonding during the casting procedure, forming an integrated, monolithic component. Particular attention was paid to the bond between the AM inlays and the die-cast part by means of specifically developed interface structures.

In order to determine the mechanical properties of the connections between the different geometries and materials, special test specimens were developed, evaluated against multiple criteria and physically tested within the project. Well-established test procedures have been applied, according to standards such as DIN EN 50125 and DIN 50099.

By using different adapter elements for the power steering pump connector, a wide range of variants of the "bracket engine auxiliaries" can be realized in the future – out of only one diecasting die. A special interface geometry with a standardized adapter area has been designed for this purpose. Finally, a corrosion test was carried out, according to PV 1210 with 15 cycles, and successfully passed, with no excessive corrosion to be detected between the materials (aluminum, stainless steel, copper alloy), giving reason to expect full functional capability of the die-cast component with its 3D printed features during the automobile's complete product life.

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GraMMaCAD

CAD models can be augmented with functionally graded material transitions (e.g. from stiff to flexible): The stand produced by multimaterial 3D printing damps and cushions components mounted to it.

GraMMaCAD – Digital Pipeline for Graded Products

Copied from the bone: With the help of functionally graded materials, components can be optimized to meet varying requirements. To date, the development and design of such components is a very time-consuming process. With the software GraMMaCAD, developed at Fraunhofer IGD, this becomes much easier.

GraMMaCAD is the first graphical interactive tool that offers an elegant and user-friendly definition of volumetric material distributions on CAD models. These CAD models can be imported from classical CAD tools. Thus, GraMMaCAD extends the possibilities of today's CAD systems. The user of GraMMaCAD has the option to define material gradients based on CAD surfaces, newly defined auxiliary geometries, or CAD sub-bodies. In this way, graded material information can be added to the interior of CAD models. This grading is derived layer by layer, transferred to a 3D printing process and printed.

In 3D CAD systems, so-called boundary representations (B-Reps) are commonly used to represent geometry. B-Reps provide a surface description of the object. For 3D printing, these are typically discretized and transferred to the 3D printer as STL files. However, by describing the data as a surface-only model, the possibility of influencing the interior of the workpiece is lost. This influence is of central importance regarding internally varying material distributions.

The goal of our software GraMMaCAD is therefore to enable the modeling of volumetric material distributions and to design a generic data format for their description.

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Mounting on the process head

Process reliability can be significantly increased by using the newly developed sensor "POWDERscreen".

»POWDERscreen« detects Powder Particles

Increased process reproducibility through permanent monitoring of the powder mass flow rate

Controllable alloying within the process possible

For a stable and therefore reproducible process, in addition to process shielding with "COAXshield" and the qualification of the powder cone by the »LIsec«, it is also necessary to know all input variables exactly and to control them, if necessary. Especially the continuous measurement of the fed powder quantity has been a great challenge so far. The "POWDERscreen" sensor, which is currently being developed at Fraunhofer IWS as part of an EU research project, detects exactly when and how much of the different particles are fed into the melt pool. The fed powder mass can be calculated exactly on this basis. As a result, it is possible to detect fluctuations in the particle mass flow and report them to a downstream controller. Not only does this significantly increase the process reliability, but it also enables several different powders to be mixed in a targeted manner during the welding process. A discrete-time measurement of the powder mass flow also significantly increases the process digitization level and provides data for creating a digital twin of the created component.

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Plant integrated measurement

The LIsec powder nozzle measu-rement system measures powder flows after leaving the nozzle.

»LIsec« Lights the Powder Flow

A measuring system for automated characterisation of the powder nozzle during laser powder build-up welding

Increased process reproducibility through tool measurement

While tool calibration is state of the art in conventionally used ablative processes such as milling, in laser powder buildup welding it is still a great challenge. The Fraunhofer Institute for Material and Beam Technology IWS developed the measuring device "LIsec" to solve this challenge and to move the limits to technical feasibility. The abbreviation stands for "Light Section" and already reveals the principle: A measuring laser scans the powder flow after leaving the nozzle. A right-angled camera records light sections through the powder and forwards them to an analysis software. The three-dimensional distribution of the powder flow can be calculated with high precision. This allows significantly simplified quality control and provides information on the wear degree of the powder nozzle.

For example, it can be used to repair damaged or worn turbine blades on aircraft in higher quality and more reliably than before. In this respect, the measuring device can contribute to greater safety and lower maintenance costs in aviation. The Dresden institute is already working on the industrial implementation of the technology with several well-known international companies and research institutes.

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The mobile production line MobiMed

MobiMed was developed at IAPT for the mobile production of medical protective equipment.

Mobile Factory and Assistance Systems for Decentralized Additive Manufacturing

Supply chains for goods and services are becoming increasingly complex as a result of the growing globalization. Individual failures can disrupt entire supply chains, as the SARS CoV-2 pandemic and the Ever Given accident in the Suez Canal clearly demonstrated.

At Fraunhofer IAPT, mobile production units are being developed that enable decentralized production of spare parts or medical equipment using Additive Manufacturing (AM). Polymer processes such as fused filament fabrication (FFF) or stereolitography (SLA) are used for the on-demand production of medical equipment (Figure 1). For an on-site repair and production of spare parts made of metal, the Additive Mobile Factory® was developed at the IAPT, in which a Directed Energy Deposition (DED) process is used.

A focus of decentralized factory systems should be on human-machine interaction in particular, since it is often not possible to have trained personnel on site, especially in crisis situations. Digital assistance systems are particularly suitable for this and offer a high potential for error reduction. In the MobiMed research project (funded by the Fraunhofer internal programs), the digital augmented reality (AR) assistance system supports the operator in performing maintenance processes and starting production. Printing can be started directly from the application without the need to use a CAD program or interact directly with the printer.

Fraunhofer Research Institution for Additive Manufacturing Technologies IAPT

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Prototype finger joint implants with optimized surface topology produced by Binder Jetting.

Customized Series Production through Metal Binder Jetting

Remobilization of finger joints through AI-based reconstruction

In the PREPARE project **FingerKIt**, an autonomous process chain in the production of patient-specific implants is being developed for the first time, from design and production to certification-compliant testing. With Fraunhofer IAPT, IKTS, ITEM, IWM and MEVIS, five institutes are working on this joint project. The aim of Fraunhofer IAPT is to enable improved adaptation of the implants to the original joint properties via individual design.

The potential of metal binder jetting for the production of high-precision components comes to bear in the manufacture of the filigree finger implants. The prototypes shown here illustrate the initial design of the shaft into which the bone will grow. In addition to process development and manufacturing with titanium materials, the IAPT is also involved in automating design creation. Based on X-ray data and predefined requirements, an algorithm is trained to generate the patient-specific implant design fully automatically.

Production-oriented design

In addition to developing new applications for metal binder jetting technology, the Fraunhofer IAPT is analyzing the potential and restrictions of this process. One of the aims of the **PuMa** project is to develop comprehensive guidelines for the production-ready design of components. By applying such guidelines, cost- and time-intensive iteration loops up to a process-safe component design as well as an only insufficient utilization of the design process possibilities can be avoided.

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Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

The Fraunhofer-Gesellschaft currently operates 75 institutes and research institutions throughout Germany. The majority of the organization's 29,000 employees are qualified scientists and engineers, who work with an annual research budget of 2.8 billion euros. Of this sum, 2.4 billion euros are generated through contract research. Around two thirds of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining third comes from the German federal and state governments in the form of base funding. This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As researchers, entrepreneurs and visionaries, our employees see themselves as pacesetters and innovation drivers for the economy. Just as our namesake did, they strike the right balance between research and entrepreneurship, take responsibility for the future and develop solutions for tomorrow's challenges. At the Formnext 2021, they will showcase the technologies that will truly shape the future of 3D manufacturing.

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