Fraunhofer

NEWS 1.21

COMPETENCE FIELD ADDITIVE MANUFACTURING

EXPRESS WIRE COIL CLADDING

AM OF STEEL AND PURE COPPER

NEW SYSTEM FOR METAL BINDER JETTING

ULTRAFAST 3D PRINTING

EDITORIAL

Dear Readers,

You may have noticed the changes on our cover! Since the beginning of 2021, we continue our work as **Fraunhofer Competence Field Additive Manufacturing** (Fraunhofer ADDITVE). The expertise of 18 Fraunhofer institutes in 3Dprinting in its scientific entirety is bundled within our network and this newsletter informs you about our latest research projects and activities.

Our last newsletter was published a year ago and a lot has happened since. Due to the corona pandemic, we had to convert our **Fraunhofer Direct Digital Manufacturing Conference** (DDMC), which was scheduled in March, into a virtual format on short notice. As a result, we held the 5th DDMC on 23 June 2020 as an all-digital event. The conference was broadcast and moderated live from the Fraunhofer Forum in Berlin, with almost 20 speakers dialing in live from all over the world. It was an exciting day with four keynotes by distinguished representatives from industry, short pitches by the 10 best paper authors, lively panel discussions and award ceremonies. Please visit the DDMC website and watch our review video clip.

In 2021, we have once again our own **Fraunhofer Expert Forum at Rapid.Tech.** On June 22 please join the Rapid.Tech for six exciting Fraunhofer presentations all focusing on sustainability.

But now please take your time to enjoy the articles in this newsletter on latest topics from Fraunhofer research, e.g. how adaptive processing strategies improve build part accuracy, sensor integration or AM of steels or cooper. Please find an overview of all contributions in the table of contents and enjoy reading.

Dr. Bernhard Mueller
Spokesman of the Fraunhofer Competence Field Additive Manufacturing

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Content

Fair Activities

Rapid.Tech

rapid.tech 3D CONFERENCE EXHIBITION NETWORKING

The competence field will again offer its specific expert forum at the Rapid.Tech: Six Fraunhofer institutes will present the latest research results associated with sustainability – the congress's focus. For instance, topological optimizations will be presented in laser powder bed fusion (PBF-LB/M) and in binder jetting (BJ). In addition, presentations will be given on reducing process times and energy consumption through additively manufactured and functionalized ceramic components. Furthermore, sustainability in metal 3D printing in a production environment will be presented as well as additive manufacturing using copper, and quality assurance will be illustrated in additive laser powder bed fusion (PBF-LB/M).

Rapid.Tech
Erfurt, Germany
June 22 and 23, 2021
Fraunhofer Expert Forum on June 22

formnext 2021 - where ideas take shape

formnext

International exhibition and conference on the next generation of manufacturing technologies
Frankfurt, Germany,
16 – 19 November 2021

The formnext – as the leading global exhibition and conference on additive manufacturing and the next generation of intelligent industrial production – will take place from 16 through 19 November 2021 in Frankfurt, Germany.
The fair is the leading exhibition with accompanying conference dedicated to additive manufacturing and all of its pre- and post-processes.

Please visit us on the Fraunhofer joint booth!

formnext
Fraunhofer joint booth
Frankfurt, Germany
November 16 - 19, 2021

New way of Additive Manufacturing for rotationally symmetrical parts

A team from the Fraunhofer Institute for Production Technology IPT has developed the new Additive Manufacturing process "Express Wire Coil Cladding" (EW2C) for the surface processing of shafts. EW2C saves both resources and costs and is thus an alternative to conventional ablative processes, such as turning, for machining shafts.

Express Wire Coil Cladding is a wire-based Additive Manufacturing process that uses a laser to build up a component or structure by joining metallic materials layer by layer. Unlike traditional wire-based Laser Metal Deposition (LMD-w), the material is not continuously fed as wire. Instead, the wire is initially wound into a spiral slightly smaller than needed on a commercial spring coiling machine. Afterwards, the spiral is put to the desired position on the shaft, where it is then welded with a high-power laser. Since the wire spirals are placed on the shaft with a press fit, they cannot slip or move during the laser process.

Material mix and rapid structure buildup

Investigations carried out over the past months have made the scientists of the Fraunhofer IPT confident: Pre-positioning wire spirals improves process stability compared to conventional wire-based Laser Metal Deposition, as the former process prevents unwanted movements of the awire during the cladding process. The researchers were also able to prove that the EW2C process is very well suited for depositing larger layer thicknesses: In a single layer, they were able to apply between 0.5 and 2 millimeters of material, depending on the wire material and diameter. They found that their process can keep pace with the cycle times for conventional turning: In the test series, welding a 25-millimeter-high spiral of Inconel 718 with a 1.2-millimeter wire diameter onto a steel shaft with a 35-millimeter outer diameter took less than 60 seconds. In future, deposition rates above 14 kilograms for steel and Inconel wires will be achievable.

Figure 1: From right to left: positioning, cladding and finishing

By repeating the steps, the researchers were able to apply several millimeters of material quickly. Even multi-material combinations are possible as a result: Not only geometries can be built, but also the component surface can be technically functionalized.

Further developments for solid shafts, hollow shafts and thin-walled tubes

In order to improve the new process, the team around Robin Day is working on optimizing process stability and automating the process: Various devices for automated positioning of the wire spiral on the shafts are already being tested. "To increase the process speed, we are experimenting with enlarging the focal spot geometry and thus irradiating and melting several spiral coils at the same time," explains Robin Day. In addition, highly complex volume elements are to be applied to shafts in the future by combining different spiral lengths and other wire materials. To this end, the researchers are testing the suitability of the process for both solid and hollow shafts and thin-walled tubes.

Figure 2: EW2C utilizes local shielding gas to ensure high cladding quality

Thanks to integrated sensor technology in the existing machine environment at the Fraunhofer IPT, various additional data can be recorded during the process and further processed using artificial intelligence. This data will form the basis for modeling and actively controlling the EW2C process for different materials and process parameters.

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Additive Manufacturing of Pure Copper

Pure copper exhibits a huge potential for generating complex functional parts with excellent thermal and electrical properties. Researchers at Fraunhofer IWS are focusing on novel AM approaches using green laser sources and sinter technologies to realize copper parts with outstanding performance.

Additive Manufacturing (AM) using pure copper exhibits a huge potential for generating complex functional parts with excellent thermal and electrical properties. Fraunhofer IWS is focusing on novel AM approaches using green laser sources and sinter technologies to realize pure copper parts with outstanding performance.

Introduction

Creating sophisticated parts with AM is no longer an exotic technique and has been established in various industries and even in consumer applications. This is still not the case for copper parts. As a key-material in thermal applications and electrical engineering, copper is an important element for countless components and has contributed significantly to the fast technological evolution of the last 200 years. Its optical appearance however made it difficult to process with established laser based technology. In particular additive manufacturing of pure copper parts is challenging due to its low absorption of regularly used infrared laser radiation. Even if the use of copper alloys could help solving this issue, the inherent electrical and thermal properties of the material are dramatically worsened.

Hence, without an advanced AM approach pure copper defect free parts seem out of reach. Based on new developments in laser sources as well as in AM technologies, Fraunhofer IWS has succeed in manufacturing pure copper by three different AM processes, each providing specific benefits, from micro to macro dimensions.

Laser Powder Bed Fusion (LPBF)

With the well-known LPBF, high resolution complex shaped parts with functional integrations such as inner cooling channels can be manufactured. The latter yield huge potential for efficient heat exchangers made of pure copper. To overcome the poor absorption of typically used infrared laser sources, increasing the laser power is one option to enable a selective melting of the powder. However, this shows specific

Figure 1: Pure copper benchmark geometry (left), microsection of 99,98 % dense sample (middle), mi-crostructure of LPBF pure copper (right)

disadvantages, like small overall efficiency, balling due to high energy input and possible damage of the optics system due to large backscatter of laser light. Switching to a green laser source with a wavelength of 515 nm and 280 % higher absorption results in overall better efficiency and leads to fully dense parts (99,95 % relative density) with exceptional good electrical conductivity (> 100 % IACS, International Annealed Copper Standard).

Binder Jetting (BJ)

Due to its high throughput and its separated shaping and thermal post-treatment process, binder jetting has the potential to outperform other AM methods. Additionally,

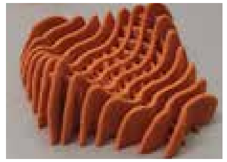

Figure 2: Printed heat sink made of pure copper by binder jetting

densities after sintering can even reach up to 97 %. Considering that there is no linear correlation between density and electrical conductivity for pure copper, recently achieved 85 % IACS is encouraging. The main challenge concerning this technology is to achieve dimensionally accurate parts during densification. Further developments in increasing the powder bed density and powder sintering characteristics are expected to lead to an enhanced performance the near future.

Laser Metal Deposition (LMD)

Laser Metal Deposition is a well-established technology for coating and repair of metal components since more than a decade. In the last years it have been also utilized to build-up metallic parts from micro to macro scale. Using a 1 kW green laser source and specialized processing heads pure dense cooper parts could be build up on substrates as well as complex semi-products. In contrast to powder bed based additive manufacturing, LMD enables hybrid manufacturing (additive, subtractive) approaches and multi-material processes in new dimensions. Various powders could be applied, exchanged and mixed up in situ to achieve multi material components with localized material properties. The latter

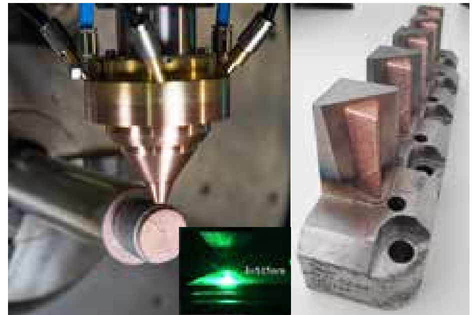

Figure 3: Laser Metal Deposition with green laser to build up multi material mould inserts (pure Cu / steel 1.2764)

recently was applied to significantly increase the performance of mould inserts by the local implementation of copper features and thus reduced cycle times. In further developments, the essential intermediate and final machining could be fully incorporated in the LMD process chain, resulting in production tools ready for industrial use.

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Build part accuracy improvement of additively manufactured components by adaptive processing strategies

One of the major challenges in Laser Powder Bed Fusion is the quality improvement of additively manufactured parts. Build part quality comprises, amongst others, geometric accuracy, surface roughness and detail resolution. In many cases, the build part quality is deteriorated by melt pool flows resulting in irregular solidified contour shapes and powder particles sintered to the surface. These phenomena increase with increased melt pool size.

Within the publicly funded research project "**I**ndustrialization of **D**igital **E**ngineering and **A**dditive Manufacturing" (IDEA) researchers from Fraunhofer ILT investigate and adaptive processing strategy for nickel-base alloy Inconel 718 for large scale components. For this purpose, a modulated pulsed-wave

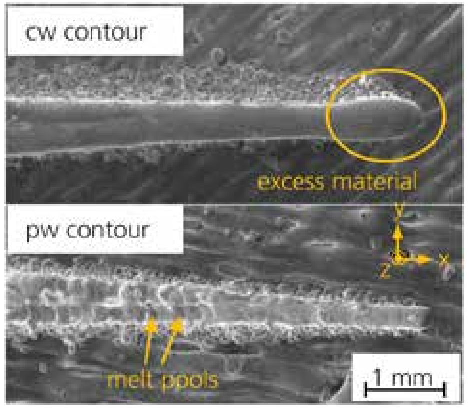

Figure 1: Sharp angled contours exposed in cw and pw emission mode. Pw contours show increased accuracy and discretely solidified melt pools compared to cw exposure.

(pw) laser beam source was used, which can be operated in both continuous wave (cw) and pw emission mode. Whilst the bulk volume of the build part is exposed in cw mode, pw emission is used for the outer

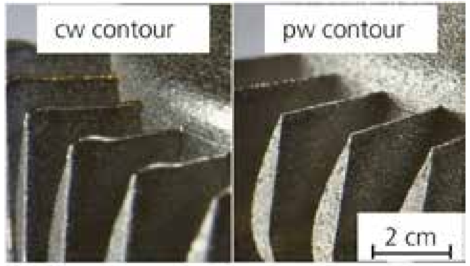

Figure 2: Turbomachinery part manufactured with cw (left) and pw (right) contour exposure

contour exposure. Due to the discrete energy deposition in pw mode, discrete and smaller melt pools, which partially overlap, are created. Smaller melt pools result in reduced melt pool dynamics, hence in reduced geometric deviations, and sintered powder and thus part accuracy is enhanced.

In a first approach, critical part regions, e.g. sharp contour angles, overhangs and small details are identified and adaptive processing strategies for the critical regions are developed afterwards. In figure 1, SEM images of sharp angled contours with a nominal angle of 5° are shown. The geometric deviation of the pw exposure is significantly lower compared to conventional cw exposure. Excess solidified material due to heat accumulation in the corners can be suppressed by use of pw exposure. As demonstrated in Figure 2 and Figure 3 this processing strategies can be applied to large scale industrial components.

Figure 3: Macroscopic view of a turbomachinery part manufactured with cw (left) and pw (right) contour exposure

Besides improvements in geometric accuracy as shown in Figure 1 and Figure 2, application of pw contour exposure can reduce the as-built surface roughness of large scale components compared to cw exposure. It is assumed, that - due to reduced melt pool flows – in average, smaller powder particles are sintered to the part surface. As a result, the measured arithmetic surface roughness Sa decreases. Thus, post processing such as sand blasting could be reduced. Moreover, reduced surface roughness can be favorable for non-machinable part regions, e.g. cooling channels.

As can be seen from figure 4, due to discrete solidification melt pool interface length increases significantly by use of pw exposure compared to cw exposure. Ongoing investigations examine, if these interfaces might be detrimental e.g. for static or dynamic mechanical properties. Due to the limited scan speed compared to cw emission, increasing pw process productivity is of special interest of future investigations.

The developed processing strategies can be applied for critical build part regions with high requirements for as built part accuracy. For Inconel 718, applications in turbomachinery components (figure 2) are promising.

In ongoing research activities, transferability of the results to alloy TiAl6V4 for aircraft components is investigated.

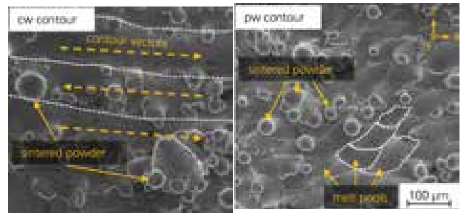

Figure 4: SEM images of cw and pw surfaces from areas indicated in figure 3. Melt pool boundaries are indicated as white dotted lines.

This research project has been publicly funded by the Federal Ministry of Education and Research within project **I**ndustrialization of **D**igital **E**ngineering and **A**dditive Manufacturing (IDEA), funding number 13N15001.

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Fraunhofer IFAM Dresden installs brand-new MoldJet® printing system

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Dresden is expanding its expertise in the field of sinter-based additive manufacturing with the new, innovative MoldJet® process. As the first European user of this system, invented by the Israeli company Tritone Technologies Ltd. in 2019, the institute is giving a new edge to additive manufacturing.

The MoldJet® technology is a synergy of two manufacturing processes. An organic mold is built layerwise with an inkjet process as a negative of the desired part. The remaining openings are filled with a water-based paste in a slot-die process.

Each layer can be different, enabling infinite variations in component shapes, including free-standing areas. Finally, the organic mold is removed, and the 3D-shaped green body is taken for heat treatment and sintering.

Each printed layer is checked by an inspection unit. Defects can be detected instantly, mechanically removed and the layer reprinted if necessary. This leads to low scrap rates, significant cost and materials savings and, overall, to an increased efficiency. Also, data on the printing process can be collected for continuous development.

New MoldJet® printing system at Fraunhofer IFAM Dresden

The MoldJet® process offers further great benefits compared to many other additive manufacturing processes:

MoldJet® is not only fit for small, filigree parts but large-volume components can be achieved, too. Due to the nature of the mold, the surface quality compares favorably to typical laser-based technologies. Internal channels as well as overhangs can be realized, both major challenges for additive manufacturing so far.

The technology is applicable across a vast range of materials. Any sinterable materials like stainless steel, pure copper, alloys based on nickel, titanium and refractories, even ceramics can be used.

The most significant advantage is the very high productivity of the process. Working with six trays for printing and six autonomous workstations, a productivity of up to 1,600 cm³/h can be achieved.

The new MoldJet® printing system was installed at ICAM®, the Innovation Center Additive Manufacturing. Here, Fraunhofer IFAM Dresden brings together its wide range of additive manufacturing processes and develops new solutions for materials and component geometries. Besides the new MoldJet® process, customers can profit from the possibilities of Selective Electron Beam Melting, 3D Screen Printing, metal based Fused Filament Fabrication and Gel Casting.

With its extensive technological possibilities and powder-metallurgical know-how, Fraunhofer IFAM Dresden covers the complete process chain from material development and printing to sintering and characterization.

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Additive Manufacturing of Plastic Components in a High-Speed Process Using Standard Pellet Stock

The SEAM process (screw extrusion additive manufacturing) takes a new approach to high-speed additive manufacturing of plastic components. With printing speeds of up to 1 m/s, it was developed by the Fraunhofer Institute for Machine Tools and Forming Technology (IWU) in cooperation with Metrom GmbH. The 3D printer is based on a combination of an extrusion-based plasticating unit that processes plastic pellets including fiber-reinforced material and parallel kinematics for rapid highly dynamic movements with accelerations up to 10 m/s^2 and very high positioning accuracy.

Figure 1: Penta SEAM new Metrom 5-axis parallel kinematic hybrid machining system

Thanks to its mechanical design, it can cross the limits of existing processes and establishes a new generation of 3D printing processes, which is eight times faster than conventional 3D printing. The SEAM process is very material efficient, since it allows components to be manufactured without supporting structures.

For this reason Fraunhofer IWU invested in a new hybrid machining system P 1400. The PentaSEAM system is characterized by a movable printing head with fixed build platform on top of a round table and a linear axis for enlarging the build chamber The construction results in a 5-axis parallel kinematic.

High Process Speed, Low Material Costs

In the SEAM process, output rates of up to 8 kg/h are generated, for example with a 1 mm nozzle. Since standard plastic pellets are processed instead of an expensive FLM filament, there is a huge material cost saving, e.g. a factor of 200, for PA6-CF. Different plastics, such as thermoplastic elastomers (TPU), PP and, as here, a PA6 with 40 % carbon fibers have already been tested. These are materials relevant for industry with high stiffness and strength, or high elasticity, which cannot be processed with conventional 3D printers. Because of the short manufacturing times, a closed material loop and the possibility of being able to subsequently subtractively process the components in one clamping (additive-subtractive hybrid manufacturing), the component costs can be reduced to a fraction, in particular for small series and prototyping.

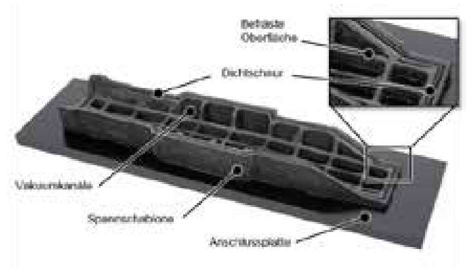

Figure 2: Vacuum clamping fixture of a B-pillar segment, manufactured by the SEAM process (©Fraunhofer IWU/IPA)

Typical Application: Fiber-Reinforced Vacuum Clamping Fixtures

CFRP components are generally manufactured with near-net-shape, so that they only need to be machined at the component edge and for functionalization, for example to introduce bores or recesses. Because of the usually open and large-area part design, they are very unstable and, despite the high stiffness, tend to oscillate, which has a negative effect on the tool life and part quality, for example the dimensional stability and edge quality.

In order to avoid such effects in the end processing, the development partners used the SEAM process to produce a special vacuum clamping device, for processing CFRP components, on which the parts lie in full contact and can be clamped with low vibration by means of vacuum. In the example shown here, this is a B-column segment with the dimensions 800 x 200 x 3 mm.

In general, the advantages of additive manufacturing lie in the fast and economic manufacture of individual end products, which permit the simple integration of functions such as vacuum fields or milling and suction channels. The targeted introduction of hollow structures additionally permits significant weight savings, which lead to greater material efficiency, shorter printing times, easier handling of the clamping means. The printed vacuum clamping fixtures can be recycled back to the starting material for reprocessing into plastic pellet stock after their useful life is over, so that the concept of a closed loop system can be applied and, on the other hand, the logistics chain is simplified. If there is subsequently a need for spare parts production, the shape can be rapidly and inexpensively recreated - there is no need to keep molds in storage for many years.

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Structurally Integrated Heatpipes

Development of the design concepts and process parameters for 3D-printed heat pipes in space (CubeSat) applications

Due to the rapid development of powerful electronic components for "new space" applications, the power and packing density and thus the demands on the structure and heat management are increasing. Furthermore, the available design space for heat conducting structures is often limited, especially in CubeSats, and requires complex shape designs.

A current research topic is the development of the design for a structural component of a 12-Unit nanosatellite to fulfil structural and thermal requirements. Several Fraunhofer institutes are working on improving the performance by exploring the potential of 3D printing. Structural optimization methods as well as integral design methods are investigated.

In order to keep the temperatures inside the nanosatellite within the operating limits, new and better ways of dissipating the generated heat are explored. For this application, new and unique design concepts benefit from the new freedom with 3D printing. The possibility to directly manufacture delicate and complex structures enables the production of a heat pipe, a two-phase heat transferring device.

The integration of heat pipes into the topology-optimised structural components of the satellite offers a promising approach to dissipate large amounts of heat without additional hardware, structural mass and volume occupation.

Additional to the integrational design freedom, also new functional concepts are explored. The complex capillary structure inside the heat pipe is essential for the fluid cycle and thus the effectivity of heat transport. Various design approaches such as axial grooves, porous sintered structures or mesh structures differ in capillary pressure as the driving force and flow resistance. With the great design freedom, the variation of manufacturing parameters and the combination of different structures, 3D printing offers a wide range of possibilities for the design and optimisation of the capillary structure. At the same time, the boundary conditions of the used material and working fluid as well as the manufacturing, cleaning and filling process have to be considered.

Complex shaped additive manufactured heat pipe sample © Fraunhofer EMI

The integration of the heat pipe usually requires curvatures, which also affect the manufacturability and function of the inner structure. In order to investigate these influences and challenges, the Fraunhofer EMI and Fraunhofer ISE are working on novel, manufacturable designs as well as on the development of process parameters for filigree and complex capillary structures for high-performance and integrated 3D printed heat pipes.

Besides the application of structural integrated heat pipes in CubeSat, further fields of application are high-power electronics, electromobility and other fields with high thermal requirements.

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Central database for AM process chains

Within Fraunhofer lighthouse project "FutureAM", technological leaps along the entire Additive Manufacturing (AM) process chain were achieved by bundling the competencies of four Fraunhofer institutes. The participating institutes have broad and in-depth technological knowledge and unique technical equipment in the field of Additive Manufacturing. The goal was to make this know-how available for digital use via a central data structure and to enable efficient collaboration between the institutes. For this purpose, a "Virtual Lab" was developed.

Based on the requirements, a distributed solution was implemented, consisting of the Virtual Lab (central) itself and several internal database instances (local). The Virtual Lab back-end is based on a comprehensive data model. The Virtual Lab front-end comprises of dashboards according to the core competencies of the four participating institutes, namely Part Management & Design (IAPT), Process & Machine Monitoring (ILT), Powder & Material Characterization (IWS) and Post-Processing & Acceptance (IWU).

Figure 1: Physical Part

Within the Virtual Lab each entity (machine, part, etc.) is assigned to a digital shadow with links to other entities. Via the Virtual Lab, the assignment of parts to machines (e.g. depending on machine workload), the adjustment of relevant process parameters in the production process (e.g. process route depending on machine availability) as well as the consideration of product (surface quality etc.) and production targets (throughput times, delivery times) are possible. In this way, an internal product memory is realized, whereby the required data is mapped along the product life cycle. Live data (e.g. sensor data) are queried during the manufacturing and post-processing processes using OPC-UA and published in the Virtual Lab via the institutes' database instances.

Figure 2: Digital part directory

The Virtual Lab can be used as a central database for the purpose of data management and data transfer along the entire AM process chain, forming the basis for efficient production planning and monitoring.

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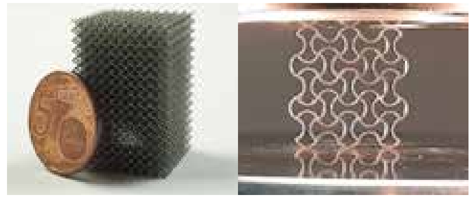
The Fraunhofer Cluster of Excellence Programmable Materials thrives for a paradigm shift in product design – with Additive Manufacturing as enabling technology

Programmable materials have the potential to initiate a paradigm shift since they can perform system functions through their internal design. This allows for increased functional integration while simultaneously reducing system complexity or even replacing technical systems of many components and materials with a single, locally configured one. Programmable materials are materials whose inner structure is designed and manufactured in such a way that properties and behavior can be controlled and reversibly changed. Furthermore, locally varying functions can be programmed into such materials.

Fully functional programmable materials require a combination of smart materials, mechanical and optical meta materials – and the ability to manufacture these architectured materials. The Fraunhofer Cluster of Excellence Programmable Materials (CPM) has started establishing Additive Manufacturing (AM) as a key enabler for Programmable Materials. At Fraunhofer IWU, Laser Powder Bed Fusion (PBF-LB) technology is being used to manufacture highly complex and extremely filigree lattice structures out of a nickel-titanium (NiTi) alloy – a smart material that can show shape memory as well as superelastic behaviour. Development and adaption of the PBF-LB process at IWU has enabled AM of programmable metal materials[1]. Researchers from Fraunhofer IWM and IZFP are underway to characterize the material properties of AM made NiTi lattice struts, helping colleagues from Fraunhofer EMI, ITWM and IWU to design a first type of a programmable metal material that features a programmed shift in structural stiffness during its deformation. In parallel, Fraunhofer IKTS, IFAM Dresden and IWU explore Fused Filament Fabrication (FFF) technology as an alternative route for AM of NiTi structures.



Additively manufactured NiTi structures: PBF-LB made lattice structure (left) and FFF made auxetic structure (right)

Further research within Fraunhofer CPM focuses on improving structural properties and on developing industrial use cases for additively manufactured programmable NiTi material.

[1] Gustmann, T., Gutmann, F., Wenz, F. et al. Properties of a superelastic NiTi shape memory alloy using laser powder bed fusion and adaptive scanning strategies. Prog Addit Manuf 5, 11–18 (2020). https://doi.org/10.1007/s40964-020-00118-6

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New possibilities in pressure-supported heat treatment at Fraunhofer IFAM Dresden

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Dresden is strengthening its technological expertise in the field of pressure-supported heat treatment with the new acquisition of a Quintus Hot Isostatic Press QIH 15L. This significantly expands the possibilities, which were previously focused on spark plasma sintering technology.

On the other hand, the new machine is also of enormous importance for additive manufacturing. For example, existing HIP treatments are to be optimized and adapted to additive manufacturing processes, which involves different microstructures compared to conventional manufacturing technologies. The HIP process is also to be combined with the additive manufacturing

New facility at Fraunhofer IFAM Dresden: Quintus Hot Isostatic Press QIH 15L | © Quintus Technologies AB

The researchers see the main areas of application for the new facility in, on one hand, the development of combined pro-cesses, i.e. heat treatment and hot isostatic pressing (HIP) for materials with complex heat treatment. Examples include nickel-based superalloys and intermetallic materials such as titanium aluminides.

process in order to significantly save process time here, for example.
Short distances are a big plus for developments, which is why the new system will be installed in the Innovation Center Additive Manufacturing ICAM® of Fraunhofer IFAM Dresden. Here, the institute bundles its various technologies for additive manufacturing. From selective electron beam melting and 3D screen printing to fused filament fabrication, gel casting, and MoldJet - the institute offers its customers a comprehensive portfolio for customized solutions from a single source.
Of course, the new system is not only used for R&D projects, but can also be used as a service for carrying out predefined HIP cycles.
Customers have access to a furnace chamber with a diameter of 170 mm and a height of 290 mm at a maximum pressure of 200 MPa and a maximum temperature of 1400 °C. The system is equipped with the URQ® technology, which enables the highest cooling rates of up to 10^3 K/min to be achieved. This makes it possible to carry out multi-stage heat treatments in the actual HIP process.

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Integration of printed electronics into LPBF parts

The collection of component condition data such as thermal and mechanical stress forms the basis for predictive maintenance, big data and AI approaches. Accordingly, components must be fitted with suitable sensors.

Additive manufacturing methods such as Laser Powder Bed Fusion (LPBF) offers a wide range of options for manufacturing application-adapted, lightweight, high performance components. In addition, laser-based coating approaches enable the additive build-up of the sensors themselves directly on to surfaces, e.g. through the wet-chemical deposition of electrically insulating and conductive materials using printing processes and subsequent thermal post-treatment using laser radiation. The Fraunhofer ILT combines these additive manufacturing methods, creating an innovative process chain that paves the way for the production of truly industry-4.0-ready components straight from the printer. The manual, labor intensive application of conventional sensors is no longer necessary.

The fully digitally manufactured component enables permanent component monitoring in the installed state to document the component load and to detect overload conditions. A telemetry system on a compact circuit board can be connected to the component, allowing an easy installation and wireless data transmission, making an according smart component ideal for both new developments as well as retrofit applications for existing systems.

Potential fields of application are classic areas such as transmission technology, large

Lightweight LPBF part with printed strain gauge and telemetry system

machines, power generation, rail vehicles and aerospace, in which predictive maintenance is already being used. In the future, the production of component and sensor in one step enables the development of new fields of application such as automotive, consumer electronics and toolmaking, in which condition monitoring used to be too time-consuming and expensive.

The demonstrator was produced in cooperation with i4M technologies GmbH.

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Additive manufacturing of milling cutter head made of bainitic steel

Additive manufacturing by means of laser powder bed fusion (LPBF) offers great potential for individual and flow-mechanically improved cooling channel guidance and nozzle arrangement in tools for machining. Due to the process-related geometrical freedom, there is almost unlimited flexibility in the development and manufacturing of components. However, with the few steel materials that have been qualified so far, the material requirements for milling cutter head cannot be met.

In collaboration with the Machine Tool Laboratory WZL at RWTH Aachen University, milling cutter heads with a flow-mechanically improved cooling lubricant supply are designed, additively manufactured from the bainitic steel to be qualified for LPBF and tested. First, a process window is determined by systematically varying the process parameters so that parts can be manufactured without defects (avoiding pores and cracks, for example) and with a high part density (> 99.5 %). In addition, the process parameters are apost-processing methods for internal cooling channels and outlet nozzles are investigated. This enables the production of milling cutter heads in a high number of variants. The focus is on deriving design guidelines for the design of additively manufactured milling tools from the collected findings. Promising results have already been achieved for bainitic steel regarding crack-free parts with a density > 99.9 % at hardness of 400 HV. Additive manufacturing with LPBF enables the reduction of tool weight by adapting the geometry (e.g. integration of lattice structures) as well as the integration of additional functions (e.g. complex cooling channels). Further areas of application for the investigated material are the automotive

Cut-outs of an additively manufactured milling cutter head made of bainitic steel (Design: Sumitomo)

industry and mechanical and plant engineering.

The research project is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) via the German Federation of Industrial Research Associations (AiF) e. V. as part of the programme to promote joint industrial research (IGF No. 21049 N).

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Additive manufacturing technologies for next-generation powertrains

A team from the Fraunhofer Institute for Machine Tools and Forming Technology IWU, together with project partners from Chemnitzer Zahnradfabrik, 3D-printpetrol and Fraunhofer IWS, addresses the prototypical development and implementation of an innovative and functionally integrated gear stage for next-generation electric vehicles, produced by using Laser Powder Bed Fusion (PBF-LB/M) and Fused Deposition Modeling (FDM) – cp. Figure 1. Two new design targets are being addressed by this approach:

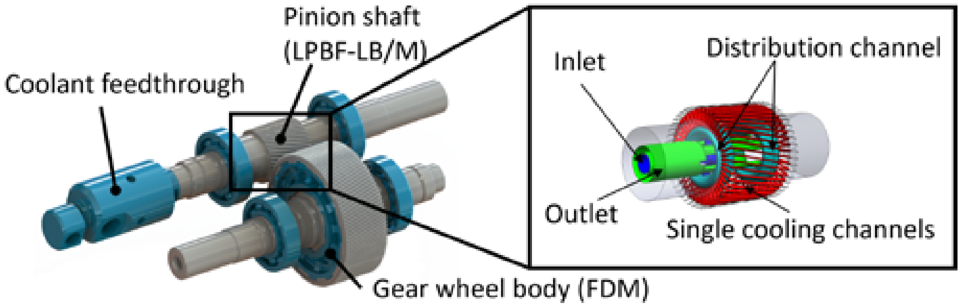

Figure 1: Overall design with coolant feedthrough at the pinion shaft (left); design of conformal cooling (right)

Oil-free operation is achieved by innovative coating of gear teeth, which enables virtually maintenance-free operation. Furthermore, a higher damping of sound transmission from tooth mesh tobearings is implemented by an optimal wheel body geometry that is realized by a combination of printable carbon-containing polymers (flange) and steel (gear rim). The innovative approach is to integrate design features into gear components that cannot be produced by milling and casting thus creating a significant benefit compared to state-of-the-art gearboxes. Functional integration, made possible by additive manufacturing, results in a very high component complexity. This is combined with gear grinding and ta-C surface coatings, ensuring maximum efficiency in dry operation to achieve economically viable production processes. The increase of the tooth mesh efficiency is achieved by optimization approaches in the design to minimize heat losses, while at the same time the best possible strength and lowest noise emission is being targeted.

For the design of the pinion shaft with cooling channels, fatigue strength analyses were performed using FEA. Critical notches due to structural weakness caused by individual cooling channels were detected in advance. Following the final design of the cooling channels, a CFD analysis was done to predict pressure losses and temperature development within the driveshaft. The boundary condition is a constant volume flow of the cooling medium at room temperature, which enters the

inlet and flows through the entire duct system up to the outlet. The simulation reveals that the pressure between inlet and outlet decreases by about 1.8 bar. This has to be considered prospectively, if the cooling is additionally connected to the rotor cooling of an electric vehicle. The temperature of the cooling fluid heats up by 9.5 K in this special load case. Figure 2 shows the temperature distribution of the critical cross section at the shaft's drive side. The tooth flank reaches a maximum temperature of 150 °C. The mass temperature of the shaft is about 90 °C. This prevents potential damage to the coating in the tooth mesh due to excessive temperatures.

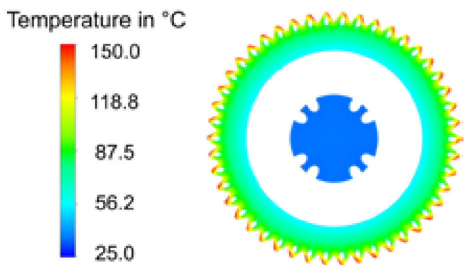

Figure 2: Temperature distribution of the critical cross section, based on CFD simulation

Based on the design and simulation of the new gear stage, prototype parts have already been produced using the above mentioned additive manufacturing processes. This enables proof of feasibility and quality of the components to be produced later. The prototypes created are shown in Figure 3. On the left side, PBF printed gears with the macro geometry of the pinion shaft are shown. After production, the gears were hardened and ground to achieve the required quality. The finishing of PBF printed gears did not show any noticeable

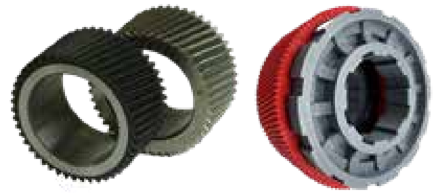

Figure 3: Prototype parts – PBF-printed and finished and coated test gear (left), extrusion printed gear body (right).

differences to conventionally manufactured gears. Subsequently, the gears were coated (see front gear in Figure 3, left), whereby a high surface quality could be proven with a measured coating thickness of 2.5 µm. Furthermore, the first test prints of the FDM wheel body have already been printed, which is shown in grey on the right in Figure 3. This wheel body is designed in two parts. It will later be connected to the steel gear rim and the output shaft.

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Venturing into new dimensions of 3D printing:
New system for Metal Binder Jetting put into operation at Fraunhofer IFAM Bremen

On September 11, 2020, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Bremen commissioned a new Metal Binder Jetting system. With a build volume of 25 liters, this 3D printer enables the gap to be closed between prototype production in quantities of one and tool-based large-scale production.

View into the new system for Metal Binder Jetting at Fraunhofer IFAM Bremen

In binder-based metal 3D printing, a cohesion of the powder particles is first created by imprinting a binder into a metal powder bed. Through layer-by-layer repetition, a three-dimensional, so-called green part is thus created. After printing, this is removed from the powder bed and then thermally post treated in a sintering furnace. Here, the final step to the finished metallic component takes place in one furnace cycle - through debinding and sintering.

Compared to other, for example laser-based 3D printing processes, significantly greater assembly speeds are realized with Metal Binder Jetting. In addition, the process allows the processing of materials that were previously impossible to process with other 3D printing methods, e.g. metal alloys that cannot be welded at all or that are difficult to weld.

"The continuing interest in industrial 3D printing as a supplement to conventional manufacturing processes has prompted us to invest in new plant technology here," says Claus Aumund-Kopp, group manager for additive manufacturing in the Powder Technology department at Fraunhofer IFAM in Bremen. "The 25 PRO system from the manufacturer ExOne represents an ideal extension of our existing capabilities," Aumund-Kopp continues. So far, three ExOne printers of the INNOVENT or INNOVENT plus type have been in operation at Fraunhofer IFAM in Bremen, on the one hand to optimize the system parameters towards robust process control, and on the other hand to broaden the range of materials for Metal Binder Jetting.

In addition to the operation of now four 3D printers for Metal Binder Jetting, metal powder analysis and handling has been part of Fraunhofer IFAM's activities for decades. In order to be able to evaluate and process the raw material metal powder, various devices for powder analysis and preparation are available. Finally, the extensive sintering furnace equipment completes the technical portfolio of the institute. Fraunhofer IFAM thus has comprehensive technical equipment and expertise along the entire process chain of Metal Binder Jetting.

In this respect, the Bremen location has all the prerequisites to allow users from industry and SMEs to experience and test the potential of this new plant technology at first hand, and to jointly develop it further for their needs. In particular, the technological proximity of the Metal Binder Jetting process to established powder metallurgical manufacturing processes such as metal powder injection molding (MIM) means that Fraunhofer IFAM can draw on extensive experience in the further development of Metal Binder Jetting.

With the new equipment technology, Fraunhofer IFAM, as one of the leading institutions in the field of metal powder-based manufacturing technologies, significantly complements its capabilities for basic and applied research in the field of sinter-based 3D printing.

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Improving Laser Metal Deposition by integrating coaxial coherence tomography

Laser Metal Deposition (LMD) is an Additive Manufacturing method for cladding, repair and new component applications. With a material efficiency of almost 100 %, wire-based Laser Metal Deposition (LMD-w) is a promising economic and ecologic process for future manufacturing questions. Beside all advantages process stability is a major issue. Small process windows need a thorough process control. Optical coherence tomography (OCT) might provide the necessary monitoring capabilities.

A M-ERA-NET research project called »TopCladd« (funding code 13N14265) aims for the development of a machine-integrated process monitoring. »TopCladd« unites European research and industrial partners from Belgium and Germany.

The idea is to set up a system that enables spatially and temporally resolved monitoring of the welding bead by means of low-coherence interferometry. As a solution a high resolution OCT-system is coaxially integrated into a coaxial processing head. Figure 1 shows the setup.

The optical setup of the processing head is extended by a beam splitter and a measuring head including a broadband light source, a spectrometer and a reference path of the OCT-sensor. To prevent mechanical disturbances during the measurement the OCT-sensor is connected to the measuring head by optical fibers.

Key innovation is the optical design of the entire system. The use of an axicon, prisms and additional specially manufactured lenses allows circular scanning around the wire guiding. This enables a messurement of the welding bead geometry without any central wire blocking the measuring light. The so created inline monitoring system allows a coaxial topography measurement of a welding bead which was shown by the »TopCladd« consortium in a full scale running process.

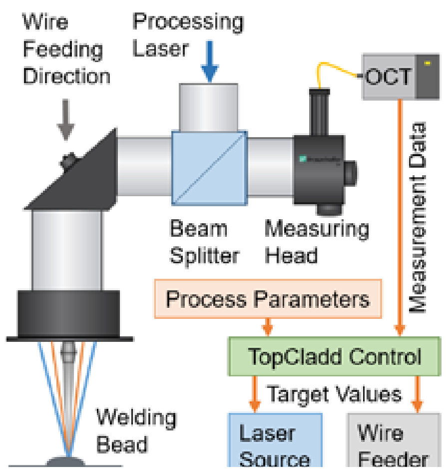

Figure 1: Schematic illustration of measuring system integration

Currently the data of the inline assessment of the welding bead characteristics are processed.

Based on the process data a process model is developed, to allow an active process control.

The implementation of the control unit based on the developed control model and real-time computation will enable a closed loop process control in near future.

At the end of the project, the adaptive measurement system can then be integrated into any LMD-w process. This increases LMD-w process robustness and LMD-w fields of application. In combination with the high degree of an automated production, »TopCladd« allows a more economic and ecologic production in the future.

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Completely recyclable, lightweight "all-polyethylene single component" composite materials for 3D-printing

All-hydrocarbon composites ("all-HC") are an ideal material for lightweight construction: since the matrix and the reinforcing component of the composite are made of the same polymer, the composite can be recycled easily – this is in contrast to e.g. glass-fiber reinforced composites, where a costly separation of fibers and matrix material is required before the materials can be recycled. The Freiburg Materials Research Centre (FMF), the polyolefin manufacturer LyondellBasell, Fraunhofer IWM and the MicroTribology Center µTC have produced and qualified a sustainable "all-PE composite". Polyethylene (PE) is a versatile polymer which is produced

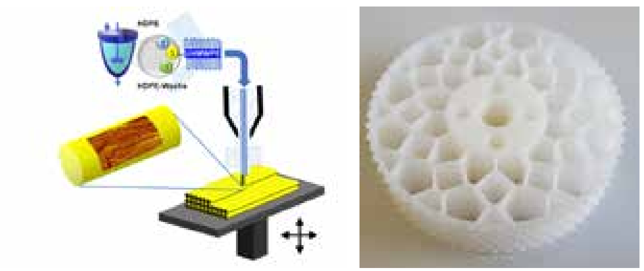

Figure 1: Right: Components made of all-PE composites: using a multisite catalysis, different unbranched PE chains are produced (top) and the fiber-like UHMWPE nanostructures produced in the 3D pressure nozzle are deposited in the desired orientation in the printed component. (© Fraunhofer Institute for Mechanics of Materials IWM). Left: UHWMPE-wheel 3D-printed with the ARBURG Freeformer

in resource- and energy-efficient catalytic polymerizations. It can be easily processed, and is found in many plastic products used every day. Ultra-high molecular weight polyethylene (UHMWPE) is a high strength and abrasion-resistant material which is used e.g. in medical implants as frictional partner or in high strength fibers. However, the processing of conventional UHMWPE is considerably more complex and costly than the processing of standard polyolefines.

Prof. Dr. Rolf Mülhaupt and his team at the Freiburg Materials Research Centre (FMF) at the University of Freiburg managed to synthesize nanoscale mixtures of low, medium and disentangled ultra-high molecular weight PE, known as reactor blends, by using multisite catalysts. These reactor blends can be processed by conventional melt processing techniques like injection molding. During processing, the UHMWPE is stretched by extensional flow and shearing and forms high-strength fiber-like UHMWPE nanostructures within the PE matrix: an "all-PE composite" with superior mechanical properties is formed.

Components can be recycled and re-processed several times without compromising the mechanical performance. However, in injection molding the position[1] within the mold and the mold geometry strongly influences the flow-rate-dependent formation of the fiber-like structures – consequently, not all injection molds will lead to the optimal formation of the reinforcement.

Extrusion based 3D printing techniques offer a solution to this problem: when processing suitable all-HC filaments, the reinforcing structures also form in the nozzle of the 3D-printer. The formation and orientation of the nanostructures can be controlled by the printing pathway and the process parameters. Therefore, the reinforcement can be tailored according to the mechanical or tribological loading of the component.

In a project supported by the Sustainability Center Freiburg, the Freiburg Materials

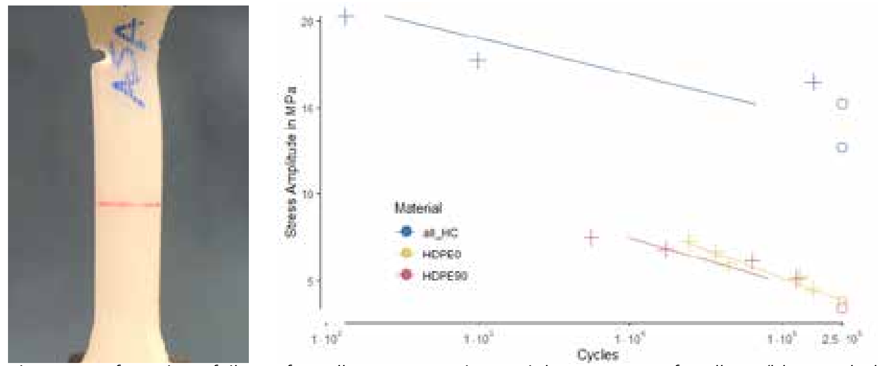

Figure 2: Left: Fatigue failure of an all-HC test specimen, right: s-N curves for all-HC (blue symbols) and HDPE (reference sample, yellow and red symbols). Symbols: +: failures, O: run-outs.

Research Centre FMF, LyondellBasell and ARBURG investigated and optimized materials and parameters of the AM-process, and the Fraunhofer IWM and the MicroTribology Center µTC studied the mechanical and tribological performance of the printed components. Using AM-techniques, components with complex shapes and tailored reinforcement can be manufactured using all-HC. The creep resistance and fatigue strength of 3D-printed all-HC test specimens were significantly higher than those of high density polyethylene reference samples. The wear resistance of printed components can be controlled by the orientation of the filaments with respect to the gliding direction: aligning filament and gliding direction results in a significant decrease of the wear rate.

Plastic gears are a potential application for all-HC: selected all-HC show a good creep-, fatigue- and wear-behavior[2], and polyolefins generally do not degrade in contact with lubricants.

[1] Hees, T., Zhong, F., Stürzel, M., & Mülhaupt, R. (2019). Tailoring Hydrocarbon Polymers and All-Hydrocarbon Composites for Circular Economy. Macromolecular rapid communications, 40(1), 1800608.

[2] T. Hees, F. Zhong, C. Koplin, R. Jaeger, R. Mülhaupt,Wear resistant all-PE single-component composites via 1D nanostructure formation during melt processing, Polymer 2018, 151:47-55.

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ONE TOPIC – 18 INSTITUTES – ONE COMPETENCE FIELD

FRAUNHOFER COMPETENCE IN ADDITIVE MANUFACTURING

The Fraunhofer Competence Field Additive Manufacturing integrates 18 Fraunhofer institutes across Germany and represents the entire process chain of additive manufacturing. It includes five major research areas: engineering (application development), materials (polymers, metal, ceramics), technology (powder-bed-based, extrusion-based, print-based), quality (reproducibility, reliability, quality management) as well as software and simulation.
Aim of the network is to advance applied developments and start trends in additive manufacturing. Many years of experience from national and international industrial assignments as well as research projects form the basis for us to develop customized concepts and to handle complex tasks. The Fraunhofer Competence Field Additive Manufacturing is aimed at sectors such as automotive and aviation, but also biotechnology, medical and microsystems technology as well as mechanical and plant engineering.

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