Fraunhofer
IAPT

FRAUNHOFER RESEARCH INSTITUTION FOR ADDITIVE MANUFACTURING TECHNOLOGIES IAPT

ANNUAL REPORT 2018 | 2019

FOREWORD

Dear Readers,

The effective handling of those resources available to us on Earth is one of the greatest challenges of our time. In addition to fossil fuels, these resources also include the materials we use. Efficient use of resources in production is achieved through, for example, the deposition of materials in layers and in the production of entire components. Parts and components are generally manufactured today using less effective material-removal processes.

Among other activities, the newly established Fraunhofer Research Institution for Additive Manufacturing Technologies IAPT, which commenced operations in 2018, is dedicated to research into resource-efficient and autonomous production. The institute was born of the LZN Laser Zentrum Nord and the Institute of Laser and System Technologies (iLAS) at the Hamburg University of Technology (TUHH). As an extremely youthful and still small institute, the first two years were dedicated to the development and structuring of Fraunhofer IAPT and the iLAS at the TUHH in Hamburg. Despite this, pioneering results were already being achieved during this period.

Additive manufacturing technology enables the production of bionic structures (i.e. involving the application of structures found in nature). This, in turn, makes completely new functionalities possible. Aside from resource-efficient lightweight construction, this also applies to an optimized heat flow, improved vibration behavior, and, consequently, reduced noise, and the integration of sensors and conductor paths in the component structure. LZN and iLAS at TUHH have been heavily involved in the development and production of bionic structures for many years. The development of bionic structures and their additive manufacture are now an issue of intense interest at Fraunhofer IAPT.

A completely new form of manufacturing engineering is currently being developed with the aid of additive manufacturing. This is important for both the manufacture of individual parts and series production. It represents an important step on the road to individualized production and, notably, is also significant for medical engineering.

Fraunhofer IAPT is dedicated to the further development of additive and autonomous manufacturing technology. In addition to bionic design, Fraunhofer IAPT has also embraced the challenges of digitization, process optimization, the development of autonomous systems, and the use of artificial intelligence. We would like to illustrate just a few of these innovative findings on the following pages of our annual report.

We are extremely optimistic for 2020, and we are confident that next year's annual report will see us presenting further innovative developments.

Prof. Ralf-Eckhard Beyer | Director

Prof. Claus Emmelmann | Director

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MISSION

"Our mission is to industrialize additive manufacturing and, as a result, design resource- and energy-efficient products for the future."

VISION

"We are your first contact when it comes to the development of industrial and autonomous solutions in additive manufacturing technologies."

FRAUNHOFER IAPT – A BRIEF PORTRAIT

Fraunhofer IAPT can avail itself of the most varied technologies and systems when it comes to additive manufacturing and laser technology. We can, therefore, always select the most suitable manufacturing technology and appropriate system, depending on component requirements. This applies to both metals and plastics. From laser beam melting (LBM) for filigree medical implants and wire arc welding (WAAM) for large structures, to laser hybrid joining of components manufactured in different processes, we can select the appropriate process in every case to meet your requirements. Our technology and system portfolio is regularly expanded, with our primary goal being to provide our customers with the best cross-technology and non-proprietary solutions for their application. A few of the processes and systems available to us are illustrated below.

Powder bed processes for metals

Fraunhofer IAPT has been working for years in the area of additive manufacturing based on metal powders. The goal is to improve the speed and stability of the process and document each working step in a transparent manner.

Nozzle/wire processes

Fraunhofer IAPT exploits both laser and electric arc processes to supply energy to the process for nozzle- or wire-based additive manufacturing. If they are robot-guided, both variants are subject to almost no build space restrictions. They are particularly suitable for cost-effective spare parts production and repairs. Post-processing involving machining is generally necessary.

Laser beam processes

Fraunhofer IAPT has been involved for many years now with laser beam fusion, cutting, and deposition. Integrated solutions and adapted processing systems with sensors for automated process control and quality assurance are available. One special option that is available is a 30 m long portal system.

Polymer and non-metal processes

The development of bionic component structures and integration of new functions in polymer components are particular focal points of Fraunhofer IAPT. The integrated implementation of electrically conductive traces in three-dimensionally shaped electronic components should be highlighted. In addition, tests are being conducted on new polymer materials that can be cost-effectively processed.

Finishing

Surface qualities achieved directly with additive manufacturing processes usually require a post-process involving smoothing. Finishing can, depending on the requirements components need to meet, be realized at Fraunhofer IAPT through post-processing involving abrasive blasting or, also, milling, grinding, vibratory grinding, or electro-polishing. Finishing is optimized at Fraunhofer IAPT to suit the component involved.

Bionic design

A core aspect of the successful use of additive manufacturing is the implementation of new product designs. Fraunhofer IAPT researches and develops new cloud-based optimizing algorithms in this context. Simultaneous optimizing of different technical properties is also possible in this regard, taking manufacturing restrictions into consideration. One focus of activities at IAPT is bionic-based component designs. These enable the realization of component developments characterized by optimized lightweight construction that conserve resources and component design with optimized heat flow and vibration characteristics. Furthermore, Fraunhofer IAPT develops new cloud-based optimization algorithms that optimize different technical properties simultaneously, taking manufacturing restrictions into consideration.

Medical engineering

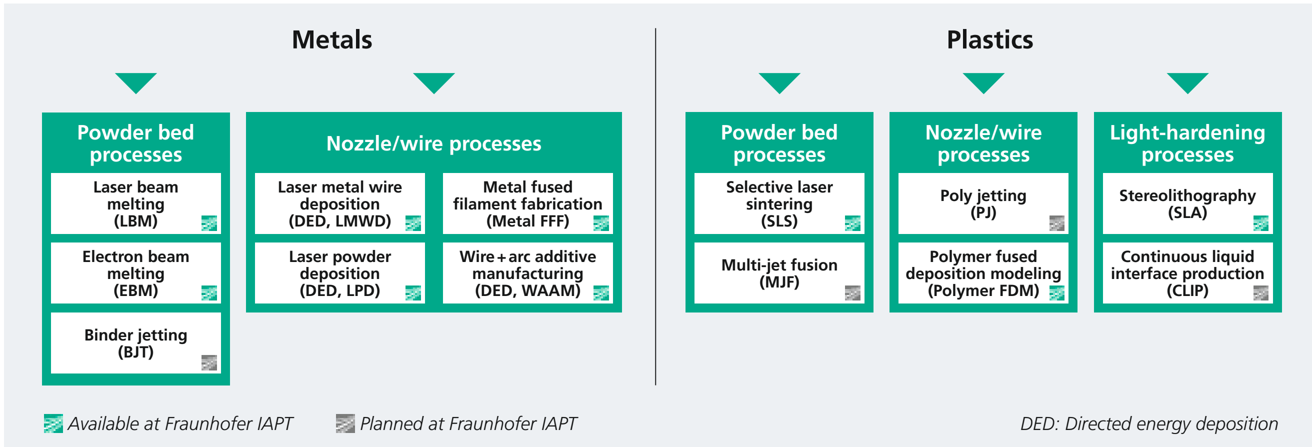
Medical engineering is a separate division at Fraunhofer IAPT. Individual parts manufactured here need to meet particularly strict requirements, which is why medical engineering is concentrated in a dedicated Fraunhofer IAPT center.

Autonomous systems

Fraunhofer IAPT works on the development of intelligent autonomous systems with the aim of implementing the data and the function of the desired component into the system, then obtaining the completed component. Systems of this nature are developed individually and as a whole in the form of an autonomous container-based production factory.

Education and training

Fraunhofer IAPT has established an Additive Academy for education and training. The training offered extends across the complete additive manufacturing spectrum and is aimed at personnel ranging from employees of companies involved in design engineering and operational specialists to managers. It is possible to choose between one-day crash courses and individual training courses extending over several days.



ORGANIGRAM

PR/MARKETING

Bettina Laux
+49 40 484010-517

STRATEGIC BUSINESS UNIT DEVELOPMENT

Sina Hallmann
+49 40 484010-733

INSTITUTE MANAGEMENT

Prof.
Ralf-Eckhard Beyer
+49 40 484010-510

FRAUNHOFER IAPT

Prof.
Claus Emmelmann
+49 40 484010-510

ADMINISTRATION

Martina Gerloff
+49 40 484010-820

IT

Marco Haß
+49 40 484010-752

AM DESIGN

Tim Wischeropp
(Head of Dept.)
+49 40 484010-722

Bionic Function & Design

Melanie Gralow
+49 40 484010-748

Quality Ass. & Certification

Peter Lindecke
+49 40 484010-730

Digitization

Fritz Lange
+49 40 484010-766

AM PROCESSES

Dr. Philipp Imgrund
(Head of Dept.)
+49 40 484010-740

Powder Bed Metal

Philipp Kohlwes
+49 40 484010-745

AM Polymers

Lennart Waalkes
+49 40 484010-762

Materials & Finish

Maximilian Kluge
+49 40 484010-728

AM SYSTEMS

Frank Beckmann
(Head of Dept.)
+49 40 484010-620

Automation & Sensors

Malte Buhr
+49 40 484010-628

DED Systems

Markus Heilemann
+49 40 484010-627

IAPT CENTER

Medical Engineering

Prof. Jan Wolff
+49 40 484010-732

Lasers & Large Structures

Olaf Steinmeier
+49 40 484010-622

BUSINESS UNITS

Ship & Rail

Olaf Steinmeier
+49 40 484010-622

Machinery & Tooling

Nora Jaeschke
+49 40 484010-629

Aerospace

Ina Ludwig
+49 40 484010-768

Automotive

Ruben Meuth
+49 40 484010-772

ADDITIVE ALLIANCE & ACADEMY

Additive Alliance

Maximilian Vogt
+49 40 484010-749

Additive Academy

Jochen Loock
+49 40 484010-736

OUR CORE COMPETENCES

"My team and I develop smart system solutions that enable customers to achieve high-quality, efficient AM production."

"The key to developing innovative 3D printing solutions for industrial applications is a combination of new materials and the latest process technology."

"Efficient exploitation of additive manufacturing technologies is only possible with the right bionic component design and efficient quality assurance."

AM DESIGN

The component design is of primary importance in Additive Manufacturing to achieve resource- and cost-efficient products. The quality of a component also depends heavily on the design and planned processing steps. It can be supervised and controlled directly during manufacture through appropriate continuous monitoring.

Design for additive manufacturing

In the Bionic Function and Design Group, we focus extensively on the completely new design possibilities additive manufacturing technologies offer. We help to find components that can be produced more efficiently through additive manufacturing and also imbued with expanded functionality. To achieve a cost-effective design, it is essential to take subsequent post-processing steps into consideration.

One of our strengths is the fact that we can combine bionics and computer-aided optimization with experience in additive manufacturing technologies gained over many years.

We focus in particular on structures:

- for resource-efficient lightweight construction
- for optimized heat transfer
- for improved acoustics
- for one-piece joint and gripper systems
- for sensor integration
- for catalytic converters
- for efficient hydraulics

Quality assurance and certification

The final quality of a component depends to a considerable degree on the design. Monitoring of all relevant manufacturing steps is important, particularly when new production processes are involved.

In the Quality Assurance and Certification Group, we develop solutions for automated quality monitoring and control. Cost savings can be achieved in many cases through an appropriate combination of process monitoring systems (e.g. recording of melt pool emissions) and downstream QA systems (e.g. µCT or destructive testing).

Our know-how relating to different QA technologies means we can develop and test solutions tailored to meet the special requirements of our customers.

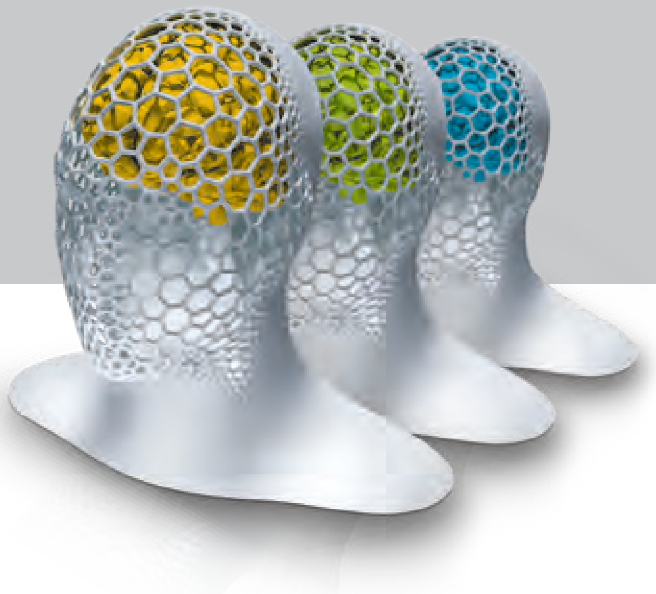
In order to document and analyze all quality-relevant process and component data along the process chain, a digital platform called Additive Quality Manager (AQM) was developed. This "digital laboratory journal" provides the basis for the later use of artificial intelligence.

Digitization of the AM process chain

Consistently digitized and automated product development and manufacturing will be a decisive factor for the future success of enterprises. For this reason, we develop software solutions and modules in the Digitization Group for additive manufacturing technologies that provide assistance during both product selection and the design of bionic components and automate production planning, process monitoring, and quality assurance. Our products can be adapted to suit individual customers and integrated in existing software solutions.

CONTACT
Tim Wischeropp
+49 40 484010-722
tim.wischeropp@iapt.fraunhofer.de

AM PROCESSES



The AM Processes department focuses on the development and optimization of materials, manufacturing processes, and post-processing steps for additively manufactured components. The primary objective is to minimize production costs by, for example, increasing process speeds or appropriate beam shaping and to enhance the quality of the components.

Development and optimizing of the process

One focus area in additive manufacturing lies in the further development of powder-bed-based processes. These include selective laser melting of metals and selective laser sintering of polymers.

A strategic goal of the department is to optimize the process with regard to costs and productivity by developing new process and build strategies. Among other factors, the position of the component in the powder bed and the shape and geometry of the laser beam play a decisive role in this respect.

The intention is to be in a position to offer efficient alternatives during production of individualized prototypes, spare parts, and low-volume production runs. This applies to metal components and components made of polymers.

A central research task of the department will be the development of suitable system components and their integration into the build process.

A further focus area of the department is extrusion-based additive manufacturing processes such as filament printing of polymers and binder-based printing of metals for prototypes and, also, for series production in future.

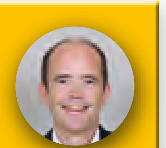
The handling of loose, fine metal powder is currently still hazardous, both in terms of occupational and health safety. Fraunhofer IAPT develops special handling and monitoring components for safe additive manufacturing.

Finishing

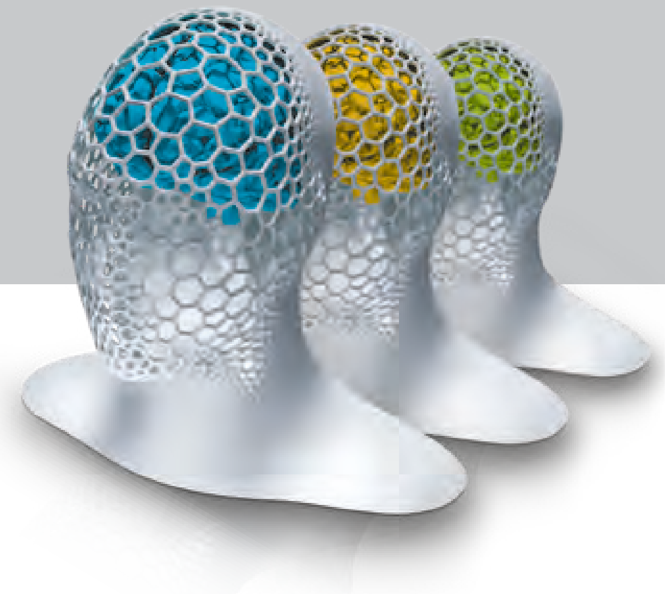
The use of additively manufactured components requires the implementation of an appropriate finishing process. This post-processing needs to be optimized in the same manner as the actual manufacturing process.

The entire process chain ultimately governs the costs relating to the component. Further development of surface treatments and post-processing at Fraunhofer IAPT is investigated closely in a dedicated working group and adapted for customers.

CONTACT
Dr. Philipp Imgrund
+49 40 484010-740
philipp.imgrund@iapt.fraunhofer.de



AM SYSTEMS



The AM Systems department develops customized solutions for smart and highly automated additive manufacturing. Concepts from quality-assured "First Time Right" production of complex batch size 1 components are developed here and realized as intelligent machine networking pursuant to Industry 4.0. The department is divided into two specialized groups in which the required technological modules are developed and implemented for industry. The service in this context encompasses development of individual system components, the linking and realization of completely autonomous process chains, and their implementation as the Additive Mobile Factory. Added to this is the mapping of process flows in a digital twin and simulation-aided optimization of production lines through a self-developed tool.

Sensors and Automation

The goal that the Sensors and Automation Group has set itself is to develop AM production processes that are more precise and automated through specially developed sensors, calibration, and automation solutions. This enables the reduction of costs for manual interventions and manual post-processing. These developments include:

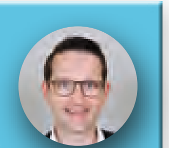
- the development of innovative optical sensor solutions for additive and conventional processes
- greater accuracy through sensor and system calibration
- the development of smart-robot- and CNC-based automation solutions
- system control through sensors and augmented reality

DED Systems

The focus of this group is on development of highly productive Directed Energy Deposition (DED) processes and their peripheral system technology for additive manufacturing. Adapted from the coating and repair of components, this process encompasses laser powder, laser wire, and wire arc additive manufacturing technologies. This means that customized solutions can be developed to suit component and production requirements. The focus of this specialized group includes:

- development of path planning tools for deposition welding of complex 3D structures
- DED process development through machine learning algorithms
- the design and realization of location-independent and autonomous production units, including final processing of components
- simulation-aided optimization of factory and production structures, including their mapping by a digital twin

CONTACT
Frank Beckmann
+49 40 484010-620
frank.beckmann@iapt.fraunhofer.de



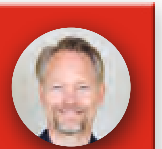
MEDICAL ENGINEERING

The immense technical advancements in medicine in recent years have ushered modern clinical practice into a new era. Digital techniques to capture and analyze anatomical structures for the purpose of pre-operative treatment planning, computer-guided surgery, computer-aided design, and manufacturing are becoming ubiquitous. For the first time, the concept of designing a virtual patient is becoming reality. Similarly, the increasing availability of rapid, compact optical scanners and 3D printers is revolutionizing the design and manufacturing procedures of medical components to rehabilitate patients. To date, medical 3D printing combined with artificial intelligence (AI), virtual reality (VR), augmented reality (AR), and robotics is evolving rapidly in clinical settings. Currently, we are moving away from serial production towards patient-specific production of crowns, bridges, prostheses, orthodontic appliances, and medical/dental implants, from copies towards iterations. This paradigm shift is causing a major disruption in the medical and dental industry.

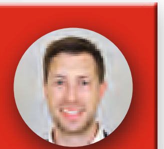
Key services

Over the past years, the Medical Center has built its own infrastructure of 3D printers and AI software solutions. The center provides support to companies, hospitals, and medical professionals in adopting, implementing, and deploying the aforementioned technologies. Furthermore, the center offers companies the possibility to collaborate on a wide range of different medical research projects. Education and training of medical specialists is also a key service offered by the Medical Center at IAPT.

CONTACT
Prof. Jan Wolff
+49 40 484010-732
jan.wolff@iapt.fraunhofer.de



CONTACT
Phillip Gromzig
+49 40 484010-742
phillip.gromzig@iapt.fraunhofer.de



LASERS AND LARGE STRUCTURES

Fraunhofer IAPT operates its own competence center for laser processing and the creation of large structures. The specialized know-how encompasses both laser-based joining technologies and a variety of additive manufacturing processes for metals, plastics, and concrete. Development goals and tasks focus on innovative and optimized processes, improved material properties, required processing and monitoring systems, and associated automation solutions.

High-power laser applications

The Fraunhofer IAPT center for lasers and large structures provides its cooperation partners with unique system technology for these tasks. A 30 kW fiber laser is available for welding thick sheet metal with a welding penetration depth of up to 25 mm in a single position. Cutting and material removal processes for a variety of materials are examples of further high-power laser applications. Moreover, numerous robot systems and a portal system for processing components up to 30 meters in length can be utilized.

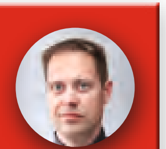
Laser and laser hybrid welding

As the successor to LZN, Fraunhofer IAPT has gained years of experience in laser and laser hybrid welding. In major publicly funded shipbuilding projects, low-distortion joining processes have been developed since 2009 that, through a combination of laser beam and electric arc, enable the achievement of higher welding speeds and reduce heat input, thus contributing to a reduction in component distortion due to thermal influences. The gap-bridging capability has also been significantly improved (cf. p. 64: Report on ShipLight). In addition to shipbuilding applications, Fraunhofer IAPT has also been immensely successful in the development of highly productive laser welding processes for the automotive industry and both crane and rail vehicle manufacturing.

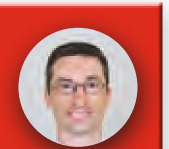
Large structures

Large structures are not only welded at Fraunhofer IAPT, but also increasingly built through additive manufacturing. Additive manufacturing offers a maximum degree of design freedom and a function integration option, even for large-scale components. The particular challenge here is to achieve a high build rate while, simultaneously, ensuring no loss in accuracy. On the one hand, this enables the rapid and efficient creation of large structures while, on the other, keeping the level of post-processing low. Component dimensions mean that robot-assisted use of the DED process (directed energy deposition) is predestined for metals and the FDM process (fused deposition modeling) for plastics. 3D printing of concrete is also part of the research conducted at Fraunhofer IAPT. Additive manufacturing with concrete makes a high degree of automation and realization of additional functions such as air conditioning in technical buildings possible.

CONTACT
Olaf Steinmeier
+49 40 484010-622
olaf.steinmeier@iapt.fraunhofer.de



CONTACT
Georg Cerwenka
+49 40 484010-632
georg.cerwenka@iapt.fraunhofer.de



ADDITIVE ACADEMY

Basis for the additive future of enterprises

The training of designers, engineers, and decision-makers in the economy continues to play a key role in the further market penetration of additive manufacturing. A fundamental rethink needs to take place in component design if the potential of additive manufacturing is to be exploited for the relevant product range in the form of radical lightweight construction or component integration.

Under the Additive Academy label, Fraunhofer IAPT has offered successful training seminars to the market since 2014 in the area of additive manufacturing, providing advanced training to over 1,500 engineers for customers in the aviation and automotive industries, mechanical engineering, and the service sector. The positive experience gained in training seminars means that customers can shape their additive future in other Fraunhofer IAPT services ranging from bionic design to series production.

The Additive Academy provides application-oriented knowledge on issues relating to the industrial use of additive manufacturing. In addition to theoretical seminars, the training program also includes hands-on training that takes place directly on machinery and is supported by a total of 40 experts from one of the leading institutes for additive manufacturing.

Seminars cover all business areas: design, production, and management. The requirement levels of training seminars are also adapted to the prior knowledge of participants. Seminars are divided into starter, advanced, and expert training, facilitating selection of the right training course to suit individual levels of knowledge. In addition, tailored, customized training seminars can also be arranged.

6 different additive manufacturing technologies and 13 machines at our institute in Hamburg allow us to cover a very broad spectrum. Training seminars can also be conducted on-site at the company if additive software and hardware are available.

Training services offered by the Additive Academy are, of course, subject to continuous further enhancement. For example, a two-week certificate course addressing the topic of the "Metal Additive Manufacturing Design Professional" was created in 2019 and is available from 2020. An e-learning course on the subject of "Additive Manufacturing Process Selection" has been on offer since November 2019.

The Additive Consulting business segment is currently developing as an offshoot of the Additive Academy, offering advice at management level to customers during the introduction of additive manufacturing. In addition, Additive Consulting collaborates with specialist departments at Fraunhofer IAPT to develop technology studies, some of which are published.

	Design	Production	Management
Starter	AM Basic Training*	AM Basic Training*	Learning Expedition
Advanced	Design for Additive Manufacturing Training Hands-on Training* Bionic Design Training	Hands-on Training*	Management Deep Dive
Expert	Bionic Design Expert Training Workshop Design	Data Preparation Workshop Powder Workshop	Strategy Workshop

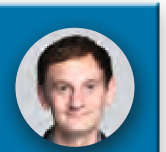
*Based on metal or polymer AM technology.

Customer-specific modification of training content possible

Implementation	
Part Feasibility Screening	Design Challenge

Your contact for all Academy-related issues
Get in touch with our experts to help you identify the potentials, the feasibility on a part-specific level, and the successful implementation of 3D printing in your company.

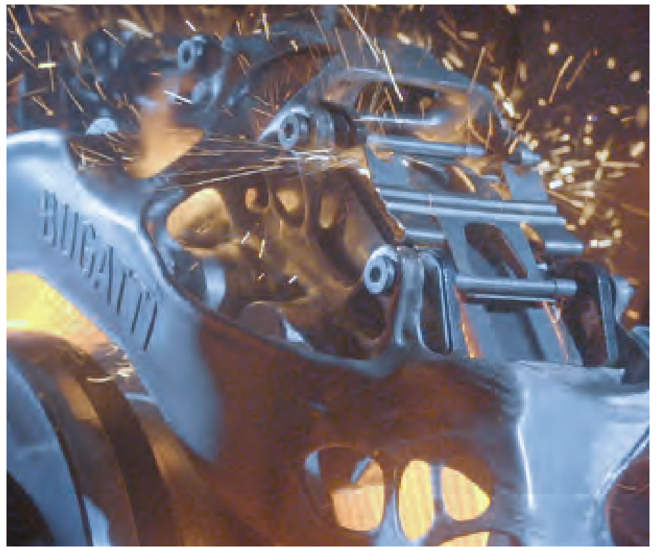
CONTACT
Jochen Loock
+49 40 484010-736
jochen.loock@iapt.fraunhofer.de



LARGEST TITANIUM SERIES COMPONENT IN AUTOMOTIVE MANUFACTURING: BRAKE CALIPER FOR BUGATTI – FROM INITIAL IDEA TO SERIES PRODUCTION

In cooperation with Fraunhofer IAPT, engineers from Bugatti have developed and manufactured the most powerful brake caliper in the automotive industry.

Early 2018 saw the unveiling of the largest functional titanium component created through additive manufacturing – the functional prototype of a brake caliper for the Bugatti Chiron. The eight-piston monoblock brake caliper is also the largest brake caliper used in the automotive industry. It finally underwent successful testing on a test bench at the end of last year. The development team of Bugatti Engineering GmbH and experts from Fraunhofer IAPT cooperated in the realization of this additive manufacturing innovation. The result is a high-performance brake caliper that can effortlessly decelerate this superlative sports car from maximum speed to a complete stop. But the vehicle in which the brake caliper is used is not the only dynamic factor here, as the pace of development is also moving at breathtaking speed. An initial prototype was successfully printed at Fraunhofer IAPT in Hamburg only three months after the idea was first broached.



Source: Bugatti video

41% weight saving using titanium and bionic design

The result is impressive. Despite a length of 410 mm, a width of 210 mm, and a height of 140 mm, the brake caliper only weighs a mere 2.9 kg, making it 41% lighter than its conventionally manufactured predecessor.

On the one hand, this was made possible by an alloy of titanium, aluminum, and vanadium that is primarily used in aerospace and is now making inroads in the automotive industry. On the other, the design is based on principles found in nature. A combination of the new material and a bionic approach made better performance and load-bearing capacity possible.

However, the extremely high strength of titanium makes conventional manufacture of components of this type through milling or forging difficult. Experts at Fraunhofer IAPT were called upon to solve this problem. The brake caliper was produced at the Hamburg location through additive manufacturing. Indeed, it was this process that made production of the raw component possible in the first place.

The laser beam melting system was employed to manufacture the brake caliper. This system has four lasers, each with 400 watts, and these simultaneously build the component. Despite its size, this method allowed the brake caliper to be freed from the surrounding powder bed after a printing time of 45 hours, following which it was subjected to heat treatment for ten hours to relieve any residual stress.

What followed was a series of further post-processing steps, including removal of the support structures required for the build process, and polishing. The latter is a mechanical/physical/chemical process for smoothing the surfaces. Finally, the contours of all functional surfaces were machined on a five-axis milling machine.

Operating temperature up to 1,100 °C

The prototype brake caliper was tested at the end of last year on a test bench, impressively demonstrating its fundamental ability to meet the requirements for future use. The YouTube video of the brake caliper showering sparks during testing has already attracted more than 15 million views, 2.9 million of which were on the VW Group website alone.

"The proof that a metal component created through additive manufacturing can also meet very extreme strength, rigidity, and temperature demands has been provided at speeds exceeding 375 km/h, constant decelerations of 1.2 g, and brake disc temperatures of up to 1,100 °C", says Frank Götzke, Head of New Technologies at Bugatti.

The next steps are further trials by Bugatti with regard to series production. Part of this also involves optimizing the entire post-processing procedure to drastically reduce the manufacturing time and costs with a view to using the brake caliper in the next production vehicle from Bugatti. The brake caliper has therefore become another important example of how additive manufacturing of metal components can accelerate industrial development in the automotive industry.

Greater performance and 5.3 kg weight saving

Further developments in the automotive sector in which additive manufacturing is employed demonstrate that the brake caliper is not an isolated case. The development teams from Bugatti and Fraunhofer IAPT have joined forces again in another cooperative project and optimized the rear wing mechanism of the Chiron.

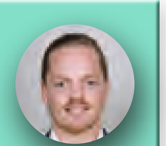
The adjustable mechanism enables adaptation of the aerodynamics to suit requirements. This helps the vehicle to reach a speed of 400 km/h in 32.6 seconds and come to a complete stop again within a mere 9 seconds.

In this case, too, it was possible to demonstrate and exploit the enormous potential of a combination of bionic lightweight construction and additive manufacturing. The optimized rear wing mechanism is 5.3 kg lighter and exhibits greater rigidity.

In cooperation with:

BUGATTI

CONTACT
Ruben Meuth
+49 40 484010-772
ruben.meuth@iapt.fraunhofer.de



FRAUNHOFER IAPT GOES TO MARS – INTO ORBIT WITH 3D PRINTING

May 2018 saw the NASA lander InSight lift off from California and eventually land successfully on the surface of Mars following a voyage of around seven months.

The goal of this mission is to carry out a comprehensive study of the inner structure of the Red Planet. This includes recording the physical properties of the soil and the motion of the axis of rotation of Mars. Equipment included the HP³ sensor package from the German Aerospace Center (DLR), which was installed on the lander to provide corresponding measurements.

DLR and Fraunhofer IAPT established a successful cooperation during the development of HP³. The HP³ mounting bracket was specially designed for this application, and its cost-effective manufacture only proved possible through the selective laser melting process. In addition to the low weight achieved through a thin-walled lightweight design (700 micrometers wall thickness), use of a titanium alloy (Ti-64) also assured thermal insulation properties. Furthermore, mechanical targets for the component were also effortlessly achieved (30 G load). Consequently, the 2.3 million kilometers the lander traveled every day (at 100,000 km/h) also proved to be no technical obstacle for the 15-gram bracket produced through additive manufacturing.

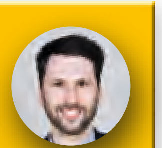
Measurement data of heat flows in the interior of Mars will be recorded within the next two years (one Mars year) with the aid of the HP³ R sensor package. A probe referred to as the mole buries itself up to five meters deep in the surface of the planet for this purpose, introducing temperature sensors into the Martian soil that, together with additional infrared radiation measurements recorded by the radiometer on the surface, provide information on the heat flow.

In addition to the Mars bracket, a further cooperation with the DLR saw a component being sent on June 29, 2018 to the ISS via the SpaceX CRS-15 Commercial Resupply Service mission.

The DESIS spectrometer is used to record hyperspectral data and employed for Earth observation, in humanitarian aid, and for precision agriculture.

Fraunhofer IAPT manufactured a thin-walled Ti-64 lens hood, which was then coated in black and is now being used successfully on the ISS. The monolithic structure of this part could not be realized using classic production processes. The special design, which should minimize reflections and absorb as many emissions as possible, was ultimately manufactured both rapidly and cost-efficiently through selective laser melting (SLM) and put into use in space after the first production iteration.

CONTACT
Maximilian Kluge
+49 40 484010-728
maximilian.kluge@iapt.fraunhofer.de



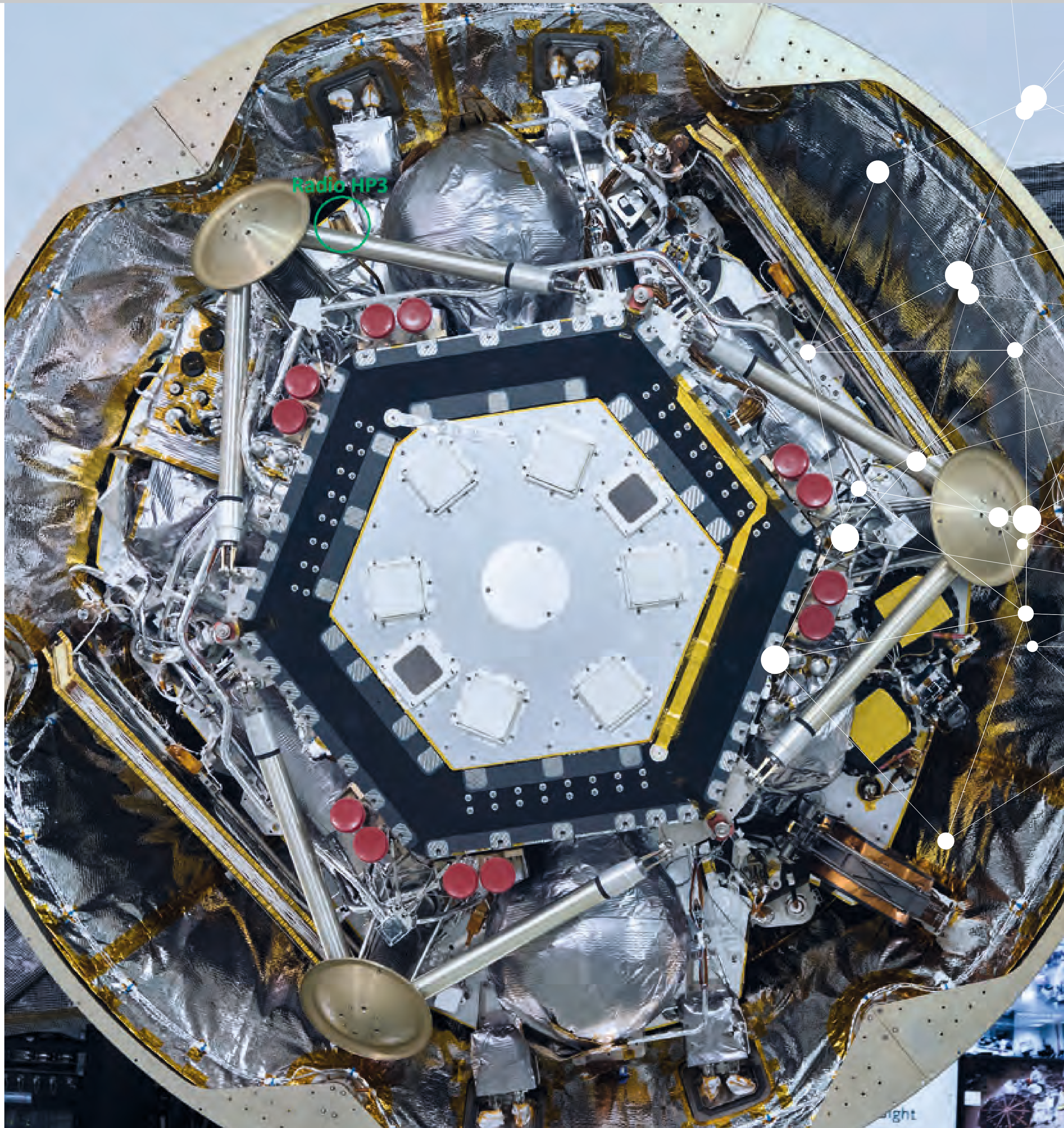


Photo source, page 27:
www.nasa.gov/image-feature/getting-insight-on-the-interior-of-mars

AWARDS FOR COLLEAGUES

A particular highlight at the end of 2019 was the honoring of Fraunhofer IAPT employees who, through their research results, have achieved something very special and taken a giant step towards the future. A search was conducted for a group or individuals who have demonstrated outstanding performance in the scientific and technical field. This photo shows the award winners, flanked by the Institute Management. They are, from left to right:

- **Robert Lau** — **Award for Best Student Performance**
- **André Fischer** — **Award for Best Innovative Product Idea**
- **Tim Röver** — **Award for Best Student Performance**
- **Arnd Struve** — **Award for Best Technical Performance**
- **Fritz Lange** — **Award for Best Scientific Performance**
- **Tobias Keßler** and **Friedrich Proes** (not visible in photo) — **Award for Best Innovative Product Idea**

THE INSTITUTE IN FIGURES

Expenditure

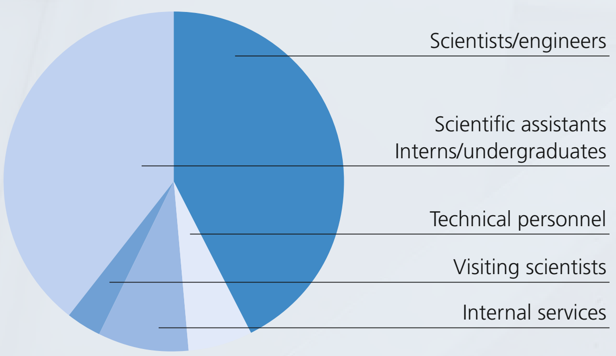
Fraunhofer IAPT

	in mil. €
Personnel costs	6.0
Non-personnel costs	2.9
Investments	0.8
Total	**9.7**

Employees

Fraunhofer IAPT

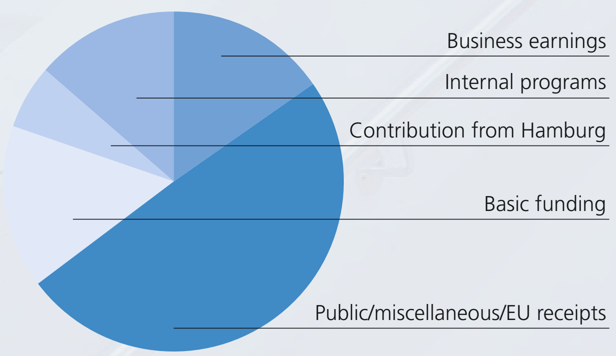
	Number
Scientists/engineers	63
Technical personnel	9
Internal services	13
Visiting scientists	5
Scientific assistants/interns/undergraduates	58
Total	**148**



Revenues

Fraunhofer IAPT

	in mil. €
Business earnings	1.5
Public/miscellaneous/EU receipts	4.8
Basic funding	1.5
Contribution from Hamburg	0.6
Internal programs	1.3
Total	**9.7**



As of: December 2019

BOARD OF TRUSTEES/ GROUP FOR PRODUCTION ENGINEERING

The Board of Trustees acts in an advisory capacity to the management committee of the institute and other Fraunhofer-Gesellschaft bodies and promotes links to interested groups involved in research work. The Board of Trustees included the following members in the reporting period:

Fraunhofer IAPT is a member of the Fraunhofer Group for Production, a cooperative amalgamation of 11 Fraunhofer institutes and entities. The goal is to jointly pursue production-related research and development. Utilizing the latest findings in production, engineering, and computer science, the group offers a range of services that cover the complete product life cycle and entire value chain. Cooperation between research and industry here is interdisciplinary and takes place within a close network. Bundling the diverse expertise and experience of individual members means the customer can be offered comprehensive solutions to problems. Companies are readied for the “manufacturing of the future” in this manner. Fraunhofer IAPT is an important element in this, making its expertise in the area of industrial and autonomous solutions in additive manufacturing technologies available to the group.

ADDITIVE ALLIANCE

Network redesigned for 2020

The Additive Alliance is the industrial research network for Additive Manufacturing of the Fraunhofer-Gesellschaft. The network was created in 2014 to promote an exchange of knowledge and has since established itself as a relevant institution in 3D printing. Regular network meetings of the more than 30 members encourage the knowledge exchange between all 3D printing stakeholders, allowing them to contribute significantly to the industrial future through long-term cooperations.

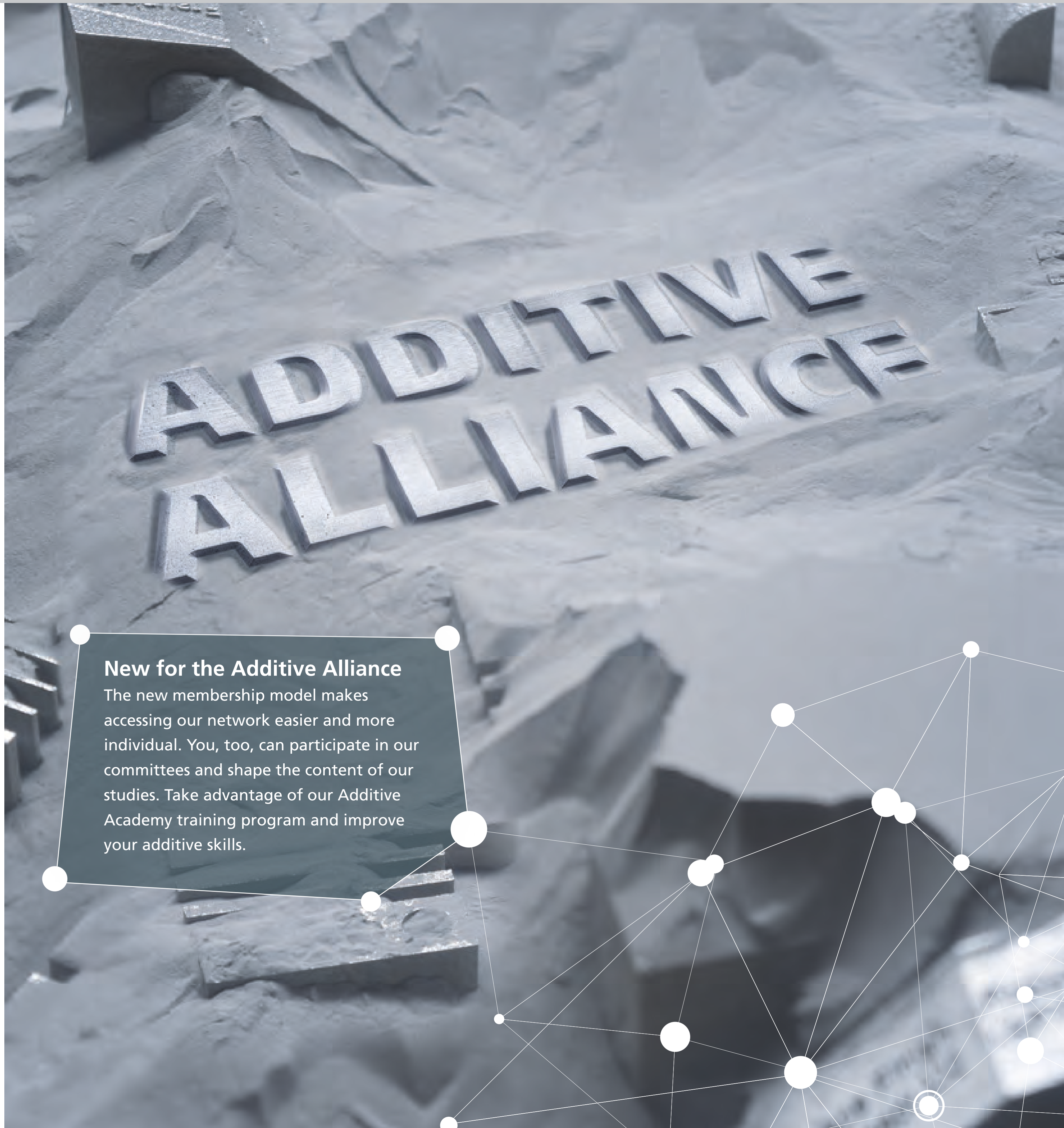
The Additive Alliance was redesigned this year to allow companies to participate in shaping this future to a greater extent than before. As of 2020, companies have the opportunity to become part of three new committees. In these specialized committees, the members decide which research topics the departments of Fraunhofer IAPT should work on and further elaborate in studies. Companies are involved even more closely in the identification of research topics, and the Additive Alliance continues to evolve into an active collaboration of future-oriented companies. Members discuss the content, scope, and goals of studies in practical workshops and develop new pioneering projects. Studies are presented exclusively within the Additive Alliance, with some of these published later on. Individual consulting and development services are also possible, depending on the membership. The Additive Alliance is a must for anybody who wishes to take a decisive step towards an additive future with their company and is looking for a dynamic network for this purpose:

- Innovators, visionaries, and networkers
- Engineers, designers, and managers
- Cross-industry: automotive, medical, machinery & tooling, ship & rail, polymers, and aerospace

In addition to offering members important contacts from a broad variety of business and research areas, the Additive Alliance is also their expert partner for future projects. It provides target-oriented support during the realization of industrial and research projects and develops solutions to tackle common challenges in individually tailored working groups. Regular events at Fraunhofer IAPT and inspiring evening events for networking in one of the numerous Hamburg restaurants complete the membership.

As a member of the internationally active Fraunhofer-Gesellschaft, Fraunhofer IAPT is distinguished by its extensive knowledge and broad experience in the area of additive manufacturing. The institution is highly ambitious, aiming to cover the complete spectrum of AM technologies and understand the general environment of additive manufacturing to advance the industrialization of 3D printing and significantly influence this innovation. Engineers, economists, computer scientists, and natural scientists cooperate across disciplines at Fraunhofer IAPT to provide cross-industrial knowledge. After all, a comprehensive view is essential when it comes to designing your additive future.

CONTACT
Maximilian Vogt
+49 40 484010-749
maximilian.vogt@iapt.fraunhofer.de



New for the Additive Alliance
The new membership model makes accessing our network easier and more individual. You, too, can participate in our committees and shape the content of our studies. Take advantage of our Additive Academy training program and improve your additive skills.

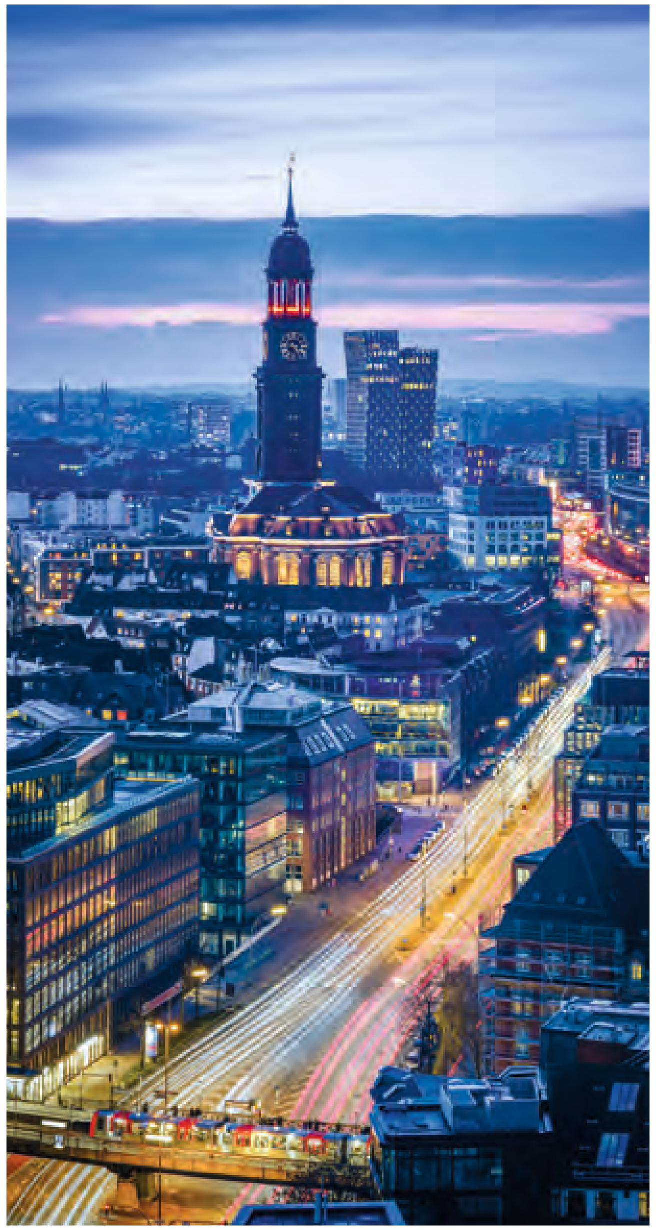
COOPERATIONS

COOPERATION WITH THE HAMBURG CHAMBER OF COMMERCE: 3D PRINTING NETWORK

In cooperation with Fraunhofer IAPT, a meeting of 3D printing users and experts from the business, science, and political communities in the Hamburg metropolitan region was held for the first time in 2018, the meeting having been an initiative of the Hamburg Chamber of Commerce. Supported significantly by Fraunhofer IAPT, the meeting provided a venue to introduce newcomers and future experts to cutting-edge technology and research. The network is influenced strategically and in terms of content by Fraunhofer IAPT.

This cooperation aims in particular to provide small and medium-sized enterprises with the tools they need. The network considers itself to be primarily an exchange platform and competence forum for 3D printing in Hamburg and the metropolitan region. As a free entry-level platform, this network offers a springboard into the industry network of the Additive Alliance.

HK Handelskammer Hamburg



COOPERATION WITH THE DEUTSCHE BAHN NETWORK: MOBILITY GOES ADDITIVE

Along with companies like Deutsche Bahn and Siemens, Fraunhofer IAPT is a founding member of the Mobility goes Additive network. This network set itself the goal in 2016 of exploiting and promoting additive manufacturing technologies for the mobility sector. Mobility goes Additive has since become one of the world's largest and most significant 3D printing networks, with more than 100 members. Fraunhofer IAPT heads the Working Group on Education in the network, in which education and training strategies and specific measures are developed to improve the qualification of personnel in the area of 3D printing. Moreover, Fraunhofer IAPT is particularly committed in the Working Groups on Materials and Approval to the development of new materials (e.g. with enhanced fire protection) for 3D printing, and the approval of printed components for rail transport.

Additionally, when the Medical goes Additive network division was created in 2019, Fraunhofer IAPT was also immediately prepared to contribute the experience in medical engineering it had gained over many years and support its network partners with comprehensive expertise.

mga WE BOOST AM

CONTACT
Olaf Steinmeier
+49 40 484010-622
olaf.steinmeier@iapt.fraunhofer.de

COOPERATION BETWEEN THE HAMBURG MINISTRY OF CULTURE AND MEDIA, THE HAMBURG CHAMBER OF COMMERCE, AND THE GERMAN-INDIAN ROUND TABLE: INDIA WEEK

The eighth Hamburg India Week was held from October 28 to November 3, showcasing 70 different cultural and scientific events. It is organized every two years by the Hamburg Ministry of Culture and Media in conjunction with the Hamburg Chamber of Commerce and the German-Indian Round Table (GIRT) to strengthen German-Indian cooperation in science. As a member of the GIRT, Vishnuu Jothi Prakash from Fraunhofer IAPT coordinated some of the scientific and business events on the topic of additive manufacturing.

In the context of German-Indian cooperation in research and development, Fraunhofer IAPT collaborated with DESY to organize a presentation on the subject of "Nano-Material Research using X-Rays and New Possibilities using 3D Printing". This event illustrated innovations and the latest advantages of additive manufacturing technology in aerospace and the automotive sector.

BEST PRACTICES IN POST-PROCESSING OF AM COMPONENTS MADE OF TI-6AL-4V

Additively manufactured components frequently still fall short of the technical requirements demanded of the final component when they come out of the machine. Subsequent post-processing can represent as great a challenge as the actual manufacturing process. Together with Aalberts Industries Holding, Fraunhofer IAPT has set out to embrace this challenge.

Lack of standardization makes post-processing difficult

Post-processing of additively manufactured components commences with the removal of supports and, depending on the application, may require further steps such as heat or surface treatment. Each process stage harbors its own challenges, such as the in-part manual and complex removal of supports, a variety of surface treatment processes, or a material structure in heat treatment that differs greatly from conventionally manufactured components. This means that existing standards and familiar process designs cannot be applied without restrictions to additively manufactured components, additionally increasing the difficulty of orientation in individual application cases.

Cooperation goals

Fraunhofer IAPT has joined forces with Aalberts Industries with the aim of reducing these deficiencies associated with post-processing adapted to additively manufactured components. Specific issues in this respect are the improvement of lifespan properties and optimizing of the topology and density of components made with the alloy Ti-6Al-4V.

The combination of chemical and electro-polishing techniques is being examined in the area of surface treatment. Initial studies here indicated that an improvement in the surface (roughness) of 80% and completely automated removal of supports can be achieved during surface treatment.

Hot isostatic pressing (HIP) is being studied intensively in the heat treatment category. Process limitations with regard to the size and number of pores are determined in an initial step. A second step involves the development of process parameters adapted to additively manufactured components to achieve optimum results on the basis of the fine lamellar structure.

Aalberts Industries as project partner

Aalberts Industries is a service provider active all over Europe and at a few locations in North America and Asia. Its portfolio encompasses 58 different surface treatments, 15 heat treatments, some of which are already used on additively manufactured components, and a variety of coating processes.

RESEARCH & DEVELOPMENT

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52 Profitable Powder Bed Metal Processes
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55 Wire Arc Additive Manufacturing (WAAM)
56 Innovative Polymer 3D Printing
58 Functional Additive Polymers
59 Additive Metals and Finishing
60 Profitable DED Systems through High-Precision Process Control
61 Digitized Automation of DED Processes
62 Smart Additive Factories
63 Additive Mobile Factory – One-Stop Solution
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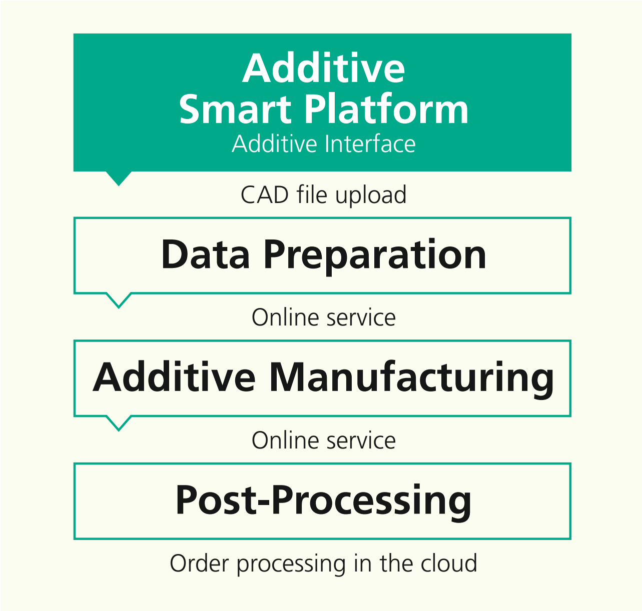
68 Quality Assurance and Certification
70 Additive Quality Manager
71 Ecological Sustainability through Additive Manufacturing

ADDITIVE SMART PLATFORM FOR EFFICIENT "CHANGE FOR ADDITIVE"

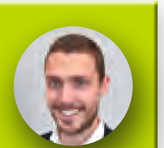
ADDITIVE POTENTIAL EVALUATION AND ORDER PROCESSING IN THE CLOUD



Service providers in additive manufacturing are confronted by agile supply situations. In particular, speedy production is indispensable in the area of rapid prototyping if market displacement by competitors is to be avoided. Customers frequently fail to understand the complexities of different additive manufacturing processes and their impact on design recommendations for components, or are incapable of estimating the potential of additive manufacturing when compared to conventional manufacturing processes. Consequently, demand exists for a platform solution that accelerates the entire order processing procedure from the online customer inquiry via browser to delivery of the finished component to the customer and automatically checks components with regard to adherence to production restrictions and the potential of additive manufacturing. Fraunhofer IAPT has spent several years developing such a solution. The Smart Platform represents a cloud-based solution that enables identification and exploitation of potential in additive manufacturing. The customer uploads the component via their browser, the CAD file is automatically checked for production restrictions and Additive Manufacturing design guidelines, and an offer is generated. In this context, smart algorithms optimize the orientation of components and the distribution of the parts in the build space to ensure the best possible quality and lowest possible costs. The customer can then place a manufacturing order via the platform and track the entire order processing through the cloud.

Optimizing potential (e.g. lightweight construction potential through topology optimization) can be estimated in advance to evaluate the economic potential of a component and, consequently, answer the question of whether additive manufacturing is economically viable. In addition, a costing comparison relative to competing manufacturing processes such as material machining and casting can be provided. Components with economically viable business cases for additive manufacturing can be identified through the costing comparison.

CONTACT
Fritz Lange
+49 40 484010-766
fritz.lange@iapt.fraunhofer.de



BIONICS FOR MAXIMUM CUSTOMER BENEFIT

MULTIPHYSICAL TOPOLOGY OPTIMIZATION WITH MOONBEAM

Multiphysical optimization

Topology optimization is one of the most powerful tools when it comes to exploiting the potential of a component to the full. The classic approach in this context is to reduce the component weight during the design process by removing material that contributes little to component rigidity.

The bionic-like results are, in most cases, no longer feasible using conventional processes such as turning and milling, whereas additive manufacturing can demonstrate its potential to the full here. Furthermore, the optimization is not restricted to target values such as rigidity and weight.

Fraunhofer IAPT conducts research on new optimization algorithms for additively manufactured components in the context of the Fraunhofer "FutureAM" lead project. This means that production restrictions such as a steep overhang angle or walls that are too thin can be avoided during optimization. Furthermore, multiphysical topology optimization, a subject that has thus far not been heavily researched, is also investigated. This method goes beyond the capabilities of available software and also permits incorporation of a wide variety of physical effects (e.g. heat transfer or fluid mechanics) in optimization, or even their combination with each other.

This means that not only lightweight components can be designed, but also compact cooling elements, efficient heat exchangers, and low-loss, complex internal fluid channels. Components developed in this manner can be used wherever there is a demand for compactness, a lightweight design, and a high degree of functionality (e.g. in aerospace, the automotive sector, or special machine engineering).

Automation of the design process

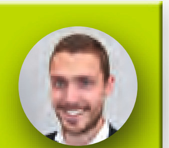
In order to exploit these new algorithms and models, Fraunhofer IAPT is developing a software framework that automates complex optimization tasks in the design process. The function determines the design, and the algorithms ensure the manufacturability of components.

Using the software framework, Fraunhofer IAPT can develop customized optimization apps within a very short time for applications in industry. These include:

- classic rigidity and lightweight construction optimization
- thermal conduction and transfer optimization (e.g. for heat sinks and heat exchangers)
- flow optimization (e.g. for hydraulic and pneumatic components)
- multiphysical optimizations (e.g. of mold inserts)

Packaged in user-friendly applications, design processes are accelerated in this manner by fully exploiting the potential of additive manufacturing. High-performance components are created, along with simplified applicability, shorter design phases, and lower costs.

CONTACT
Fritz Lange
+49 40 484010-766
fritz.lange@iapt.fraunhofer.de



AUTOMATED BIONIC MANUFACTURING OF ADDITIVE "DIAMONDS"

AUTOMATED TOPOLOGY OPTIMIZATION FOR AN ADDITIVELY OPTIMIZED HEAT SINK DESIGN

Part screening

Fraunhofer IAPT has an extensive history when it comes to finding economic applications for additive manufacturing. For this reason, Fraunhofer IAPT automates and industrializes part screening, identifying in this manner ever new applications for 3D printing – the additive "diamonds". One such diamond is to be found in heat sinks for the automotive and aerospace industry that are particularly demanding in terms of system weight and build space. Major levels of thermal dissipation need to occur in confined spaces to, for example, increase the performance and service life of electronic components.

Automated optimization

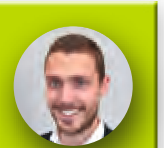
Optimization of heat sinks through simulation aids the search for the best design for a specific application. Topology optimization in particular is an interesting method in this context, as it represents a completely function-driven approach. For example, in the case of thermal conduction optimization, material is only applied at those places where it is necessary for the optimum distribution and dissipation of heat. Fraunhofer IAPT automates these optimization processes and packages them in application-specific apps.

This leads to the creation of innovative bionic designs that open up enormous potential in lightweight construction. One problem encountered frequently in this context is the manufacturability of these complex structures – a perfect application case for additive manufacturing. The tool-free build-up in layers that characterizes the additive manufacturing process enables efficient and resource-conserving production of complexly optimized structures that would otherwise be infeasible.

The partially rough surface quality achieved with the selective laser melting process benefits the application in this respect. In addition to enlarging the overall surface area, a high level of surface roughness increases turbulence close to the surface, further improving the heat transfer.

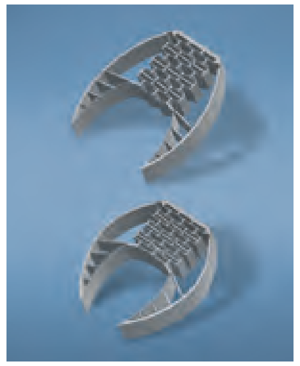
This makes a weight saving of around 35% and a build space reduction of approximately 40% possible when compared to the conventional design. In addition, the new design reduces the number of individual components considerably, along with the installation effort.

CONTACT
Fritz Lange
+49 40 484010-766
fritz.lange@iapt.fraunhofer.de



SOFT ROBOTICS THROUGH ADDITIVE MANUFACTURING

LOW-WEAR ARTICULATED JOINTS, THANKS TO COMPLIANT MECHANISMS



Compliant mechanisms offer many advantages when compared to multi-part connection systems, which are still the standard solution today. Additive manufacturing technologies open up new options for exploiting these advantages in the design of products.

Nature shows the way

Technical articulated joints are normally multi-part systems that give an otherwise rigid structure a certain freedom of movement. A quick look at biology quickly demonstrates that other considerably more flexible solutions have emerged in the natural world. In addition to the motion they enable, systems of this kind can also have other functions, which, for example, act as an energy storage system or for shock absorption. Additive manufacturing opens up an enormous degree of design freedom for the replication of geometries with these special properties. In addition, depending on the process, different materials can be processed simultaneously or material properties configured locally. This opens up a range of options for the design of flexible, highly integrated systems.

Potential of compliant connections

The use of flexible materials enables the reduction of assemblies and flexible connection of originally separate components with each other without using additional connecting elements. It is not only assembly that is dispensed with in the case of these connections. Friction between components and resulting problems such as vibration, noise development, or the release of minute particles are also avoided. An additional advantage is the fact that no lubricants are required. Among other things, this makes compliant connections particularly suitable for use in a clinical environment.

Compliant structures in use

The principle of compliant mechanisms is exploited by scientists at Fraunhofer IAPT, an example being the expansion of inspection drone applications for the maintenance of wind turbines. Some inspections require direct contact with the system, and a compliant, adaptive mechanism makes this contact possible. One specific example is the illustrated gripper, a concept developed in the context of the InspectionCopter project (FKZ: 16KN069937). The central structure of the gripper is not only designed for shock absorption during contact. Compressing the structure automatically closes the gripper jaws, while stored kinetic energy opens the gripper again as soon as the structure is no longer subjected to loading.

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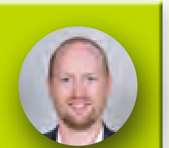
CONTACT
Felix Weigand
+49 40 484010-652
felix.weigand@iapt.fraunhofer.de



INNOVATIVE TOOLING WITH ADDITIVE MOLDS

INNOVATIVE MOLD INSERT FOR PROCESSING EPP*

*Expanded polypropylene

One of the greatest challenges when making molds is cooling behavior. Additive manufacturing enables the optimization of this and, consequently, represents an enormous advance in this sector. In the context of the LaEPPFo project (laser additive produced EPP mold) funded by the German Federal Ministry for Economic Affairs and Energy, a revolutionary mold concept was developed for particle foam processing by the project partners Werkzeugbau Siegfried Hofmann GmbH, WSVK Oederan GmbH, and Fraunhofer IAPT.

EPP processing

To produce EPP components, small foam beads are melted together using hot steam. The component can be removed after the mold has cooled to the demolding temperature.

Conventional mold manufacturing

Conventional manufacturing of a mold involves machining of an aluminum block, the subsequent introduction of steam jets, and creation of the desired surface structure. Material is only removed here where necessary and where this can be realized efficiently. This creates a bulky component that requires a great deal of time and energy for the heating and cooling process.

Exploiting potential through additive manufacturing

The above-mentioned production steps can be combined by exploiting additive manufacturing. In addition, the steam jets can be optimally positioned and integrated directly into the surface structure.

Advantages of the innovative mold

Additive manufacturing made reduction of mold weight by 95% (130 kg to 6.7 kg) possible. Moreover, the mold consists of steel, considerably enhancing its wear resistance and service life. The innovative design and the material saving also enabled a reduction in steam consumption of 97% and shortening of the cycle time by almost 50%. This will lead to a massive increase in productivity in future while simultaneously saving large quantities of energy.

Industrialization of the concept

Following the success of this project in the third and fourth quarter (2018), Hofmann manufactured over 400 further mold inserts based on this model for particle foam processing. Aside from molds for EPP processing, additive manufacturing also helps other technologies such as injection molding to achieve advantages of this nature.

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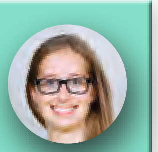
CONTACT
Nora Jaeschke
+49 40 484010-629
nora.jaeschke@iapt.fraunhofer.de



SPARE PARTS FROM THE 3D PRINTER – INNOVATIVE SPARE PARTS LOGISTICS THROUGH ADDITIVE MANUFACTURING

EFFICIENT COMPONENT DIAGNOSTICS FOR OPTIMUM REPLACEMENT LOGISTICS AND MANUFACTURING

→ ***Fig.:*** *Additively manufactured shaft*

With the increasing variant diversity evident today and the shortening of product cycles, a variety of spare parts needs to be held in stock for many years. The growing number of components results in higher costs by tying up capital. Spare parts may not be needed, but for a variety of reasons need to be manufactured and stored, pushing up costs and also negatively impacting the environment. Additive manufacturing can help here and optimize the situation, as use of technology can reduce stocks of parts and, consequently, lower costs. In addition, rapid and decentralized provision of components is possible all over the world.

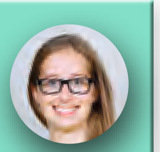
Location-independent provision of parts

A CAD file is all that is required for manufacturing components. This can be "stored" in place of the physical component. Using this file, components can be manufactured at any time and in any place – whether in the desert, on the Moon, or on a container ship.

Spare parts at Fraunhofer IAPT

We at Fraunhofer IAPT are particularly involved in the identification of suitable components for additive spare parts manufacturing. This requires a detailed examination of economic and production aspects if feasibility is to be assessed. However, certain specific characteristics of components can help during preselection. If a defective component could lead to long downtimes and, consequently, result in high opportunity costs, additive manufacturing offers the ideal solution as, in addition to rapid availability, it also replicates spare parts that are no longer available on the market. Moreover, it pays to take a second look at components that generate high inventory costs or are only held in stock for an individual machine. A further common case for the use of 3D printing in the spare parts sector is where a component is not individually procurable. The image illustrates an additively manufactured shaft that is fitted in a disconnector. This shaft, which for the most part is responsible for malfunctioning of the switch, can only be obtained by purchasing the complete assembly. This circumstance has made 3D printing an attractive option for the provision of the components. Instead of keeping the complete assembly in stock, only the shaft is additively manufactured if required. Storage costs could be reduced as a result (through a smaller component that can be manufactured if needed), and wear characteristics could be improved through a change of material (metal instead of plastic) and adaptation of the design. In addition, manufacturing costs for the "new" shaft are considerably lower than those for purchasing the complete assembly.

CONTACT
Nora Jaeschke
+49 40 484010-629
nora.jaeschke@iapt.fraunhofer.de



HYBRID 3D PRINTING FOR PROFITABLE ADDITIVE AUTOMOTIVE APPLICATIONS

ADDITIVE SPACEFRAME FOR THE AUTOMOTIVE FUTURE

Next Generation Spaceframe 2.0 (NGSF 2.0)

In the Next Generation Spaceframe 2.0 project, an innovative hybrid aluminum vehicle front section structure was developed together with the partners EDAG, Siemens PLM Software, Constellium, Concept Laser, and the BLM Group. The design is load-optimized and combines individually manufactured hollow chamber profiles with 3D-printed aluminum nodes with an optimized topology. This innovative design enables flexible reaction to different drive and build space concepts, thus providing an optimum lightweight construction and functional design in every case. The omission of high-investment molds means that an efficient construction can be achieved through hybrid AM design for small and medium quantities. For the first time, software was used during development for the seamless engineering of additively manufactured body nodes and extruded aluminum sections, with this bionic design being validated in simulation.

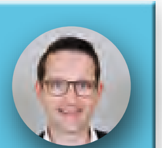
The conflict between maximum functional fulfillment and economic viability can only be solved through the hybrid design of cost-effective sections and highly intelligent AM components. Different Spaceframe connections were joined in the project through laser beam welding, arc welding, and gluing, with intelligent plug connections helping to reduce fixture construction to a minimum. The hybrid structure also proved its suitability in the event of a crash during the drop tower test.

➜ ***Fig.:*** *Next Generation Spaceframe 2.0 – flexible front section structure in hybrid design (source: EDAG)*

A joint innovation project with the partners:

EDAG
SIEMENS
Constellium
CONCEPTLASER
BLM GROUP

CONTACT
Frank Beckmann
+49 40 484010-620
frank.beckmann@iapt.fraunhofer.de



FLIGHT SYSTEM FROM THE 3D PRINTER

[S]LS-MANUFACTURED [QU]ADROCOPTER WITH [IN]TEGRATED ELEC[TRON]ICS (SQUINTRON)

➜ ***Fig.:*** *SQuInTron*

Selective laser sintering (SLS) is an additive manufacturing process in which, initially, a layer of plastic powder with a typical layer thickness of 120 micrometers is applied to a build platform. This can be melted to correspond to the contours of the component through exposure to a CO_2 laser and then solidified. Repetition of this process permits the creation of practically any component structures, layer by layer. The advantage of the SLS process is that components with complex geometries can be manufactured economically in low quantities.

Research is being conducted at the Fraunhofer Research Institution for Additive Manufacturing Technologies IAPT into further developments of the SLS process, the aim being to enhance the functionalization level of components through new materials and designs. One approach is the functionalization of SLS components with electrical conductivity. A special material that can be selectively metalized on the surface following the printing process is used for this purpose, enabling the creation of conductor traces with metallic copper. One method of implementing this selective metallization is activation of the surface of a component using a laser beam. The laser beam is guided over the surface of the component for this purpose in accordance with the desired trace pattern. During the subsequent chemical metallization, the deposited copper merely settles on the activated surfaces, rendering these electrically conductive. Inactive areas remain electrically insulated. The process had only been implemented previously on simple test specimens, and was employed in a specific application for the first time on the SQuInTron.

The goal of the SQuInTron project was to gain experience in the challenges involved in this approach under practical conditions. The WiFree Copter from Open DIY Projects was used during this and developed further to create the SQuInTron. The objective here was to replace as many conventional cables as possible with integrated galvanically reinforced traces. SQuInTron is completely airworthy, with a remote control system that uses a tablet linked to the integrated camera.

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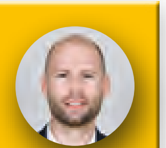
CONTACT
Lennart Waalkes
+49 40 484010-762
lennart.waalkes@iapt.fraunhofer.de



BIONIC DESIGN OF NEW ULTRALIGHT STRUCTURES

The overall objective of the EU research project "Bionic Aircraft" coordinated by Fraunhofer IAPT is to contribute to resource efficiency in aviation over the entire aircraft life cycle by exploiting additive manufacturing, as additive manufacturing opens up completely new possibilities for the design of lightweight structures. It also enables flexible, resource-efficient manufacturing of parts with highly complex geometries. A further weight saving is made possible through the introduction of high-strength aluminum alloys.

One major challenge in the contemporary AM production chain is the time-consuming and expensive design process for bionically optimized parts. The high costs associated with the development and manufacturing of bionically optimized parts prevent the use of AM in the production of aircraft components in many cases, meaning potential savings of energy and resources over the aircraft life cycle cannot be exploited. Consequently, one primary goal of the project is to provide an automated and simplified design process for biomimetic lightweight structures while safeguarding the structural integrity of components. Fraunhofer IAPT has developed bionic supports and a catalog of parameterizable bionic lightweight elements here to minimize the use of materials. The company CENIT exploits these to develop a software module that adds automated bionic elements to the component during design creation. Integration of the design process in commercial 3D CAD software (CATIA V5) allows CENIT to depict the entire design process seamlessly in a single piece of software for the first time, from part design, build preparation, and manufacture to post-processing. Airbus plans to use the software in the design process in future.

In terms of process technology, Fraunhofer IAPT is developing suitable manufacturing parameters for laser beam melting of an innovative new Al-Si-Sc alloy, promising tensile strengths of up to 550 MPa in the heat-treated state for an elongation of five to seven percent. The company TEKNA is contributing to an increase in added value by preparing recycled Al-Si-Sc powder in a plasma spheroidizing process and making it available to the AM manufacturing process again.

Fraunhofer IAPT is developing optimized laser beam intensity profiles to enhance the productivity of the printing process. Using an innovative 2D simulation of the melt pool, it proved possible to show that a significantly more homogeneous melt pool and higher process productivity can be expected with an M-profile. A test bench developed specially for the Bionic Aircraft project is used for experimental validation of models. The results indicate that, when compared to a classic Gaussian profile and with the same component density, a productivity increase of 30% and an improvement in energy efficiency of 35% can be achieved when an M-profile is used.

Other innovative aspects of the project are the development of inspection systems to monitor component integrity during the printing process and, on the other hand, for defect recognition when components are in use. The company HEXAGON develops suitable innovative, non-destructive test methods for this purpose that are validated at Fraunhofer IAPT. Our partner TECNALIA has developed a lifetime prediction simulation based on the actual component condition and the defects. TECNALIA also develops and validates cost-effective repair and recycling processes for manufactured components. The goal is to repair large-scale defects without impairing the structure/microstructure and mechanical properties and validate these on the basis of representative complex geometries. Recycling of ALM powders and parts for the manufacture of high-quality powders is also planned.

BIONIC AIRCRAFT

The introduction of bionic designs and the innovative high-strength aluminum alloy enabled a reduction in the weight of demonstrators developed in the project of up to 40%. In addition to major weight-saving potential, additive manufacturing and the recycling of powders and components enable a reduction in material waste of up to 90% when compared to classic machining. The reduction in weight and waste achieved through the introduction of AM harbors a major opportunity for the minimizing of CO_2 and NOx emissions over an aircraft life cycle.

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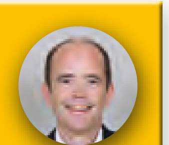
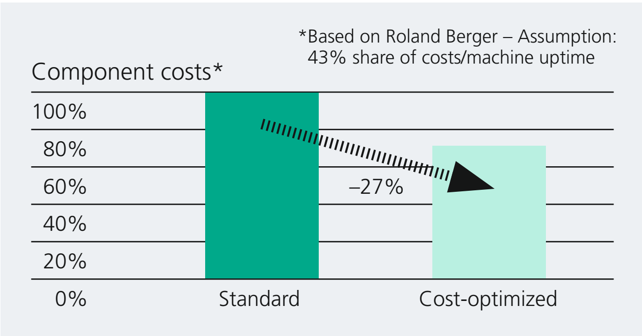
CONTACT
Dr. Philipp Imgrund
+49 40 484010-740
philipp.imgrund@iapt.fraunhofer.de



PROFITABLE POWDER BED METAL PROCESSES

PRODUCTIVITY ENHANCEMENT FOR SELECTIVE LASER MELTING (SLM, LBM)

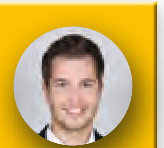
3D printing through selective laser melting has already demonstrated its enormous application potential in a variety of sectors. New functions and previously unachieved degrees of lightweight construction were successfully transferred to low-volume production runs through completely new design options, excellent material properties, and a high degree of manufacturing flexibility. However, it has not yet proved possible to make the jump to medium-sized series. The pivotal reason for this is costs, which are currently still prohibitive. Around 40 to 70 percent of these costs are machine-related (specifically the build rates of the process multiplied by machine hour rates). This is why processes that are individually tailored to the respective customer and represent a cost-effective manufacturing process are developed at Fraunhofer IAPT.



This is underpinned by numerous projects where, for example, alternative laser beam profiles or innovative laser sources were used and the processes optimized with regard to the resulting component properties – and not with regard to component density. For example, the latter was realized with a steel alloy, and it proved possible to increase the process speed for components with a density >99.5 percent by 160 percent when compared to process parameters, resulting in a density >99.9 percent. Density values of this kind are frequently adequate for end users when it comes to meeting their requirements. Cost savings for this example are around 27 percent. Furthermore, a combination of existing process expertise and innovative control options allows Fraunhofer IAPT to assign requirement-specific material properties to components through intelligent process control. It is therefore possible to configure different load-dependent strength ranges for components and, as a consequence, realize even more complex geometries.

The high degree of diversity of existing laser beam melting systems and daily handling of the systems by personnel enable the development of system components tailored specially to the customer. For example, if requested by the customer, a flow analysis of the customer's own system can be realized, the gas flow optimized, and new flow components manufactured and installed at the customer's premises. An optimized gas flow also makes it possible to avoid process-inherent faults, generate higher build rates, and ensure a high degree of process reproducibility. Consequently, our experts successfully offer their partners and customers cheaper and both mechanically and technologically optimized components, and also optimize customer systems to achieve a higher degree of reproducibility and profitability.

CONTACT
Philipp Kohlwes
+49 40 484010-745
philipp.kohlwes@iapt.fraunhofer.de

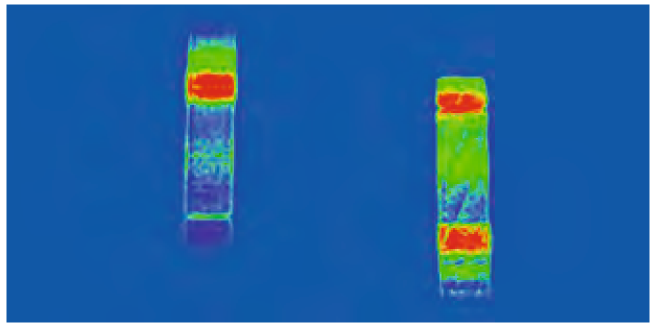


PRODUCTIVITY ENHANCEMENT OF LBM PROCESSES

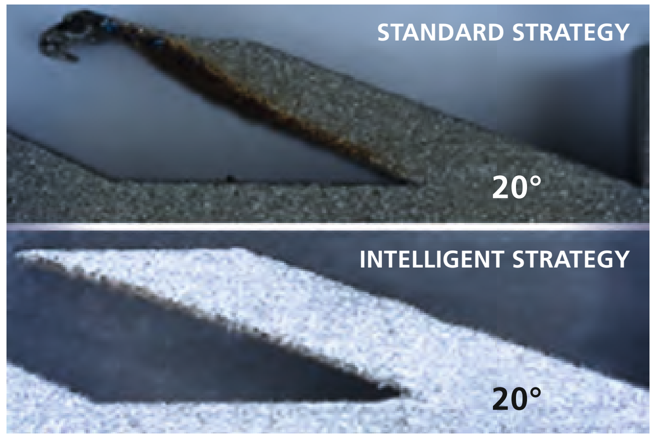
INTELLIGENT SCAN STRATEGIES

Selective melting of the powder material creates excess heat in powder-bed-based laser additive manufacturing. The majority of this heat is dissipated over the completed component.

Thermal conditions during melting and solidifying have an effect on both the macro- and microstructure and, consequently, the mechanical properties. Both geometric component designs such as tapering and overhangs and process parameters such as laser output, scan speed, and the exposure strategy determine local thermal conditions.

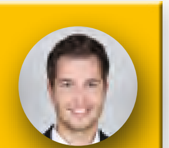


In a number of research projects, Fraunhofer IAPT investigated the impact of thermal conditions on component properties and developed optimized process control strategies. Using simulations of the heat flow during the build process, a specific exposure strategy was developed together with ISEMP from Bremen with which the surface roughness of overhang structures at an angle of 30° to the substrate plate was reduced by 45 percent. Furthermore, it enabled the intelligent scan strategy to generate overhang structures with an angle of 20° without using support structures.



The dependence of the morphology of defects and the resulting mechanical properties where dynamic loads are involved on thermal conditions was analyzed through μ CT images and fatigue testing. It was demonstrated in cooperation with the Department of Materials Test Engineering (WPT) at TU Dortmund University that the morphology of residual porosity is irregular in the case of unsuitable thermal conditions. Irregularly shaped pores lead to premature failure in the case of dynamic loads. Thanks to suitable process control, thermal conditions were influenced to such a degree that the residual porosity primarily exhibited a spherical morphology. This change had a positive effect on the mechanical properties. In addition to a clear increase in lifespan during fatigue testing, the reproducibility of mechanical parameters was also enhanced.

CONTACT
Philipp Kohlwes
+49 40 484010-745
philipp.kohlwes@iapt.fraunhofer.de

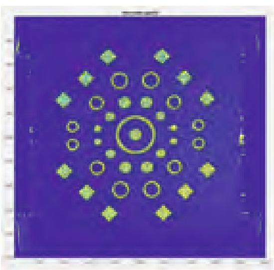


ANALYSIS OF LBM TOPOGRAPHY FOR ROBUST ADDITIVE MANUFACTURING

HIGH-RESOLUTION TOPOGRAPHIC MEASUREMENT IN LBM POWDER BED

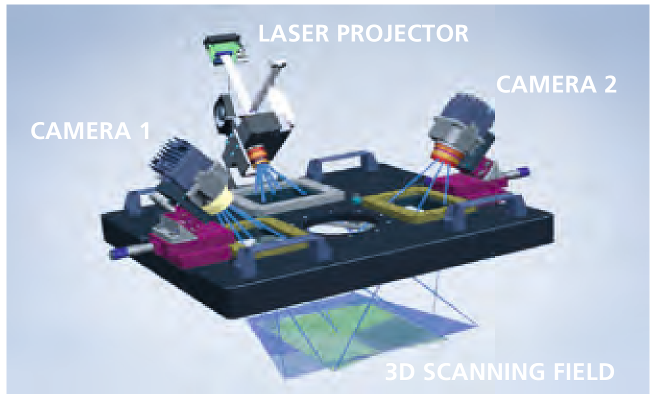
One of the central challenges associated with the establishment of additive technologies in industry is the current inadequacy of process monitoring that enables quality measurement within the production process.

The complex printing process exhibits detectable instabilities that are responsible for the formation of component defects and largely determine the resulting component quality. A new technology for powder and component layer monitoring was developed together with the Hexagon Technology Center in Heerbrugg (Switzerland) in the context of the Horizon 2020 Bionic Aircraft project for in-situ quality control of printing in powder-bed-based additive processes. For the first time, the Structured Light 3D system enables layer-by-layer recording of the 3D topography of unmelted and melted areas of the powder bed during the printing process. High-resolution CMOS cameras (50 megapixels) are used in conjunction with stripe light projections for this purpose. These enable the creation of a 3D image with a spatial resolution <15 micrometers.



Component measurement and 3D process visualization

The high resolution of the 3D topography in all three spatial directions prior to and after exposure grants the user deep insights into the dynamics of the process. Evaluation of the data recorded through methods involving statistical analytics and artificial intelligence enables the detection, identification, and classification of process instabilities that may occur and the resulting component quality.



Stacking of the layer data recorded permits the generation of a digital image of the component in production, with which a geometric measurement is also possible. Recording of the powder bed condition prior to and after exposure means that the system is an ideal supplement to on-axis process monitoring systems that, for example, record the emissions of the molten pool in the beam path using photo diodes to monitor process stability.

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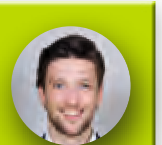
CONTACT
Peter Lindecke
+49 40 484010-730
peter.lindecke@iapt.fraunhofer.de



WIRE ARC ADDITIVE MANUFACTURING (WAAM)

HIGH PRODUCTIVITY MEETS LOW SYSTEM COSTS

Do you find the established laser melting process too slow or too expensive? Do you need large components? Then wire arc additive manufacturing represents a suitable alternative. Whereas build rates in the powder bed process were up until now limited to 20 to 100 cm³/h and component costs frequently far exceeding €500/kg were too expensive, the WAAM process offers the chance to work more quickly and cheaply and create components that are close to the final contour. The process is particularly suitable for large-scale components of medium complexity, with final dimensions being efficiently achieved using familiar post-processing methods.

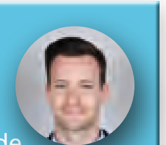
WAAM has already demonstrated its technological maturity for use as a rapid manufacturing process and is employed in an initial series application in the manufacture of structural components (e.g. for aerospace and shipbuilding). Favorable system technology and simultaneously high build rates >600 cm³/h indicate that the potential for WAAM to establish itself quickly in other sectors is enormous.

Fraunhofer IAPT is therefore intensively involved in industrialization of the WAAM process, along with elimination of existing obstacles and the transfer of its potential to new materials and applications. Fraunhofer IAPT develops process strategies, programming and sensor tools, and post-processing methods for this purpose and applies these to new industrial applications in different sectors. The result is the creation of non-porous and low-distortion components which, in their complexity and size, can be transferred in future to large structures with dimensions of several meters using software support developed at Fraunhofer IAPT. At the same time, conventional repair and cladding processes for applying wear- and corrosion-resistant layers are also among the application options.

Mobile and stationary cell solutions are developed at Fraunhofer IAPT that, using wire arc additive manufacturing technology on cooperating robots in conjunction with machining processes, provide manufacturing systems for series applications. The interaction of individual systems and process support via a digital twin are appropriately adapted to the task and developed according to the specific requirements of customers. In this context, a conscious emphasis is placed on robot-guided processes that offer maximum freedom and enable simultaneous working on a component to minimize the time requirement.

→ ***Fig.:*** *Cell solution for stationary manufacturing of maritime components based on the WAAM process*

CONTACT
Markus Heilemann
+49 40 484010-627
markus.heilemann@iapt.fraunhofer.de

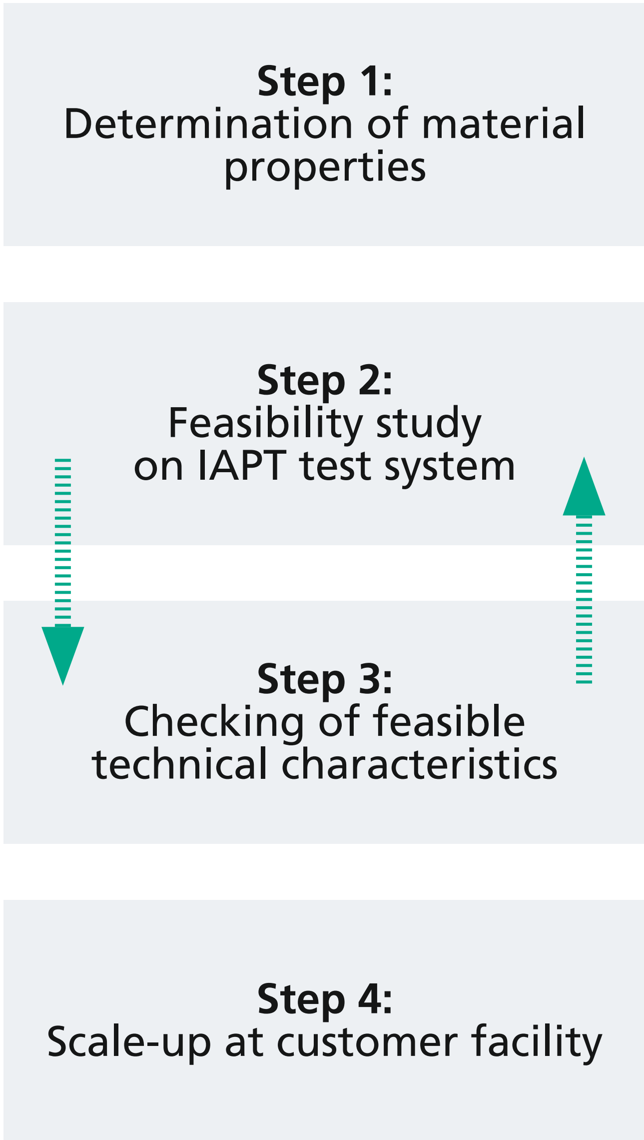


SCALABLE SELECTIVE LASER SINTERING PROCESSES (SLS)

From material development to series

Plastics such as PA12 and their derivatives are currently primarily used for selective laser sintering (SLS). Meanwhile, many industrial applications demand application-specific characteristic profiles that go beyond standard SLS materials (e.g. polyethylene). However, time-consuming and cost-intensive material and process development is necessary to make new materials accessible for the SLS process, not least due to the large build spaces of industrial SLS systems. New powders need to be available in large volumes if the initial printing trials are to be conducted at all, and if these are to ultimately contain valid statements concerning their processability in the SLS process.

The possibility of being able to test several different powders rapidly is, therefore, limited due to the larger material volumes required for this. Moreover, a material and process development of this kind is marked by numerous iteration loops, which only appears sensible in economic terms to a limited degree where larger volumes of powder are involved. For this reason, a modular build space for an individual SLS system (manufactured by EOS) was developed at Fraunhofer IAPT in which powder volumes can be tested at laboratory scale (50 grams) under otherwise real conditions. Feedback loops in the material and process development are significantly reduced as a result, which ultimately permits the testing of numerous different powder variants at an earlier development stage. The results achieved can then be transferred with ease to an appropriate industrial system. The build space module is dismantled for this purpose and the system charged with standard industrial powder volumes.



How can customers benefit?

- An initial feasibility study for a material is possible as of 50 grams of powder material (the customer does not require a large-scale test reactor to manufacture powder)
- 98 percent reduction of material consumption for process development
- Process development in the reduced build space is, with regard to a material, 30 percent cheaper than in the full build space
- You receive the results on development of a material 25 percent earlier
- Direct transfer of results is possible on an industrial scale
- During process development for numerous material variants, further costs and time savings of up to 50 percent in each case can be achieved when compared to the full build space
- Process development for high-priced materials can be realized in a cost-efficient manner

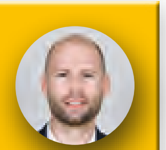
Example: Process development for electronic components

When manufacturing so-called molded interconnect devices (MID), the SLS process provides an option for a more flexible design of the conventional process chain that is based on injection molding. It will therefore be possible to realize prototypes and low-volume production runs that previously could not be economically implemented with the SLS process.

MID manufacture is based on selectively depositing conductor traces on the component surface through a chemical process. The material composition, which, in addition to the plastic matrix, consists of a special additive, is decisive in this context. The additive type and concentration are selected for each specific application and also depend on the polymer type of the plastic matrix. An experimental approach is necessary if the material composition is to be configured to suit the process. The process development must be realized for every material composition and, subsequently, the suitability for metallization should be examined. As at least six variants are typical for each combination of plastic matrix and additive, the material requirement for these developments is very large.

Fraunhofer IAPT can provide the aforementioned customer benefit in this application case with its expertise and the developed build space module and reduce the development time from months to a few weeks.

CONTACT
Lennart Waalkes
+49 40 484010-762
lennart.waalkes@iapt.fraunhofer.de



COMPOSITES FOR DISTORTION-FREE SLS COMPONENTS

Many industrial applications demand plastics with specific characteristic profiles that are not covered by materials currently available on the market for selective laser sintering (SLS) – primarily PA12 and its derivatives. However, process development of new materials is increasingly complex when using the existing system technology, particularly large build spaces. Cost-efficient process development of new and promising materials is now possible with the reduced build space developed at Fraunhofer IAPT.

One such material is ultra-high-molecular-weight polyethylene, or UHMWPE, which exhibits excellent chemical and physical properties and is used in applications such as medical engineering for knee joint inserts. UHMWPE is further distinguished by its resistance to wear and low coefficients of friction. This is complemented by excellent compatibility with foodstuffs, making this plastic ideal for use in the food industry.

However, the excessive viscosity of the material in the SLS process has in the past led to components with inferior mechanical properties and a high level of warping.

In cooperation with the Institute for Technical and Macromolecular Chemistry at the UHH (Universität Hamburg), the viscosity problem of this material is being addressed at Fraunhofer IAPT with the development of dUHMWPE (disentangled UHMWPE). A combination of in-situ polymerization and simulation-aided temperature control makes the manufacture of dimensionally accurate components possible through SLS.

The addition of additives is also being investigated to further optimize optical and mechanical properties. For example, carbon nanotubes (CNTs) increase the absorption of laser light and both electrical and thermal conductivity. The possibility of their use is the subject of current research at Fraunhofer IAPT. In addition to the experimental aspect, simulations in the context of process development in particular are especially interesting. A simulation model that encompasses all significant material and process parameters and delivers time-dependent and valid predictions of the temperature profile in the powder bed is currently being created for this purpose. The simulated temperature profile is subsequently correlated with the material-specific crystallization behavior of dUHMWPE. Predictions concerning component warping can then be made on the basis of the inhomogeneity of crystallization, and this warping can then be countered proactively with the aid of targeted cooling commensurate to the simulation results.

As a consequence, Fraunhofer IAPT will for the first time succeed in ensuring the process stability and freedom from distortion of dUHMWPE in the SLS process, making the outstanding characteristics profile of this material available for industrial applications in the form of new products with highly complex geometries.

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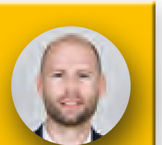
CONTACT
Lennart Waalkes
+49 40 484010-762
lennart.waalkes@iapt.fraunhofer.de



NEW MATERIALS FOR ADDITIVE MANUFACTURING

Exceptional design freedom and direct processing of digital models make additive manufacturing a technology that continues to grow in relevance. However, an assessment of the raw material used is necessary if the full potential of this manufacturing process is to be exploited.

The list of metal materials that can be used in additive manufacturing is currently somewhat limited. Although there have been calls from many users for materials adapted to specific industry needs, the majority still falls back on standard alloys. Accordingly, the alloy most frequently used for powder-bed-based laser beam melting (LBM) is AlSi10Mg, an aluminum casting alloy. This limited selection of materials is in clear contrast to the comprehensive range of materials available for conventional manufacturing processes. However, not every alloy used in conventional processes can be simply transferred to the LBM process. High-strength magnesium or zinc-based aluminum alloys would add to this range, but the material composition may lead to increased smoke development or cracking during processing.

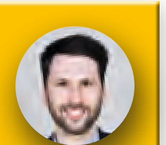
One approach to solving this problem is offered by Fraunhofer IAPT in the development of material-specific process strategies for new materials in the LBM process. Customized Al alloys have already been generated for automotive applications, including highly ductile materials for crash-relevant components, and high-strength aluminum materials that have been created for the aerospace industry.

Fraunhofer IAPT has adopted a three-pillar strategy to promote the establishment of new materials in additive manufacturing. Commencing with analysis of the powder, influences on component quality can be identified and quantified through special characteristics. Furthermore, quality limitations, handling guidelines, or an evaluation of the general suitability of the powder for additive processes can also be deduced as a consequence of this. Building on many years of experience, the second stage sees the adaptation of the manufacturing process to the material. A variety of measuring and plant systems are used in combination with innovative analysis tools to vary the most important process parameters and optimize these with regard to individual targets. Test specimens are available at the end of this iterative methodology, which can be tested to ascertain their material properties. Material-specific heat treatment strategies and other parameter optimizations can be used to achieve the properties demanded by the customer in a reproducible form.

Step 1: Definition of material and powder specifications	**Step 2:** Feasibility studies and development of process parameters	**Step 3:** Examination of powder and material properties

This successful concept has enabled Fraunhofer IAPT to make numerous steel and aluminum alloys usable for additive manufacturing. In addition, current research projects are also addressing the processing and testing of composites. Fraunhofer IAPT is therefore making a major contribution to expanding the scope of additive manufacturing even further and making suitable materials available to modern technology.

CONTACT
Maximilian Kluge
+49 40 484010-728
maximilian.kluge@iapt.fraunhofer.de



PROFITABLE DED SYSTEMS THROUGH HIGH-PRECISION PROCESS CONTROL

SENSEPRO – THE ROBOT EYE WITH AN ALL-AROUND FIELD OF VISION

Robots can move – but not see – in every direction. Help is on hand in the form of the SensePRO laser sensor from the Fraunhofer Research Institution for Additive Manufacturing Technologies IAPT. Many contemporary production processes are realized purely through the handling system, meaning the machine program is programmed once and then repeatedly executed, all without the use of supplementary sensor technology for environmental perception. This means that tolerances in the component, inaccuracies in machine design, and errors and deviations in the actual manufacturing processes remain undetected. As a result, it is frequently necessary to fall back on high-precision and, consequently, expensive CNC systems as a machine tool to ensure the required degree of process accuracy.

SensePRO sensor technology from Fraunhofer IAPT provides a solution to this problem. Originally developed for additive processes such as laser material deposition, wire arc additive manufacturing, or fused deposition modeling, this sensor system enables precise detection of the machine position and identification of the component position and geometry. This allows continuous control of deposition processes, reducing errors and rejects. Furthermore, it enables the use of cost-effective handling robots instead of expensive CNC systems, as their accuracy can be increased to the necessary degree using the control system. This reduces system costs significantly, thus facilitating the economical processing of components.

In contrast to familiar one-dimensional triangulation sensors, SensePRO is direction-independent, allowing a maximum degree of process and component geometry freedom. The 360° measurement field eliminates non-productive time previously required for repositioning the robot and minimizes process times to productive manufacturing. To complement process control, SensePRO allows recording of deposition and the entire component geometry during processing. This in-process digitization facilitates direct recording of quality in the process. The integrated target/actual comparison of the geometry renders the transfer to a separate measuring station, which was previously necessary, obsolete. This saves time and money.

The modularity of both its hardware and software allows this sensor to be adapted with ease to the most varied applications and effortlessly configured for different robot control systems. As a result, the sensor can be integrated without difficulty into other processes and existing production systems in future.

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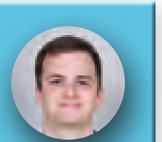
CONTACT
Malte Buhr
+49 40 484010-628
malte.buhr@iapt.fraunhofer.de



DIGITIZED AUTOMATION OF DED PROCESSES

AUTOMATED PROCESS PLANNING TOOL FOR DED PROCESSES (SLICEME)

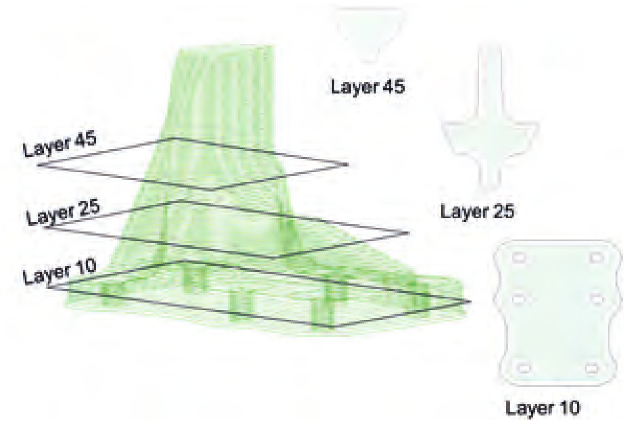
In contrast to powder bed technologies, directed energy deposition processes (DED) offer a high deposition rate and flexibility during the manufacture of hybrid and large structures. Flexible and robot-based handling is part of a variety of DED processes such as laser metal deposition (LMD), wire arc additive manufacturing (WAAM), and electron beam additive manufacturing (EBAM). Layer-by-layer deposition of material with processing heads for each specific process is achieved through robot motion, which should be prescribed by the underlying CAD geometry. Path planning and build strategies play an important role in robot-controlled AM processes of this nature, shaping the final geometry and microstructure achieved, which directly influence the mechanical properties of the component.

Fraunhofer IAPT has developed the SliceMe solution for automated preprocessing of CAD data and robot code generation without manual intervention. The tool consists of three modules – a geometry analysis module, the slicing and path generation module, and a robot code generation module.

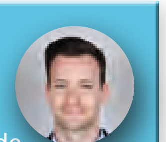
The geometry analysis module automates preprocessing of the CAD geometry with topology detection through calculation of the priority axes. Overhang detection and volumetric segmentation are implemented in this module for complex free-form structures to enable manufacturing free of support structures.

The slicing and path generation module defines the unidirectional and multidirectional slicing of segmented CAD data. An integrated process database with predefined slicing and hatching parameters based on process parameters enables the optimized slicing of 2.5D and 3D structures. The robot path for each individual step is generated automatically on the basis of one of the many path generation algorithms available. A slicing viewer then visualizes the robot path in a three-dimensional view.

The robot code generation module integrates build strategies defined by the user in layer information to generate the robot actuation code. Predefined functions and standard modules allow the user to create build strategies flexibly with reduced effort and in less time. Overall, the SliceMe process planning tool constitutes a vital basis for an automated digital process chain in the area of robot-based DED processes.



CONTACT
Markus Heilemann
+49 40 484010-627
markus.heilemann@iapt.fraunhofer.de



SMART ADDITIVE FACTORIES

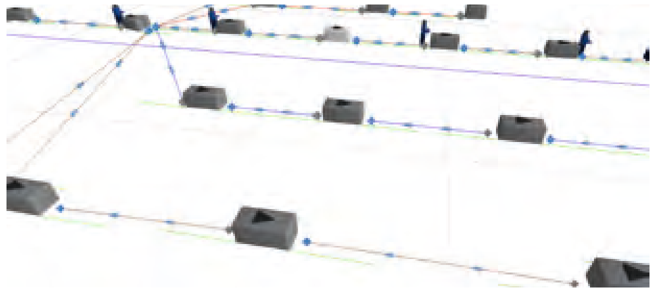
INDIVIDUAL PRODUCTION WITH SMART ADDITIVE FACTORY SOLUTIONS

Factory simulation

The development of an additive manufacturing factory frequently involves investments running into millions, which means that every design error can be very expensive and have repercussions for component costs or throughput. Fraunhofer IAPT has developed a simulation model that can simulate different factory layouts at an early stage to avoid expensive errors. Flexibly structured models enable the examination of different scenarios without any risk. The user can evaluate which factory structure is capable of realizing prescribed target criteria with the aid of the simulation. Typical examples of targets are producible quantities and the lead time per component. Suitable cost models make it possible to calculate necessary investment costs and the resulting operating expenses. Appropriate factory layouts differ, depending on the component portfolio to be manufactured. When it comes to spare parts production, the most prioritized target criterion is delivery time, while unit costs should be reduced in the area of mass customization. Accordingly, the required number and type of machines and their efficient layout differ.

Digital twin of the factory

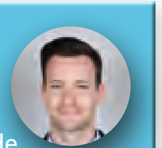
Existing productions can also be replicated in the simulation and investigated for optimization potential. Specific recommendations for action to enhance efficiency can be derived from the results. Once established, the simulation model can be adapted at any time to reflect changing requirements. The current state of production can be illustrated with the aid of a digital twin. A digital twin replicates a physical object in the virtual world. The current status of the entire production line and each individual production station is rendered visible in this manner. Consequently, this means greater transparency and a better understanding of correlations. If critical conditions are detected on systems, downtimes can be reduced through predictive maintenance. Reasons for component faults are easier to identify, thanks to the collection and storage of production history, and the causes of faults can be remedied much quicker.



➜ ***Fig.:*** *Simplified simulation model of a production line*

The data used is primarily read directly from the systems, but this is inadequate for complete virtual imaging of production. For this reason, Fraunhofer IAPT has developed sensor boxes that, depending on the application case, can record additional relevant data. Taken together, the simulation and digital twin are ideal tools for monitoring and enhancing the efficiency of production lines.

CONTACT
Markus Heilemann
+49 40 484010-627
markus.heilemann@iapt.fraunhofer.de



ADDITIVE MOBILE FACTORY – ONE-STOP SOLUTION

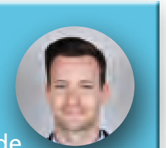
MOBILE PRODUCTION UNIT FOR EVERY APPLICATION

The concept of a modular, container-based production unit essentially arose to meet the challenge of having spare parts available locally and only when they are needed. The speedy availability of certified prefabricated components is of particular relevance in remote locations or places that are difficult to access. Expensive downtimes and storage costs can be reduced to a minimum in this manner.

In the Additive Mobile Factory, the component geometry is built close to final contour in the shortest possible time with the aid of additive manufacturing technologies and subsequently undergoes automated post-processing. The entire physical and digital process chain from design to the quality-assured component is contained in a space-saving container that can be operated anywhere without difficulty. And that means exactly where capacities are needed. Plug and play, so to speak. In combination with robot-assisted post-processing, the targeted focus on deposition technologies offers a robust, cost-effective system solution. The link with the SensePRO sensor solution developed by Fraunhofer IAPT guarantees consistent and reliable component quality in this respect. A customized software package controls the complete process chain, thus ensuring ease of operation.

The implementation of the Additive Mobile Factory represents the bringing together of the broad expertise of Fraunhofer IAPT along the entire additive process chain to create a highly automated system solution. Modular product architecture facilitates customized configuration with regard to AM technology, post-processing, manufacturing capacity, and the degree of automation. A simplified model of this mobile production solution was demonstrated in a 10-foot container at Formnext 2019 and can now be viewed by visitors to Fraunhofer IAPT in Hamburg.

CONTACT
Markus Heilemann
+49 40 484010-627
markus.heilemann@iapt.fraunhofer.de



SHIPLIGHT – INNOVATIVE SHIP DESIGN THROUGH AUTOMATED 3D LASER HYBRID JOINING

SUSTAINABLE LIGHTWEIGHT CONSTRUCTION OF SHIPS THROUGH AUTOMATED 3D LASER ARC HYBRID WELDING

Motivation and objective

The central objective of the ShipLight research project was to develop a new welding process that eliminated the discrepancy between metal active gas welding (MAG) and high-power laser MAG hybrid welding in shipbuilding applications. With regard to the MAG process, the aim was to achieve an increase in speed in conjunction with a clear reduction of energy input per unit length. On the other hand, when compared to the laser MAG hybrid process as employed in shipyards in panel production lines, considerably greater gap bridgeability and improved component accessibility are necessary.

A consistently low-distortion welding process relative to the process chain is a prerequisite for the use of thinner sheet material in shipbuilding. The sheet thickness is frequently chosen for reasons of dent resistance, rather than strength. This means that manufacturing restrictions are the main obstacle to lightweight construction. If these restrictions are eliminated through a new manufacturing method such as the ShipLight process, material can be saved and production made more resource-efficient.

ShipLight process

A beam source limited to a maximum laser output of two kilowatts, for reasons of laser safety, supporting an energy-optimized MAG arc – that is the ShipLight process. With a spot diameter of 1.2 millimeters, the laser beam stabilizes the arc welding process and improves its performance.

During process development, sheet thicknesses of three to ten millimeters with preset gap widths ranging from a technical zero gap to a gap size of five millimeters were investigated. These specifications applied to both I- and T-joints. The test material was of the A36 and S355 quality typically used in shipbuilding.

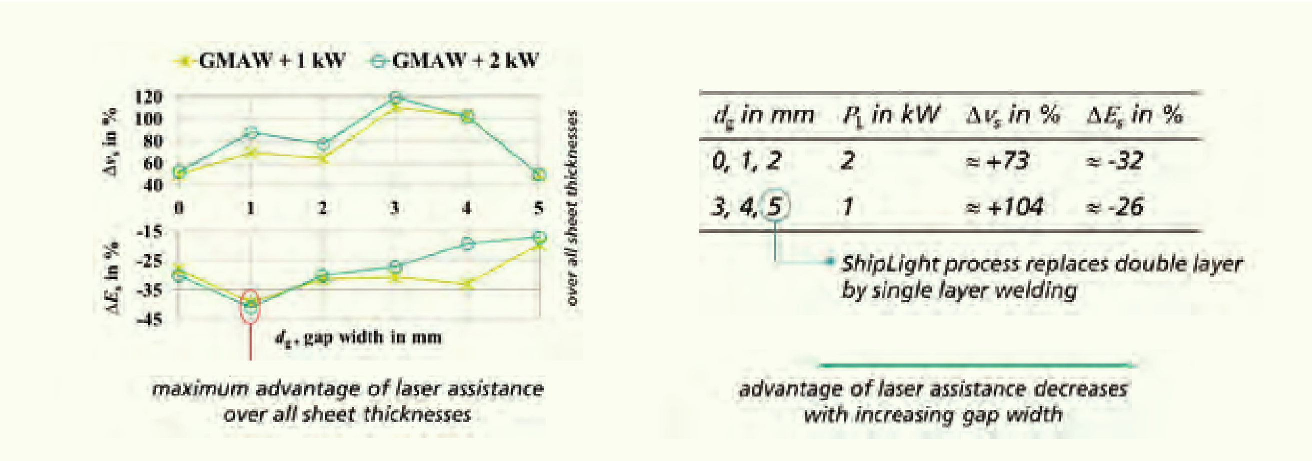


Fig. 1: *Advantages of ShipLight process over conventional MAG process on T-joint (source: Fraunhofer IAPT)*

The energy input for at least the same weld quality and component distortion were taken as the decisive assessment criteria for the suitability and quality of the ShipLight process. A reduction of energy input (the amount of energy expended relative to a welded unit of length without any consideration of efficiency) has, in principle, a positive effect in the form of low distortion of the welded construction. Laser support increases the welding speed, which potentially lowers the energy input. However, overcompensation is necessary in this respect for the additional laser power introduced. Trials were conducted with one-kilowatt and two-kilowatts laser output P_L to detect the most favorable variant in terms of energy input, individually related to the sheet thickness and gap conditions.

In the process application involving I-joints, sheet thicknesses of up to ten millimeters were subjected to single-layer welding, and gap sizes of up to one millimeter without weld pool backup and three millimeters with ceramic pool backing were bridged. In the case of T-joints, single-side fillet welds were created with the ShipLight process. The goal was to achieve a weld penetration depth that was at least 50 percent of the web width, thus enabling the achievement of full welded attachment on both sides with a backing pass. In general, laser support helps increase weld penetration depth when compared to the purely MAG process. In the case of a three-millimeter sheet thickness, it even proved possible to achieve full attachment on one side (regardless of the gap conditions). Only in the case of a sheet thickness of more than seven millimeters did the attachment length reduce to only 40 percent of the web width (while the laser output and welding speed remained the same).

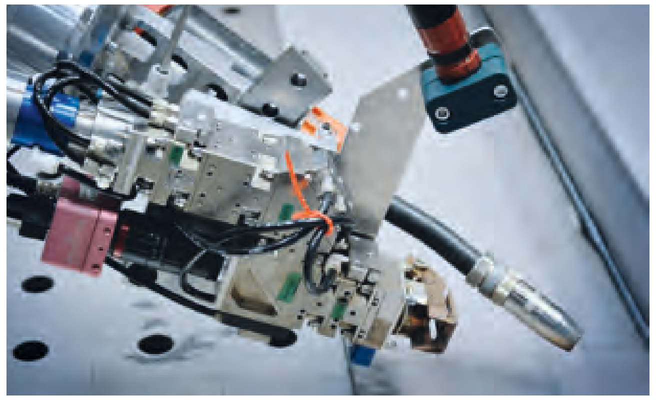


Fig. 2 and 3: *2) See photo above – ShipLight processing head from Cloos with integrated joint tracking sensors; 3) Fully automatic processing system in operation at Fraunhofer IAPT (source: Fraunhofer IAPT)*

When compared to the MAG process, use of the ShipLight process developed in the project successfully achieved a significant increase in the welding speed and weld penetration depth, thereby reducing the energy input and positively affecting the heat distortion of the joined components. With regard to the high-power laser hybrid welding process, the process tolerance was considerably improved and, at the same time, similarly high maximum welding speeds of up to 2.4 m/min were achieved. In contrast to the ShipLight process, gap sizes greater than 0.5 millimeters already represent the upper tolerance limit in the high-power laser application. The gap limit in the new process is three millimeters for I-joints and up to five millimeters for T-joints. However, it can generally be said that, in the case of both I- and T-joints, the advantage gained through laser support diminishes in the ShipLight process as the gap size increases. Fig. 1 illustrates the results achieved for T-joints in a comparison with the conventional MAG welding process that to date has been the method usually employed in shipyards.

System technology for the ShipLight process

New processing systems were urgently needed if the ShipLight process was to be used, and these evolved iteratively and parallel to the process. The systems developed during the project address the entire 3D processing chain in shipbuilding and are divided into a fully automated, semi-automated, and manual welding unit. Cloos provided a very slim and flexible design for the automated processing head, which, in functional terms, only has a minimum interference contour and, as it is robot-guided, can be moved with comparative ease in the ship structure. Positioning on the component is realized with the process monitoring and control system (PMCS) developed by Fraunhofer ILT, which is coaxial (i.e. functions through the laser processing optics) and enables texture-based joint position detection and gap width measurement for situational adaptation of the welding parameters.

Requirements in block production and subsequent shipboard fitting with regard to accessibility on the component demand an additional system solution that encompasses a particularly high degree of mobility and versatility. Consequently, a plan was hatched at Fraunhofer IAPT to develop a light and compact welding system that can be guided by hand for the ShipLight process. The geometric layout of the laser beam and electric arc corresponds to the processing head for the fully automated process application. The manual unit can be converted from an I-joint to a T-joint variant and vice versa for adaptation to the joining situation. The unit needs to be operated at a relatively high welding speed to exploit the advantages of the ShipLight process. This is why the welder first needs a guide in the form of wheels or casters that are supported on the sheet to be welded and, secondly, a motor drive that ensures uniform movement.

➜ ***Fig. 4–6:*** *Evolution stages of ShipLight manual welding unit for different joining layouts developed by Fraunhofer IAPT (Source: Fraunhofer IAPT)*

Following numerous travel and welding trials with different functional models, the decision was ultimately made to use a miniature tracked vehicle characterized by good traction and stability and a particularly low chassis. The height of the carriage for supporting the laser processing optics and welding torch can be manually adjusted to align the laser-assisted hybrid welding process with the workpiece. Moreover, the welding torch can be removed from the unit in order to, for example, weld a component corner solely using the MAG process (i.e. without laser assistance). This means that the shipyard welder can still make use of their familiar tools. Following work on a position that is difficult to access, the MAG torch can be reattached to the manual welding unit and locked in position with the quick-release fastener.

Fig. 6 illustrates the final evolution stage of the manual welding unit in the configuration for use on a T-joint. The system was successfully tested in a shipbuilding application in the last six months of the project year. When it comes to mobile laser operation in the shipyard environment, the question of laser safety is, alongside process suitability, of particular relevance. This aspect was addressed through limitation of the laser output to two kilowatts and implementation of a special safety concept, which was also approved by the employers' liability insurance association.

Acknowledgment and thanks

The ShipLight research project was funded with the kind support of the German Federal Ministry for Economic Affairs and Energy (BMWi) following a decision by the German Bundestag. We wish to express our thanks for this funding and to Projektträger Jülich (PtJ) for the excellent cooperation. We would also like to thank all our project partners for their support. The ShipLight project research association numbers a total of 14 partners: Meyer Werft, Lürssen Werft, Fraunhofer IAPT, Fraunhofer ILT, Carl Cloos Schweißtechnik, Laserline, IPG Laser, Precitec, Laser on demand, SET, DNV GL, Trumpf, simufact engineering, and BALance. The project management role was assumed jointly by Meyer Werft and Fraunhofer IAPT.

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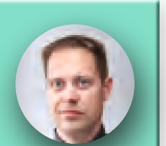
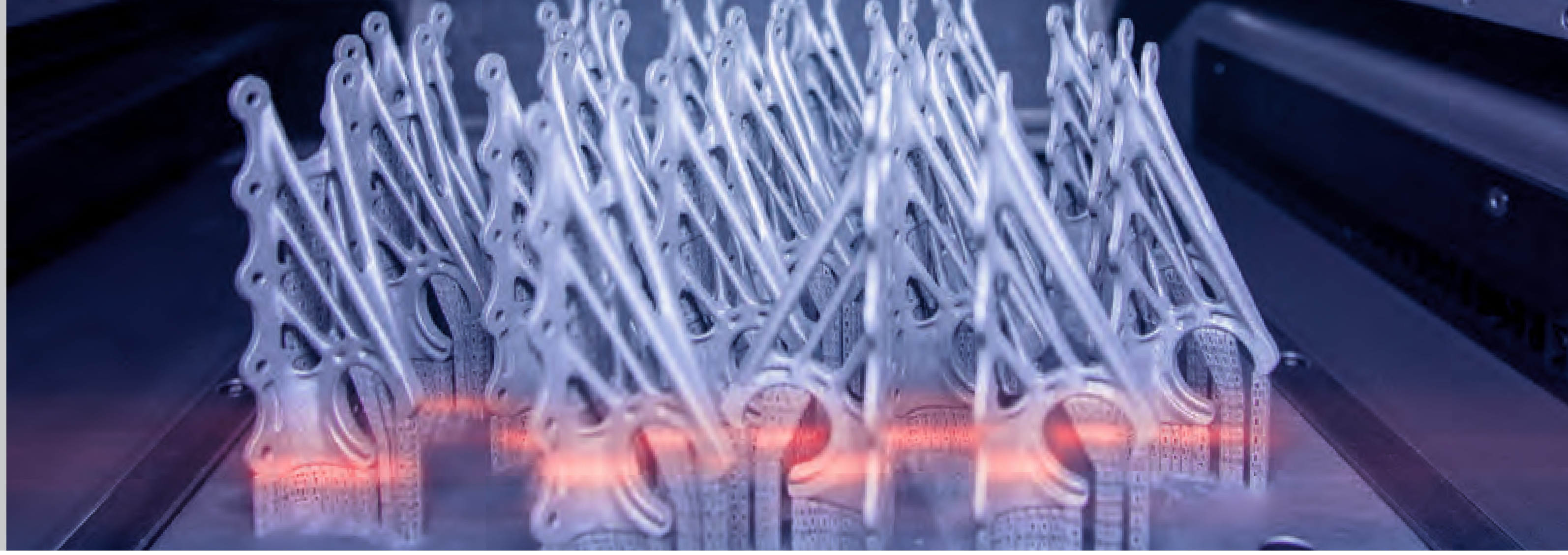
CONTACT
Olaf Steinmeier
+49 40 484010-622
olaf.steinmeier@iapt.fraunhofer.de



QUALITY ASSURANCE AND CERTIFICATION

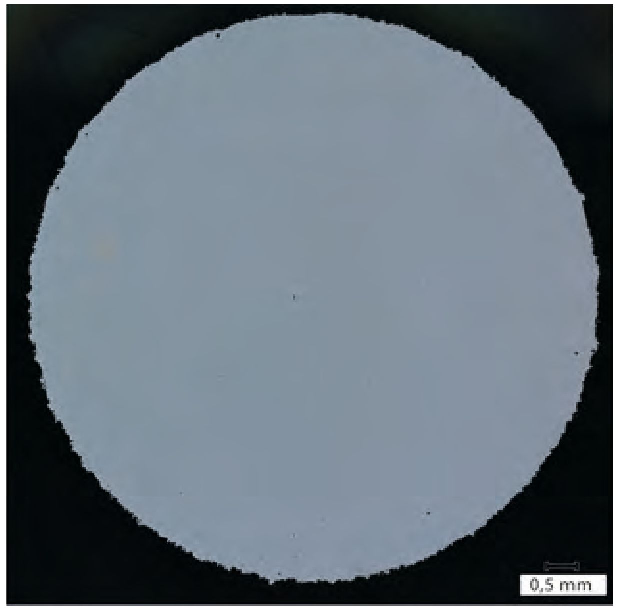


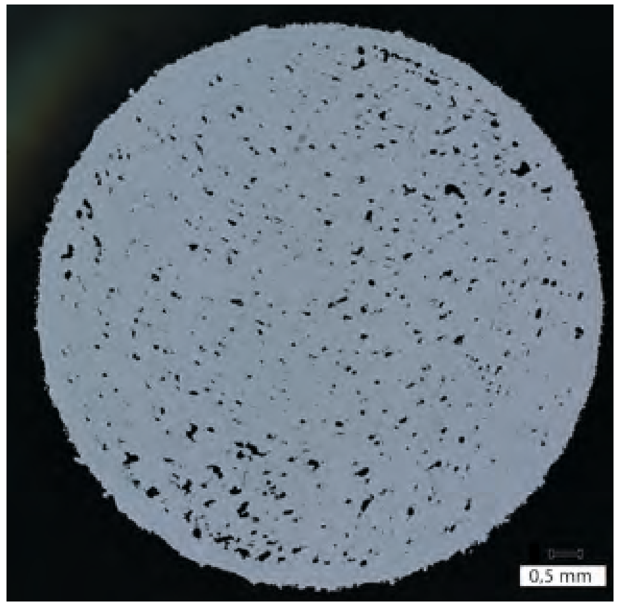
IN-PROCESS QUALITY ASSURANCE

Quality assurance in additive manufacturing is a critical barrier to the broader use of the processes in industry. The Quality Assurance and Certification Group at Fraunhofer IAPT brings advanced technologies and state-of-the-art QM methods together to develop industry-relevant solutions for the qualification and certification of AM components and processes. We offer our customers and business partners an independent and impartial assessment of quality assurance methods and technologies for the additive manufacturing industry.

The key to quality: Process reliability

An additive manufacturing process is influenced by over 120 different parameters. The identification of those parameters that significantly affect the quality of AM components is a decisive step in the implementation of a stable manufacturing process. It must be capable of producing the desired mechanical parameters in the components, reliably and with high repeatability. Extensive research in recent years has enabled us to identify the most significant quality-relevant parameters in powder-bed-based additive manufacturing. This was made possible through implementation of the latest sensor systems and data processing with advanced statistical methods such as Six Sigma. One of the main goals of the Quality Assurance and Certification Group at Fraunhofer IAPT is to broaden the level of knowledge in this area. The latest insights are applied in a targeted manner to minimize process uncertainties that lead to quality-critical problems in AM components.





Achieving efficient quality assurance

Process monitoring plays a key role in efficient and economical quality assurance. The Quality Assurance and Certification Group at Fraunhofer IAPT develops solutions for the direct identification of critical component defects during the manufacturing process and, on this basis, corrects them or interrupts manufacturing processes.

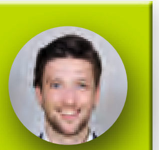
The efficiency of different sensor-based process monitoring systems and their specific advantages and disadvantages have been successfully proven in numerous projects. Following a comparison of monitoring data with retrospective component inspections (e.g. using X-ray and CT technology), correlations are developed between monitoring data and defects and continuously improved.

This comprehensive know-how allows us to provide our customers with tailored solutions for the quality assurance of their AM processes.

Quality standards and certification

Quality standards and certification are decisive factors in broadening the distribution of AM technologies in the manufacturing industry. As a member of important bodies involved in standardization of the AM process (e.g. DIN and ISO), the Quality Assurance and Certification Group at Fraunhofer IAPT helps in the development of the latest industrial standards for the quality of AM components. Moreover, the group also works on the development of methods for the certification of additive manufacturing processes and parts.

CONTACT
Peter Lindecke
+49 40 484010-730
peter.lindecke@iapt.fraunhofer.de



ADDITIVE QUALITY MANAGER

QUALITY ASSURANCE THROUGH DIGITIZED DATA MANAGEMENT

The complex additive manufacturing process is influenced by over 130 different process parameters. Along the entire process chain, from powder production to post-processing, these parameters all contribute to component quality.

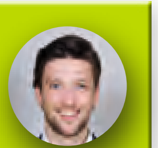
It is therefore critical for quality-assured and certified production to recognize, measure, and analyze these significant parameters. The Additive Quality Manager (AQM) developed by Fraunhofer IAPT ensures that data is collected, stored, and analyzed efficiently. All relevant sensor and metadata from the manufacturing system and the entire factory is saved automatically to a secure local server where it is centrally accessible and made available for analysis.

Software and hardware from AQM offer users a dynamically expanding database for securing, interpreting, and documenting central process data. Aided by statistical analyses (Six Sigma) and machine learning, process capability can be continuously improved on the basis of the database, as process deviations can be identified and corrected at an early stage. Reject components are reduced to a minimum as a result.

The ergonomically optimized web interface facilitates efficient data management on all common media, meaning the status of AM machines can be checked at any time, regardless of the location. As accessing of live data is possible, statistical process control can be implemented via alerts on the user's device.

The combination of automated process monitoring and process analysis is the key to sustainable assurance of process capability in additive manufacturing and will simplify your quality assurance considerably.

CONTACT
Peter Lindecke
+49 40 484010-730
peter.lindecke@iapt.fraunhofer.de



ECOLOGICAL SUSTAINABILITY THROUGH ADDITIVE MANUFACTURING

CO_2 REDUCTION – ADDITIVE ADDED VALUE VERSUS CASTING AND MACHINING

The reduction of CO_2 emissions is one of the most important climate policy goals and crucial if global warming is to be limited. Additive manufacturing can contribute in this respect.

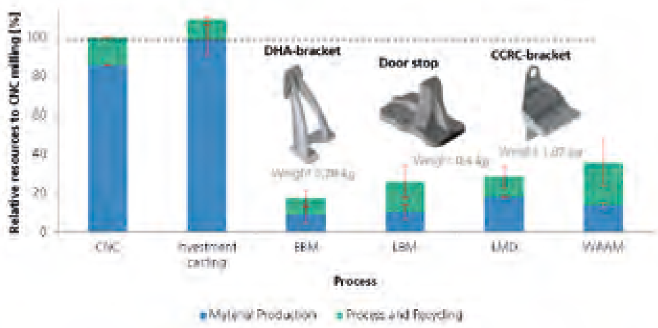
In the course of a study involving three typical aviation components, Fraunhofer IAPT compared the CO_2 footprint of manufacturing routes involving milling, investment casting, electron beam melting, selective laser melting, laser powder cladding, and laser wire buildup welding. The respective manufacturing sequence is first shown in detail, with each process step assigned the energy consumption per kilogram of the finished part and multiplied by the corresponding CO_2 footprint for the energy input. The energy consumption arises from the following possible manufacturing steps:

- Raw material production
- Shaping (forging, powder/wire production)
- Auxiliary material production (casting molds/AM build plates)
- Process preparation and actual process (milling, casting, AM)
- Post-processing (heat treatment, sand blasting, eroding, milling)
- Final processing (milling)

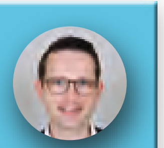
A direct comparison of the ecological balance sheets for conventional and additive manufacturing processes with selected components in the aviation industry delivered the following results. The recycling of components was also taken into consideration in this context.

The study illustrates the positive contribution additive manufacturing makes to CO_2 reduction. When compared to milling and casting, CO_2 emissions in all AM processes can be reduced by at least 50 percent. The most important driver in this respect is the close-to-final-contour manufacture of the components. This means that the amount of starting material used is insignificantly greater than the material the finished component later contains. Conversely, milling removes a high level of raw material from a solid basic body in the form of chip material. With 46.5 kilograms of CO_2 per kilogram of component, primary production of the starting material has a particularly severe effect on the volume of CO_2 generated in creation of the product. By comparison, milling produces 7.38 kilograms of CO_2 per kilogram of component, with powder atomizing generating 3.12 kilograms per kilogram.

Further additive manufacturing potential for reducing CO_2 results from the use of components in aircraft. The design freedom of the process means that considerably lighter components can be manufactured with the same properties.



CONTACT
Frank Beckmann
+49 40 484010-620
frank.beckmann@iapt.fraunhofer.de



TEACHING

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ADDITIVE ENGINEER PROGRAM INCL. 3D LAB

FOR THE ADDITIVE FUTURE OF TOMORROW

TUHH
Technische Universität Hamburg

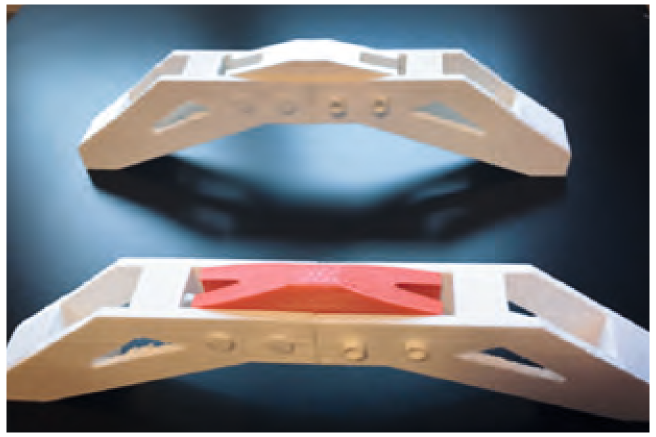
Additive manufacturing needs well-trained personnel, and Fraunhofer IAPT is cooperating closely with the Hamburg University of Technology (TUHH) in order to meet this demand in future.

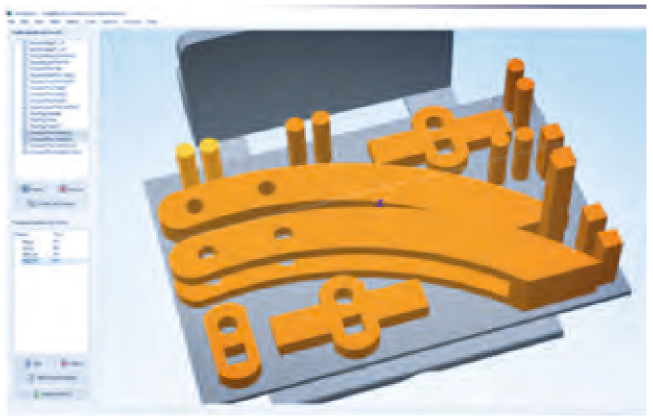
In addition to imparting a fundamental understanding of technology, the emphasis here is on practical experience. Students learn to design components for additive manufacturing and are directly involved with the technology through different practical laboratory courses and projects.

Participants are bachelor's and master's degree students of engineering science, industrial engineers, and students of commercial and technical sciences who, as vocational school teachers adopting a "train the trainer" approach, go on to educate and train young newcomers, particularly in the area of metal technology professions.

The cooperation during the apprenticeship includes courses such as Introduction to 3D Printing, Additive Manufacturing, 3D Printing Laboratory, Laser System and Process Technology, and Welding. Assignment examples include designing components for the fused filament fabrication process (FFF process), which must meet prescribed criteria. Students work in small groups and have to organize themselves to complete the task during limited lab time.

Lectures bring the students into contact with Fraunhofer IAPT. They can also write their project and final theses at Fraunhofer IAPT, giving them the opportunity to deepen their knowledge of additive manufacturing.





WELDING ENGINEER PROGRAM

WELDING ENGINEER TRAINING COOPERATION

Welding engineers oversee the construction of welded structures in all areas of application to ensure that high quality requirements are met. From the design phase to production, engineers with special welding knowledge are required to handle the extensive tasks involved in the construction of bridges, pressure vessels, high steel structures, vehicles, and other projects. Within the framework of a cooperation with the GSI SLV Nord, Fraunhofer IAPT and the affiliated Institute of Laser and System Technologies (iLAS) of the Hamburg University of Technology (TUHH) are actively involved in the training and education of these specialists. Students of the TUHH have the chance during these studies to opt for a second postgraduate academic degree with international recognition and to complete parts of the welding engineer program within the framework of the university course under Prof. Emmelmann.

GSI SLV Nord also recognizes the extensive welding experience of Fraunhofer IAPT, so the knowledge and skills of numerous Fraunhofer IAPT employees are drawn upon in different courses of the welding engineer program and scientific personnel are employed as lecturers. Different welding processes with relevant requirements in the context of material properties and welding design calculations are discussed from the design phase through to practical application examples in day, evening, or weekend courses. Additive manufacturing technologies are also discussed as part of the course. In conjunction with excursions to Fraunhofer IAPT, theoretical and practical knowledge is imparted at first hand and the latest developments in additive manufacturing are demonstrated directly on the machines.

VDINI CLUB

ADDITIVE SPARE PARTS FOR FUTURE ENGINEERS

The VDIni Club takes advantages of numerous opportunities to present companies, technologies, and experiments with a view to getting children interested in technology and science at an early age. Fraunhofer IAPT itself had the chance to awaken the interest of a few VDInis in additive manufacturing at the beginning of February.

The broken axle suspension on one participant's longboard provided the background to the meeting. It proved impossible to find a replacement, even after intensive research. A suitable part was manufactured with the aid of metal 3D printing, meaning the longboard can now be freely used again.

Instead of presenting the "young engineers" of the VDIni Club with the replacement part without any explanation of where it came from, the decision was taken to hold a workshop in which they could see at first hand how the component was made. This workshop addressed the entire process chain, from recording the geometric data, design, and preparation of the component to the manufacturing process itself.

The members of the VDIni Club were particularly thrilled and enthusiastic about the 3D design of the replacement part. They were able to develop its design themselves under supervision, learning about common CAD software during the process. Fraunhofer IAPT was delighted to host these inquisitive guests and wishes them the very best in their future technical careers – and many, many more rides on the longboard.

PUBLICATIONS

80 Best Paper Award, 27th CIRP Design Conference
81 Doctorates and Published Theses

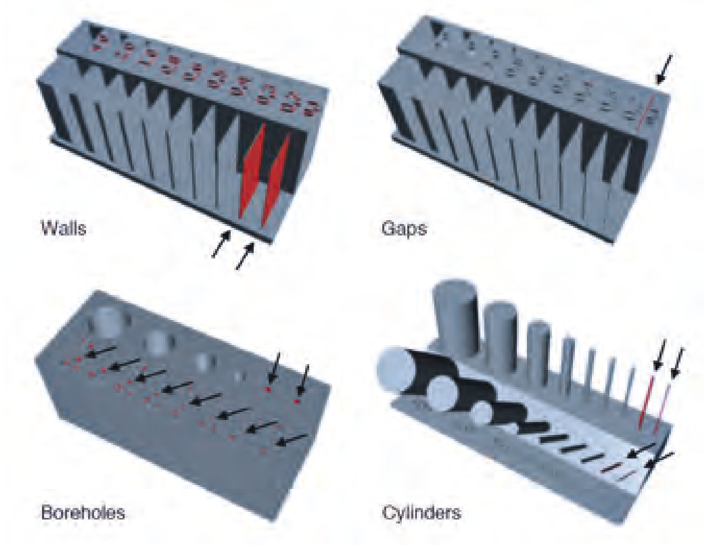
BEST PAPER AWARD, 27TH CIRP DESIGN CONFERENCE

The 27th CIRP Design Conference | *Jan-Peer Rudolph and Prof. Claus Emmelmann*
Analysis of Design Guidelines for Automated Order Acceptance in Additive Manufacturing

When compared to conventional manufacturing technologies, such as milling and casting, additive manufacturing offers a high degree of design freedom. Nevertheless, some manufacturing restrictions and design guidelines still have to be considered to ensure flawless production. In recent times, guideline catalogs have been developed for the design of additively manufactured components. However, the analysis of component geometry with regard to these guidelines still requires a lot of manual work and comprehensive expert know-how.

In particular, print service providers, who receive a broad spectrum of different design data from their customers for manufacture, are faced with a costly and time-consuming task in this respect. In addition, the preparation of offers also poses a problem, as the exact component costs depend on a variety of factors, including build space utilization, the support structures needed, and post-processing steps which, in turn, depend on the orientation of the component relative to the build platform.

For this reason, Fraunhofer IAPT has set itself the task of automating this part screening. Fraunhofer IAPT develops software solutions in this context for the algorithmic testing of design guidelines, to optimize component alignment, and for the automated creation of offers. In the course of these efforts, Jan-Peer Rudolph and Prof. Claus Emmelmann from Fraunhofer IAPT won the Best Paper Award of the 27th CIRP Design Conference for the paper "Analysis of Design Guidelines for Automated Order Acceptance in Additive Manufacturing" in recognition of their outstanding scientific contributions in this field.



DOCTORATES AND PUBLISHED THESES

2019 | Doctorates/Published theses | *Christian Daniel*
Laser beam removal of cubic boron nitride for final processing of cutting tools

Steels with a high level of strength and hardness harbor potential for lightweight construction, but are regarded as difficult to machine. Special cutting tools made of cubic boron nitride are among the solutions employed to address this. Laser beam removal offers fresh potential for the final processing of tools of this kind.

ISBN: 978-3-662-59273-1 | DOI: 10.1007/978-3-662-59273-1

2018 | Doctorates/Published theses | *Jan-Peer Rudolph*
Cloud-based exploitation of potential in additive manufacturing

A method for exploiting the potential of additive manufacturing through a cloud-based platform solution is presented in this paper. This enables enterprises and private users to exploit efficient application cases rapidly and with a high degree of validity.

ISBN: 978-3-662-58263-3 | DOI: 10.1007/978-3-662-58263-3

2018 | Doctorates/Published theses | *Vanessa Seyda*
Material and process behavior of metal powders in laser additive manufacturing

The suitability of different gas and plasma atomized powder materials from the titanium alloy Ti-6Al-4V for laser additive manufacturing was investigated. This paper succeeds in broadening understanding for the material and process behavior of metal powders, and this can be exploited to evaluate and ensure the quality of powders used in laser additive manufacturing.

ISBN: 978-3-662-58233-6 | DOI: 10.1007/978-3-662-58233-6

2018 | Doctorates/Published theses | *Markus Möhrle*
Design of factory structures for additive manufacturing

Additive manufacturing processes are on the threshold of industrialization. This results in a practical need for efficient and effective process chains for the manufacture of components of final quality. This paper addresses the need to design efficient factory structures and the necessity to further increase productivity.

ISBN: 978-3-662-57707-3 | DOI: 10.1007/978-3-662-57707-3

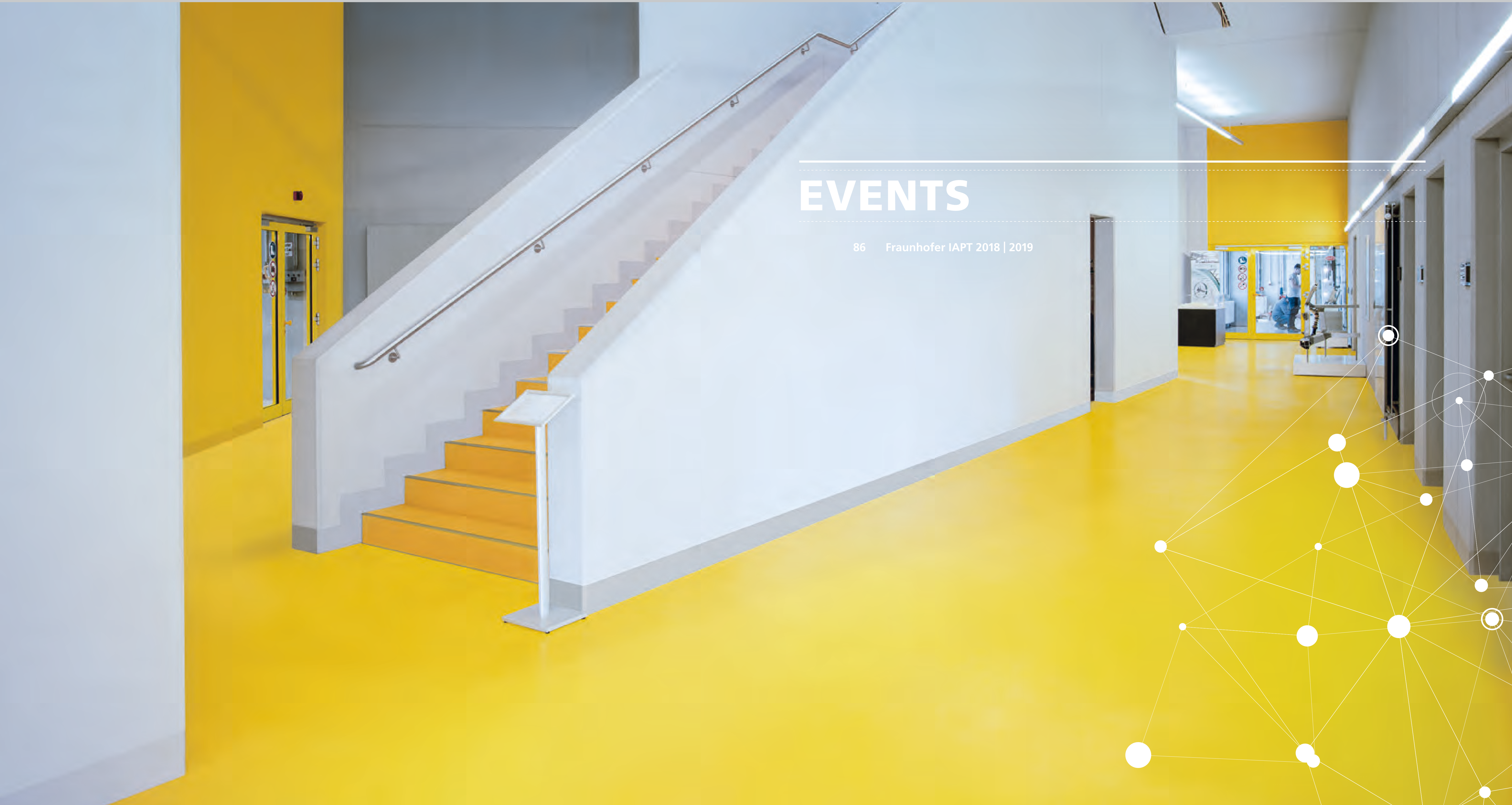
2018 | Doctorates/Published theses | *Marten Canisius*
Process quality for laser cutting of carbon-fiber-reinforced plastics

High manufacturing costs associated with, among other things, the drilling, cutting, and trimming of carbon-fiber-reinforced plastics have to date hindered widespread industrial use. This paper assesses a variety of laser-based approaches to cutting based on achievable qualities and costs and indicates paths to an optimized processing strategy.

ISBN: 978-3-662-56207-9 | DOI: 10.1007/978-3-662-56208-6

Franz-Herbert-Spitz-Preis | *Christoph Scholl*
Master thesis title: Optimization of the calibration of sensor robot systems

Winner of the Franz-Herbert-Spitz Award for the best master thesis of the master programs in the Department of Mechanical Engineering and Production Management at the Hamburg University of Applied Sciences (HAW Hamburg).



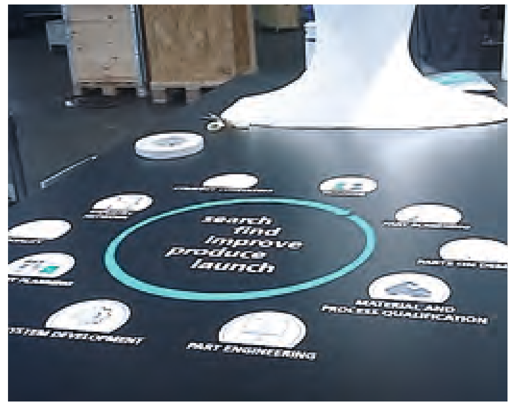
EVENTS

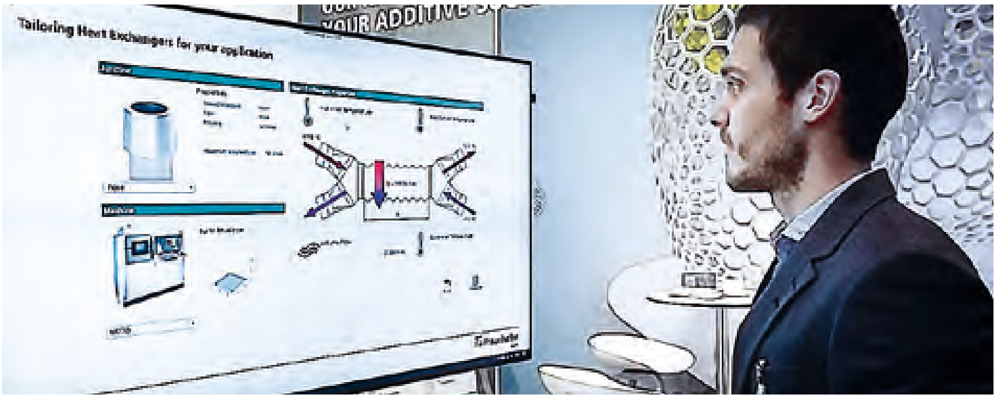
ADDITIVE 2018/WELCOME FRAUNHOFER IAPT

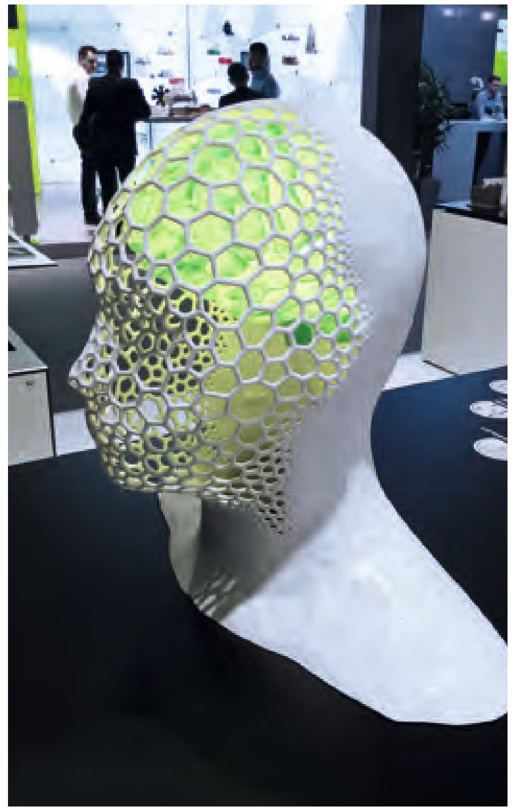
Fraunhofer IAPT was established early in 2018 as a specialist research institution for additive manufacturing technologies, meaning the Free and Hanseatic City of Hamburg gained its first independent Fraunhofer institution. Under the motto "Creating Future Layer by Layer", the grand opening was held on January 25 in the Cruise Center on the Hamburg Fischmarkt, with over 500 invited guests in attendance. Neither the Deputy Mayor of Hamburg and Senator for Science, Katharina Fegebank, nor the Senator for Economic Affairs, Frank Horch, wanted to miss the opportunity to welcome Fraunhofer IAPT personally.

In a particular highlight of the evening, Bugatti presented the first additively manufactured brake caliper, an innovation it developed together with Fraunhofer IAPT. It stands out thanks to its individual bionic design and has established 3D printing technology in automotive series production (see also page 24 and 25). The scientific element of the event was the two-day Additive 2018 conference organized by Fraunhofer IAPT, at which the most significant innovations in the area of additive manufacturing were presented in specialist lectures. In addition to experts from Fraunhofer IAPT, lectures by representatives of notable industrial companies such as Airbus, Baker Hughes, Deutsche Bahn, and Volkswagen attracted great attention, encouraging cross-sector and practical presentations of a broad spectrum of new 3D printing applications and stimulating discussion thereof.

TRADE FAIR IMPRESSIONS







Editorial notes

The Fraunhofer Research Institution for
Additive Manufacturing Technologies IAPT

Am Schleusengraben 14
21029 Hamburg-Bergedorf
Germany
Phone +49 40 484010-500
Fax +49 40 484010-999
www.iapt.fraunhofer.de
info@iapt.fraunhofer.de

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Fraunhofer-Gesellschaft zur Förderung
der angewandten Forschung e. V.
Hansastrasse 27 c
80686 Munich
www.fraunhofer.de
info@zv.fraunhofer.de