Swiss AM Guide 2018

Exploring new applications in additive manufacturing

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AM Network
Swiss AM Guide 2018

Content

Editorial

Dear readers,

The following report shows impressively how quickly the additive manufacturing technology is implemented into industrial applications. Two years ago, the AM Report 2016 mainly focused on niche and pilot applications, whereas the Swiss AM Guide 2018 shows that additive manufacturing is rapidly becoming a relevant manufacturing technology.

The selected case studies illustrate that the technology has reached mass production. The examples show that existing products cannot be copied, but have to be rethought on several levels. Companies need to reconsider design, business models and supply chain from the customers' perspective. This is uncharted territory and, above all, a learning process.

Nowadays, it is a realistic goal to implement additive manufacturing in serial products – the technology allows it; what is missing, is experience. Companies that already have expertise with additive manufacturing in serial products are in an excellent starting position to benefit from future developments.

The case studies are based on interviews conducted by Manuel Biedermann, a PhD student in my team, with people responsible for development. The examples highlight that solutions have to be completely rethought and this is the biggest hurdle for companies. Looking back, the good solutions seem obvious.

Our aim is to give you the impulses and inspiration for your additive manufacturing development project in your company with this report.

Prof. Dr.-Ing. Mirko Meboldt
Professor for Product Development and Engineering Design, pd|z ETH Zurich

Dear readers,

In order to enable development engineers, product designers and scientists in Switzerland to design even more innovative and unique products with additive manufacturing, the Swiss Agency for Innovation promotion "Innosuisse" is promoting this trend-setting technology.

In addition to initiating research projects, Innosuisse (formerly CTI) is supporting 11 national thematic networks (NTN), including the AM Network, which is facilitating additive manufacturing (3D printing) in Switzerland as of January 1, 2017.

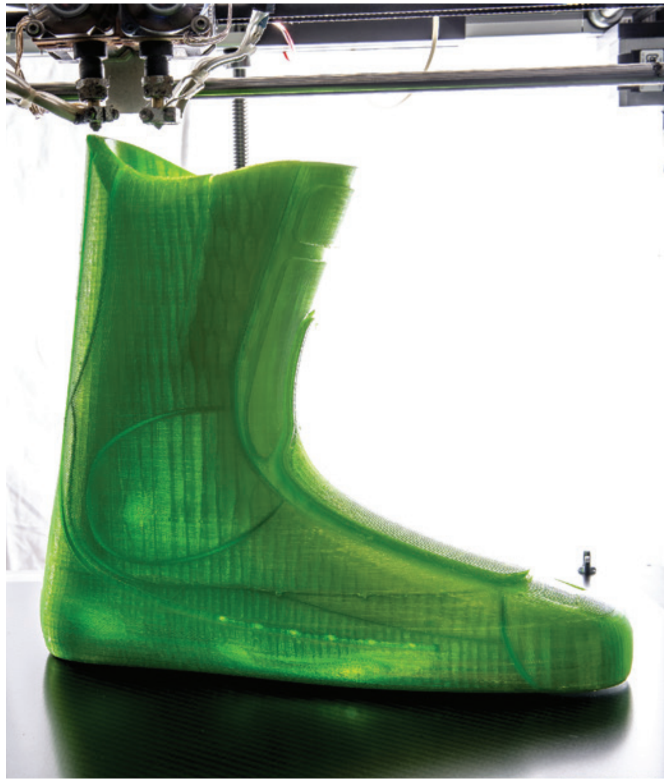
The potential of 3D printing can only make a sustainable contribution to Switzerland's growth and prosperity if industry and research institutions succeed in applying and further developing the technology within a short period of time. And this is our prime duty: to bring industry and research institutions together and by doing so, to enable know-how transfer and to develop innovations. Knowledge is the most important raw material for this purpose. The AM Network wants to increase this knowledge with its activities and impulses. Additionally the AM Network intends to familiarize the industry with the great development possibilities of this technology.

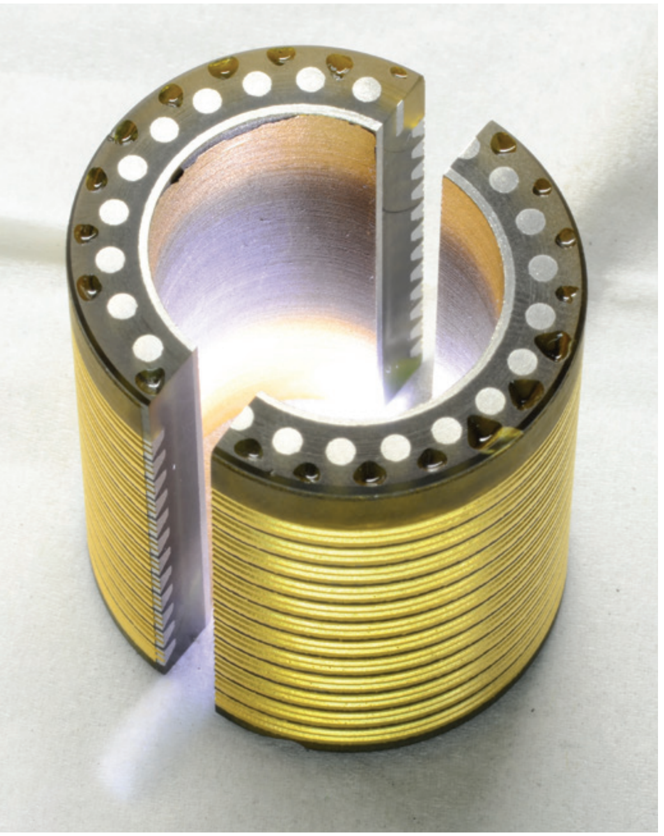
Additive manufacturing will change existing business models and completely new models will be added. Specialists will be in a position to manufacture individualized and customized products, regardless of whether they are spare parts for machines or medical implants of all kinds. Completely redesigned parts are already increasingly being used in the machining industry, medical, automotive and aviation industries. The 3D technology is intensively used in product development and increasingly in industrial production, whereby the flexibility and time to market is massively improved.

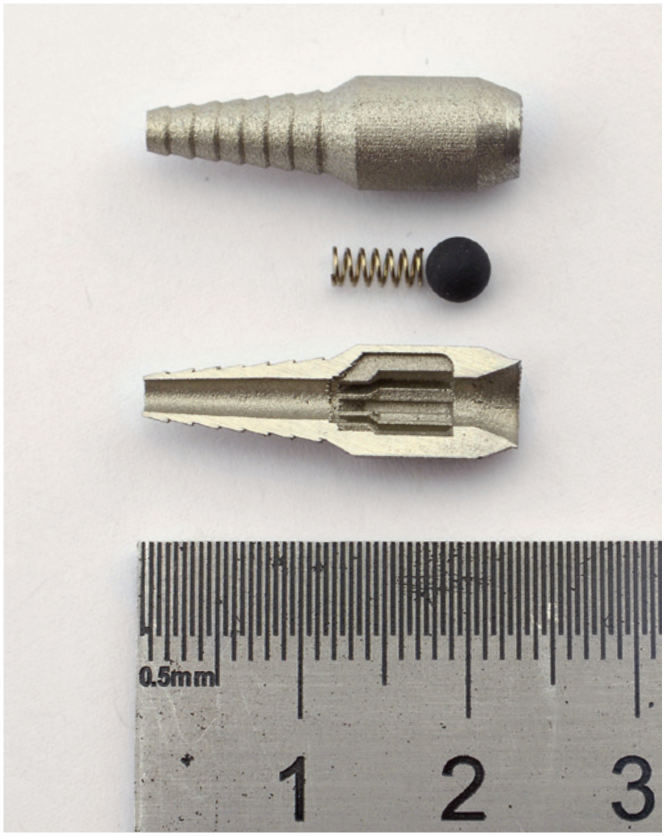
The present report is a mosaic in the picture of the various activities of the NTN AM Network. Beginners' courses, seminars, innovation workshops and a national AM Conference complement the offer and support the goal of making this technology a breakthrough in Switzerland. Hereby we limit ourselves to the materials metal, ceramics and engineering plastics.

Within one year almost 50 members from research, industry and partner networks have already registered for the AM Network membership. In the meantime, the AM Network has established strategic alliances with the SATW (Swiss Academy of Technical Sciences), SAMG (AM Division at Swissmem) and STV (Swiss Engineering). It is important for us to be able to represent the entire spectrum of the industry in the future. For this reason, we are looking forward to welcoming further active members in order to be able to perform even stronger together.

Prof. Markus Baertschi
President AM Network







Showcases: exploring new applications in additive manufacturing

The statement seems tiresome and repetitive but additive manufacturing offers a tremendous potential! As a cornerstone technology, it redefines the way we design, manufacture and distribute parts and products. In this context, it is not additive manufacturing alone but its application together with established manufacturing routes, a broad variety of materials and a digital process chain.

Implementing additive manufacturing can be complicated and challenging. Experience must first be gained and trade-offs need to be understood and resolved to find the right combination between design, material and manufacturing. For this purpose, the report aims to inspire you as a reader with a collection of real-world examples that illustrate how companies have successfully applied the technology. When reading the report, it becomes apparent that besides manufacturing a digital process chain represents a decisive enabler and driver for novel applications. I am convinced that, as a result, design automation for additive manufacturing will play a key role in the future.

What also becomes clear after reading the report – and for me personally after conducting several interviews – is that these developments are not just related to technology. Additive manufacturing is also and most importantly about the people that apply it. Throughout the interviews, a clear pattern was the spirit of the interviewed people who seek to explore new applications with an open and curious mindset. With these words, I am looking forward to new advancements in this field and hope that the report will also raise your curiosity.

Manuel Biedermann
Research associate/PhD student, pd|z ETH Zurich

Additive manufacturing: technical and market report

The additive manufacturing (AM) industry is growing substantially, with increasing numbers of machine manufacturers, material suppliers and end users. The impressive progress could recently be recognized at the world leading fair for AM, "FormNext." This exhibition in November last year was overwhelming and perfect to feel the pulse of today's AM business! Between 30% and 40% plus in exhibitors, visitors and display space compared to 2016 illustrate the massive trend AM creates today. The exhibition confirmed that all areas of the AM value chain progress considerably. In the field of main chain elements like machines, materials, process integration, pre- and post-processing, quality control news and activities were presented manifold. Further to the number of news also very interesting to recognize is that big players from other areas obviously take AM seriously now and try to enter the market at different positions. BASF, for example, founded quite recently a new company, BASF 3D Printing Solutions GmbH dedicated to AM that is solely developing materials for all standard AM plastic processes. Similar ideas for this sector can be seen from companies like A. Schulman, DSM, Clariant and others. SIEMENS attempts to become a player in the AM-supporting software and HP developed a completely new AM process called "Multi Jet Fusion (MJF)" based on their knowledge of digital printing. ADIDAS announced a future innovative concept of shoe production ("Speed Factory"), where AM processes will be an integral part of the process in order to deliver personalized midsoles in shoes. Central core of this concept is an AM process called CLIP, developed by company Carbon 3D which accelerates the production of plastic AM parts by factors and provides material properties not available so far. How big the expectations in the CLIP-technology are, is demonstrated by the fact that AUTODESK, FORD, BMW, GE, NIKON and other big players have partnered with the start-up company founded in 2014.

However, also long-term established AM companies presented groundbreaking news in already established processes. EOS, for example, the market-leading company for laser-based powder bed fusion (laser sintering of plastic (LS) and melting of metal powder (SLM)), presented a brand-new LS machine (EOS P500) possessing many features overcoming problems and shifting the technology much closer to serial production. Moreover, EOS combines the new machine also with newly developed materials (PEEK) opening the door into new market segments (aircraft, electronics) where specific properties like flame retardancy is mandatory. Many other companies announced to enter the LS-market soon with new machines (Voxeljet, VIT) or new materials (NeuMat, BASF, RICOH, Lehmann&Voss and others).

For the field of metal AM processing, the main trends at FormNext going either into large format printing or producing highly precise microparts for mass production (Desktop Metal, Xjet, ExOne). Technologies used here are based on derivatives of 3Dprinting or stereolithography (SLA) technologies using standard metal filled feedstock (metal injection moulding (MIM) recipes). For "traditional" SLM processing, the established companies are trying to get bigger ("large format printing (LFP)"). EOS, CONCEPT, SLM-Solutions presented their ideas on LFP along with enhancements regarding process stability. Particularly, a persistent process monitoring is planned in order to get closer to serial production processes with controlled and improved part quality. This point will rule the success of AM technologies in the future to a great extent. Certified AM parts licenced for the end use in different kinds of industry (aircraft, automotive, medicine) will be the key for the long-term success of AM serial production.

Also in Switzerland AM creates more and more attention in business and research now; and authorities and inter-trade organizations try to bundle and guide activities for AM. In the past two years, several new working groups emerged such as the Swissmem specialist groups SAMG, SATW and AM Network, which founded different platforms and created a good network for AM in Switzerland targeting to support the implementation of AM in the industry or linking business partners with research institutions to work in a target-oriented manneron specific solutions. From those activities and also AMX fair CH industry will benefit in future to be competitive in international markets and offer further added value to customers.

Manfred Schmid
inspire AG

Additive manufacturing of flow measurement probes

Innovation **Engineering** **Business** **End-to-End Integration**

Vectoflow GmbH makes customized measurement solutions to determine the state of a flow. Additive manufacturing is applied to fabricate flow measurement probes in different sizes, shapes and materials for various applications.

Customer	**Various customers**
Manufacturer	**Vectoflow GmbH**
Technology	**Laser melting, laser sintering**
Material	**Stainless steel, titanium, inconel, ceramics, plastics**
Machine	**Machines from different suppliers**
Produced quantity	**–**

Whether it's airplanes, drones, racing cars, gas turbines or submarines: in many areas it is essential and crucial to measure the characteristics of a fluid flow. So-called flow measurement probes are used to determine pressure, velocity and angle of an incoming flow. The example of an aircraft shows how important it is to measure the speed of the air stream correctly. If the aircraft speed is too low, the flow can stop abruptly, whereas too high a speed puts too much stress on the components.

Flow measurement probes have to meet a variety of requirements depending on the application and the flow field to be measured. For example, the size of a measuring probe must not be too large, as this would interfere with the flow field and distort the measurement results. With a reduced size, however, probes are particularly fragile and must nevertheless withstand forces during operation. Depending on the application, probes are also exposed to elevated temperatures. In case of damage, a quick replacement or repair is advantageous. Therefore, flow measurement probes have to be built robust and deliver exact results.

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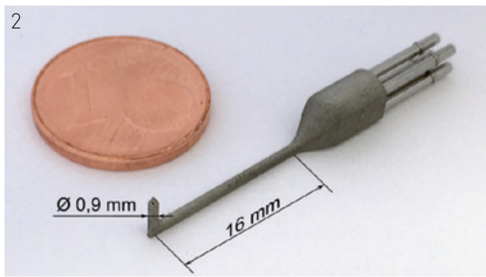

The company Vectoflow GmbH is active in the field of fluid dynamic measurement technology and develops custom-made flow measurement probes. To meet the aforementioned requirements, the company relies on the potential of additive manufacturing. Vectoflow GmbH offers a wide range of different probes in its product portfolio.

Depending on the field of application, probes can be adjusted regarding the type of probe, the shape of the probe and the probe head, the number of measuring holes, the selected material and the examined system.

For this specific application the use of additive manufacturing processes such as laser melting and laser sintering offers a variety of advantages. The design freedom can be employed to produce various configurations of flow probes. Flow probes are manufactured as stand-alone components or can be directly integrated into another part. Besides geometric freedom, additive manufacturing also offers a high degree of flexibility in the choice of materials. Depending on the field of application, a high-strength alloy such as Inconel is selected for a gas turbine or turbomachinery operating at elevated temperatures of up to 150 °C, or a material such as titanium is chosen for lightweight applications.

Additive manufacturing also has the advantage of building flow measurement probes in a very small size. One of the smallest flow measurement probes manufactured by Vectoflow GmbH has an outside diameter of 0.9 mm and integrates five channels with a diameter of about 0.1 mm. Powder removal is a challenge for such small dimensions, but can be accomplished. Decisive for the quality and correct functioning of the measurement probes is the orientation in the build space of the printer and the process parameters.

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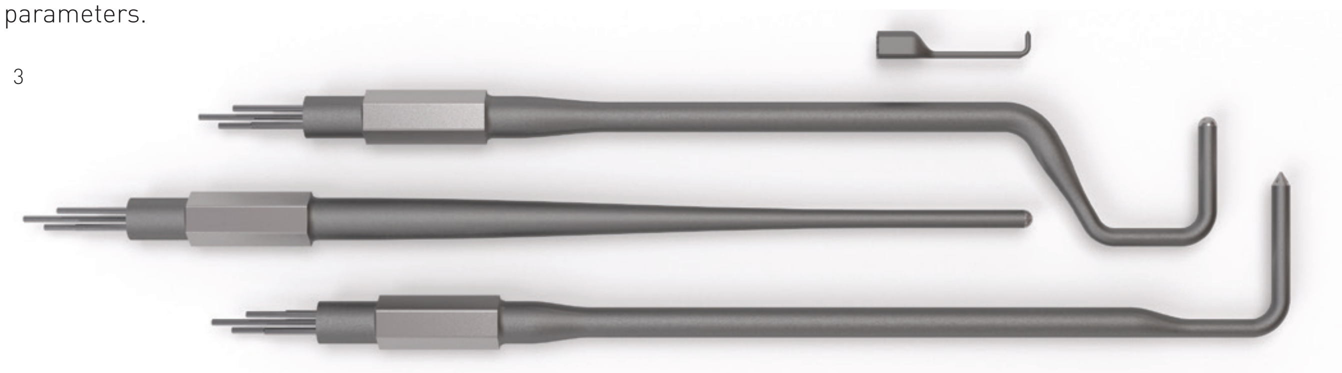


A post-processing of the additively manufactured probes depends on the selected process and application. For most probes, the tip of the probe is post-processed. No rework is usually carried out for the integrated channels. Since no fluid flows through the channels and only a pressure builds up, it is simply important that the channels are open and separate from each other. Depending on the shape of the probe and the application, the surface of the component can be optionally reworked using various post-processing techniques.

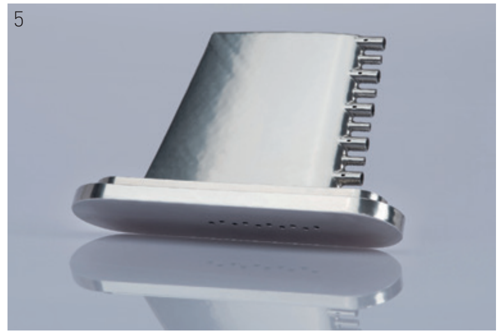
After the fabrication of a flow measurement probe, its calibration is carried out in a wind tunnel. The measuring technology and probe are aligned accordingly to the intended application. The first step is to define the flow conditions that occur during operation and then simulate them using the wind tunnel. In addition to the flow velocity, this

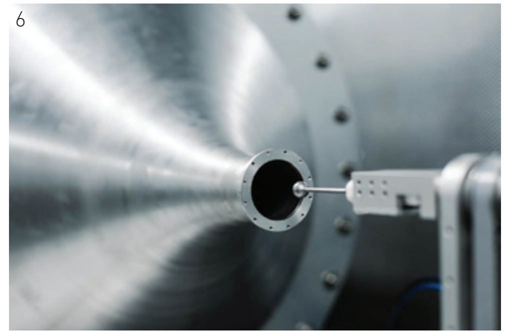
1 Kiel probes for measurement of total pressure and temperature

2 Small-sized flow measurement probe with five integrated channels

3 Measurement probes in different shapes

may also include the angle of attack of inflow. The probe is then exposed to the wind tunnel flow field. The probe takes measurements and assigns them according to the simulated flow conditions. In this way, the probe "learns" which signals occur in a given flow field. Later in operation, the probe uses this acquired knowledge to determine the flow characteristics. Depending on the intended application and the flow area to be monitored, a suitable and customized flow measurement probe can be manufactured. Pitot or Prandtl probes, for example, are available in any shape: e.g., straight, L-shaped, cobra-shaped, and drilled elbow-shaped or completely customized. So-called kiel pressure and kiel temperature probes have been specially developed for measuring





4 and 5 Rakes integrating multiple probes

6 Calibration of measurement probe in wind tunnel

the total pressure or total temperature of a flow at angles of incidence other than 0°, whereby the total pressure can be measured within an angular range of ±60°. Unsteady probes combine the robustness of a pressure probe (e.g., five-hole probe) with pressure sensors, which allow a high temporal resolution of the pressure signal. Depending on the probe geometry, frequencies of several kHz can be measured.

In order to carry out a measurement for a flow area directly at several points, e.g., during a complex test of a gas turbine in a wind tunnel, so-called rakes are frequently used. A rake combines several flow probes into one component and leads to a higher spatial resolution of the flow field. Again, additive manufacturing offers a high level of geometric freedom, allowing a rake to be adapted exactly to the application requirements and to be integrated into other components. The example of a rake also highlights how different configurations can be created with parametric CAD models. For instance, in addition to the number of probes, the type of each probe, the positioning of the probes relative to each other and other parameters, the geometry of the corresponding rake is automatically derived. For the individualization of measurement probes, the results of a flow simulation may also be used to define a suitable arrangement and selection of probes.

In summary, the application case of Vectoflow GmbH impressively shows how tailor-made flow measurement technology can be fabricated for many different areas. The advantages of additive manufacturing regarding design, size and material are leveraged in a targeted manner and combined with expertise in measurement technology. In this way, it is possible to offer customized flow measurement probes, which are robust, flexible, integral, and measure with high precision.

Customized ski boots for better comfort and improved performance

Innovation **Engineering** **Business** **End-to-End Integration**

Combining additive manufacturing with a digital process allows Tailored Fits AG to produce individualized ski boots. Besides improved benefits for customers, the case demonstrates a new way in which customers, manufacturers and stores interact.

Customer	**Sports retail stores**
Manufacturer	**Tailored Fits AG**
Technology	**Fused deposition modeling**
Material	**Thermoplastic polyurethane (TPU)**
Machine	**German RepRap FDM printers**
Produced quantity	**40 per month**

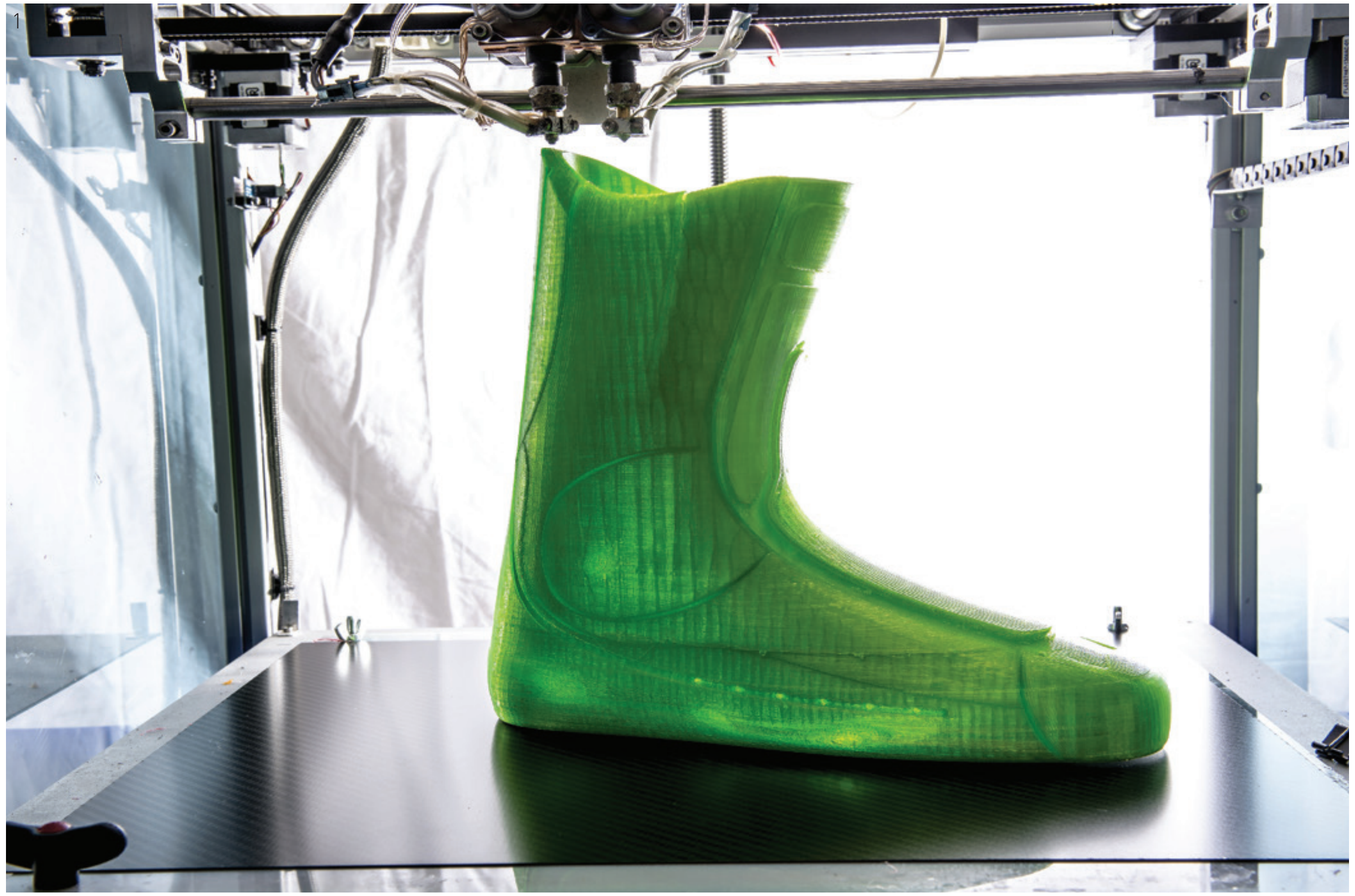
Anyone who has ever skied knows this problem: after a longer skiing trip, feet hurt – and finding comfortable ski boots can be a challenge. Ski boots are usually offered in different sizes but are not tailor made to the customer's foot. A conventional ski boot consists of a hard outer shell and a soft inner shoe or ski boot liner.

In case of a non-optimal fit, the shoe will squeeze, blood will accumulate and as a result, the wearing comfort is lowered. Since there is no tight fit between foot and boot, the necessary support is reduced and thus the force transmission between foot and ski is lowered. In addition, buckles and straps are required to maintain a stable fit of the foot in the shoe, which leads to increased pressure points. The ski boot industry has tried to address this problem with foamed ski boots. Foaming enables the individual adaptation of an inner shoe to the geometry of a foot. Although this results in a better fit, foamed inner shoes have the disadvantage that after extensive use, the foam is compressed and wears out.

Tailored Fits AG, a young start-up from Horw near Lucerne in Switzerland, has focused on this problem and is now offering customized ski boots. It is the inner shoe or liner of a ski boot that is adapted to the foot shape of a customer by means of 3D scanning and fabricated with the help of additive manufacturing. The entire process utilizes a digital, end-to-end value chain that allows the creation of tailor-made ski boots. In addition to ski boots, Tailored Fits AG offers its customers other customized footwear such as insoles for running, hiking, cycling or football shoes. In the following, the entire process, which has been set up in cooperation with the Belgian company Materialise, is illustrated using the example of the customized ski boots.

For the individualization of ski boots, the customer's foot geometry must first be captured. In a sports store, the seller scans a customer's foot with a 3D scanner. The 3D scanner is an easy-to-use, portable tablet with a structured light sensor attached to it. The contactless scanning process, which records the customer's foot geometry with sufficient accuracy, takes only a few minutes. By pulling the toe tines, the customer puts the foot sole in a stretched position, just as it is the case in an active skiing movement. In addition to the scan data, the retailer transmits the customer's weight, sole length and other preferences to Tailored Fits AG.

Once the scan of the foot geometry has been transferred to Tailored Fits AG, a quality control is carried out. Anatomical features are used to orientate the scan in space. A virtual bone skeleton is inserted into the scanned foot to morph the geometry and rotate it around the ankle in different directions. In this way, the alignment of the leg position and the angle of inclination can be adjusted and corrected in a targeted manner. This modified scan of the foot serves as an input for the design generation of the inner ski boot.



1 Soft, inner liner of ski boot made in TPU using Fused Deposition Modeling (FDM)

The design creation process of the inner ski boot geometry is fully automated. For the customer's individual scan and preferences, a software generates the corresponding inner ski boot, which possesses a varying hardness or softness at different areas. In addition to the use of a flexible material, this is achieved by the targeted implementation of distributed cavities and infill structures. Their stiffness or damping properties are determined by the specified customer weight. The closed cavities also serve as insulation for the inner shoe against the cold during skiing. The process for the automated creation of shoe insoles is similar. Depending on the chosen sport and customer preference, a different distribution of the cavities is generated for varying the insole softness.

2 3D scanning of customer's foot geometry

3 Assembled ski boot with soft, inner liner and hard shell

As previously mentioned, the inner ski boot is additively manufactured with a flexible material, in this case Thermoplastic Polyurethane (TPU), using fused deposition modeling (FDM). Compared to powder- or liquid-based processes, this AM technology allows the creation of closed cavities, which serve as a thermal insulation in the ski boot. The employed German RepRap FDM printers are very cost efficient compared to laser sintering machines, which can also process TPU material – but not with enclosed cavities. For support structures, PLA material is used. The inner ski boots are manufactured at Tailored Fits AG and Materialise in Belgium. After additive manufacturing, the inner shoe is flocked.

The final ski boot consists of an additively manufactured inner shoe and a conventionally manufactured hard shell, which is produced in various sizes by injection molding. Since the inner shoe can be adapted to a wide range of different foot geometries, only a reduced number of sizes is required for the outer shell. The final assembly of the ski boot is done by inserting the inner shoe into the shell. Since an optimized form fit is achieved through the custom-fit to the foot geometry, a single closure strap with a button snap fit is sufficient to close the shoe. Therefore, unlike conventional ski boots, several buckles are not necessary to firmly hold the foot in the ski boot. This simple design of the ski boot reduces the number of individual components from around 200 to less than 20. As a result, cost and lead-time of manufacturing, assembling and logistics are significantly lowered throughout the entire process chain. In this way, the price of individualized ski boots becomes competitive with comparable solutions.

After a quality check, the ski boot is sent to the retailer's sports shop, where the customer receives his personalized ski boot. There are many advantages for the customer. The custom-fit shape enables a more precise and direct force transfer during skiing. Better blood circulation and reduced fatigue ensure increased comfort. In addition, insulation against cold is improved. The simplified fastening mechanism makes it easier to get into and out of the shoe, and pressure points are prevented compared to a shoe with several straps.

The individualization process described above is highly complex in terms of design, production and business model. An iterative and exploratory process was required and several problems had to be solved. At the very beginning, the first idea was to directly additively manufacture the outer shell of the ski boot and use a generic, standardized inner shell. The first prototypes were laser sintered from polyamide (PA). After a joint workshop with Materialise, the idea came up to additively manufacture and adapt the inner boot. A suitable, easy-to-use, cost-effective scanning technology had to be defined together with a suitable scanning positioning of the foot. In addition, an appropriate flexible material had to be chosen together with the right additive manufacturing technology and optimized process parameters. As soon as flexible TPU with FDM was printable, the question came up at which regions the shoe had to be hard or soft. Repeatedly different models were discussed with orthopedics as well as tested by the team on the ski slope regarding comfort and performance.

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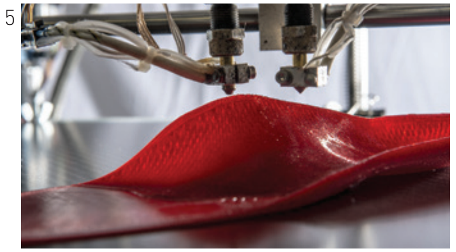

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4 Shoe insole adapted for different sports like running, hiking or cycling

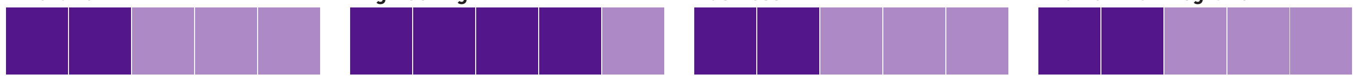
5 and 6 FDM printing of a shoe insole made in TPU

After extensive testing, the decision was made to reduce complexity, focus first on the lower part of the inner shoe, and develop a shoe insole. The properties of the insoles were progressively improved and after some development time it was decided to offer them as a first product for different sports like running, hiking or cycling shoes. The automation of the design creation process posed a further challenge. Depending on the foot geometry and customer preferences, it was necessary to automate the generation of distributed hollow structures with variable stiffness. Besides creating a continuous, traceable process chain and robust production, there was also the challenge to implement it in an industrial and scalable supply chain as well as convincing first sports retailers. Based on the gained knowledge and technical expertise, it was possible to adapt the process chain of insoles in a similar form to ski boots.

From a holistic viewpoint, it becomes clear that an innovative approach and a restructuring of the process chain for conventional ski boots was necessary in order to implement the described process and rethink the underlying business model. In this context, doubts had to be overcome as to whether the quality of additively manufactured products could be competitive and whether customers would accept such an individualized product. Overall, there are many advantages for the customer and the manufacturer. However, also the sports retailer benefits. A sports shop is no longer dependent on buying and storing a larger number of standardized ski boots long before the start of the next winter season. This significantly reduces storage costs as well as the margin due to unsold goods. Since individual ski boots are custom made, payment is usually required in advance. In summary, the described process creates new opportunities for manufacturers, retailers and customers becoming part of a shared platform.

Additive manufactured molds for particle foams

Innovation | Engineering | Business | End-to-End Integration



Particle foams such as expanded polypropylene (EPP) are characterized by their good thermal insulation and damping properties. Robert Hofmann GmbH demonstrates how the required tooling can be improved through the freedom of additive manufacturing.

Customer	**Application example**
Manufacturer	**Robert Hofmann GmbH**
Technology	**Laser melting**
Material	**Stainless steel**
Machine	**Concept Laser GmbH**
Produced quantity	**–**

Particle foams such as expanded polypropylene (EPP) have long been used in the logistics and packaging industry. In addition to a comparatively low density with good mechanical properties, expanded particle foams are characterized by high thermal insulation and damping properties. For this reason, they are also employed in the automotive industry, in insulation technology and other areas. The company Robert Hofmann GmbH recognized the potential of this material and combined it with the advantages of additive manufacturing in the area of tool making.

The fabrication of products and components from particle foam is carried out as follows: expanded polypropylene (EPP) is supplied in the form of beads. These beads are filled into the cavity between molds. Through several smaller openings in the molds, water vapor is injected under pressure and at elevated temperature of up to 150 °C. The introduction of heat energy due to the water vapor leads to the expansion and sintering of the beads, which bond together at the surface. After the forming process and removal from the molds, the water content of the component due to the water vapor is reduced with a tempering oven. Besides expanded polypropylene (EPP) other available materials include expanded polystyrene (EPS), expanded polyethylene (EPE) and expanded thermoplastic polyurethane (ETPU).

For serial production, the used molds are typically made of metal. In the design of the molds, the challenge is to introduce and distribute water vapor into the cavity as evenly and efficiently as possible. In this respect, the number and arrangement of the integrated openings in the form of slots or nozzles play a decisive role. They have a significant influence on the distribution of water vapor and thus on surface quality and component properties. Especially in the gaps between the slots there may occur air entrapment and incorrect sintering of the beads.

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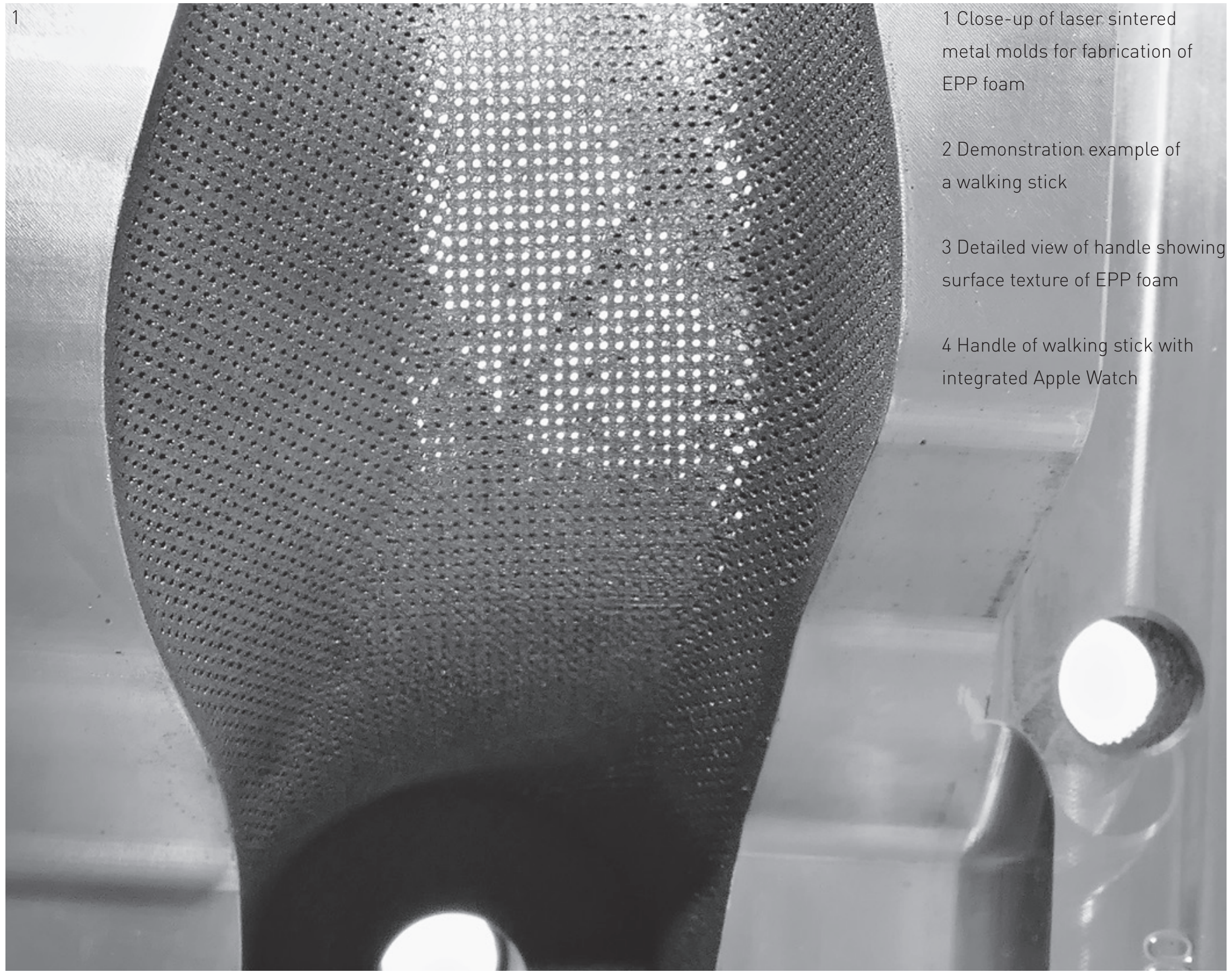

1 Close-up of laser sintered metal molds for fabrication of EPP foam

2 Demonstration example of a walking stick

3 Detailed view of handle showing surface texture of EPP foam

4 Handle of walking stick with integrated Apple Watch

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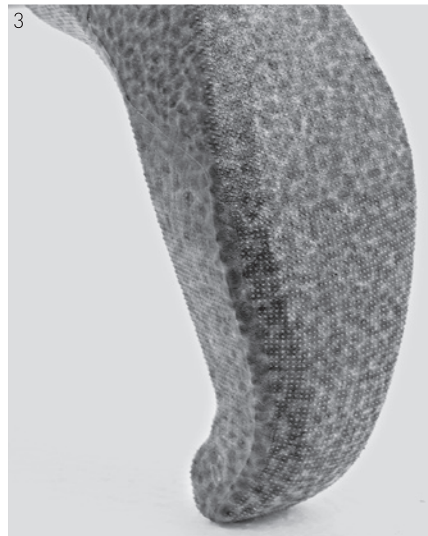

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5 and 6 Laser-sintered metal molds for fabrication of EPP foam

Copyright images: Robert Hofmann GmbH

In conventionally manufactured molds, slots or nozzles are usually drilled into the tool. At a distance of about 10 – 15 mm, a tool can have several hundred slots. Additive manufacturing processes such as laser melting make it possible to decrease the distance between the slots to less than 1 mm. In this way, slots can be arranged much closer to each other, thereby integrating several tens of thousands of slots into the mold. In addition, the width of each slot can be reduced to about 0.1 mm. This leads to a more vapor-permeable mold, which introduces vapor much more homogeneously. As a result, a significantly better surface quality and structural integrity are achieved. As there are no larger distances between the slots, the sintering of the particles is improved and potential fractures are avoided. Further advantages of the additive process are the increased freedom in complex geometries, possible material savings as well as the flexibility and time savings in the fabrication of the molds.

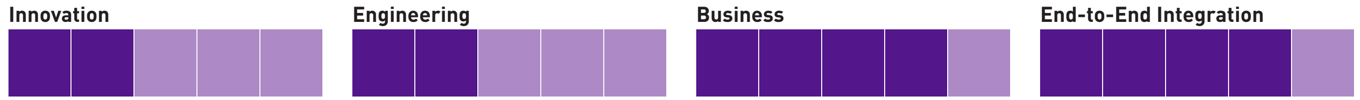
To demonstrate the potential of this process chain and the advantageous material properties of a particle foam such as EPP, Robert Hofmann GmbH developed a novel application example in the form of a walking stick. A walking stick as a product from the healthcare sector shows that the properties of EPP such as energy absorption, reduced density and high structural integrity can also be employed for consumer products. The handle of the walking stick is made of EPP using the process chain described above. The user experiences the haptic advantages of EPP, as the pressure on the palms is distributed evenly due to the "bounce effect" of foam material. In addition, the reduced mass, low liquid absorption and thermal insulation properties of EPP ensure a pleasant handling. The required molds are laser melted of steel using machines from Concept Laser GmbH.

During the forming process of the particle foam, an insert is positioned in the mold. The expanding EPP material surrounds and fixates it. The insert is made of plastic employing the additive manufacturing process fused deposition modeling (FDM). It possesses a frame for the integration of an Apple Watch and contains a screw insert to which a fiber-reinforced carbon shaft is attached. With this lightweight structure, the walking stick can support a load of up to 120 kg.

The use of additively manufactured molds for the fabrication of the EPP handle leads to improved product properties. From an economic point of view, there are further advantages. The more homogenous and finely distributed injection of vapor improves the energy efficiency of the installation. In addition, cycle times can be reduced. As a result, the targeted use of additive manufacturing not only improves the product itself but also makes the overall manufacturing process more efficient.

In summary, the showcase demonstrates impressively how several different materials and processes are combined to create an innovative product with a new design from a conventional walking stick. The advantages of particle foams such as expanded polypropylene (EPP) are linked to the freedom of additive manufacturing, thereby enabling innovative process routes with novel applications.

Improved hearing through customized hearing aids



In the hearing instrument industry, additive manufacturing has been used since the early 2000s for the fabrication of customized hearing aids. A hearing aid helps a person with impaired hearing to compensate this hearing loss by selective amplification of sound. Additive manufacturing allows to individualize and adapt the shape of these devices to the specific geometry of a customer's hearing channel.

Over time, this use case for additive manufacturing has become mature and today, customized hearing aids are sold worldwide in very large quantities. In this respect, there are a number of drivers that have a significant influence on the development and manufacturing of hearing aids. First, hearing devices should be as small as possible and provide a good wearing comfort while integrating all necessary electronic components. Second, customers from different parts of the world demand a short delivery time. Third, customers as well as hearing healthcare professionals expect a selection of different features, optical appearances and other customizable options.

Sonova AG, a Swiss company specialized in hearing care solutions, addresses these market requirements with its brands Phonak, Unitron and Hansaton by employing a decentralized network of production facilities and applying a digital fabrication process. The overall process for in-the-ear hearing aids starts by capturing a customer's hearing channel through a silicone impression. Besides this impression, a hearing aid professional defines the required functional components regarding acoustics, e.g., loudspeaker size. In addition, the customer adds additional specification e.g., type of feature (battery, tele-coil), color and lacquering. Together with the requirement list, the silicon impression is sent to a local production facility of Sonova AG.

Laser scanning the silicon impression digitizes the geometry of a customer's ear channel geometry. In this regards, it has to be noted that in general the anatomic differences between individuals can be quite large. Therefore, customizing the shape

Additive manufacturing is applied by Sonova AG for mass-customizing hearing aids. For a worldwide supply Sonova AG makes use of a distributed production network consisting of several manufacturing facilities in different parts of the world.

Customer **Hearing care professionals, audiologists, hearing aid suppliers**
Manufacturer **Sonova AG**
Technology **Direct light processing, laser melting**
Material **Acrylic resin, titanium**
Machine **–**
Produced quantity **several million hearing aids since switching to 3D printing**

based on the 3D scan allows achieving an improved wearing comfort and better fit. The generated point cloud serves as basis for the modeling of the customized hearing instrument. The task of the modeler is to design the shape of the hearing aid and place the electronic components in it. For this process step, Sonova AG developed its own Rapid Shell Modeling (RSM) software together with the company Materialise. The design automation software guides the modeler step-by-step through the shell design process. It provides ear-anatomy recognition capabilities, thereby accelerating the design process and enabling initial placement of electronic components automatically. Furthermore, the software allows the company to offer its customers benefits not possible with traditional manufacturing methods such as Acoustically Optimized Vents tailor-made for each customer based on individual acoustic requirements.

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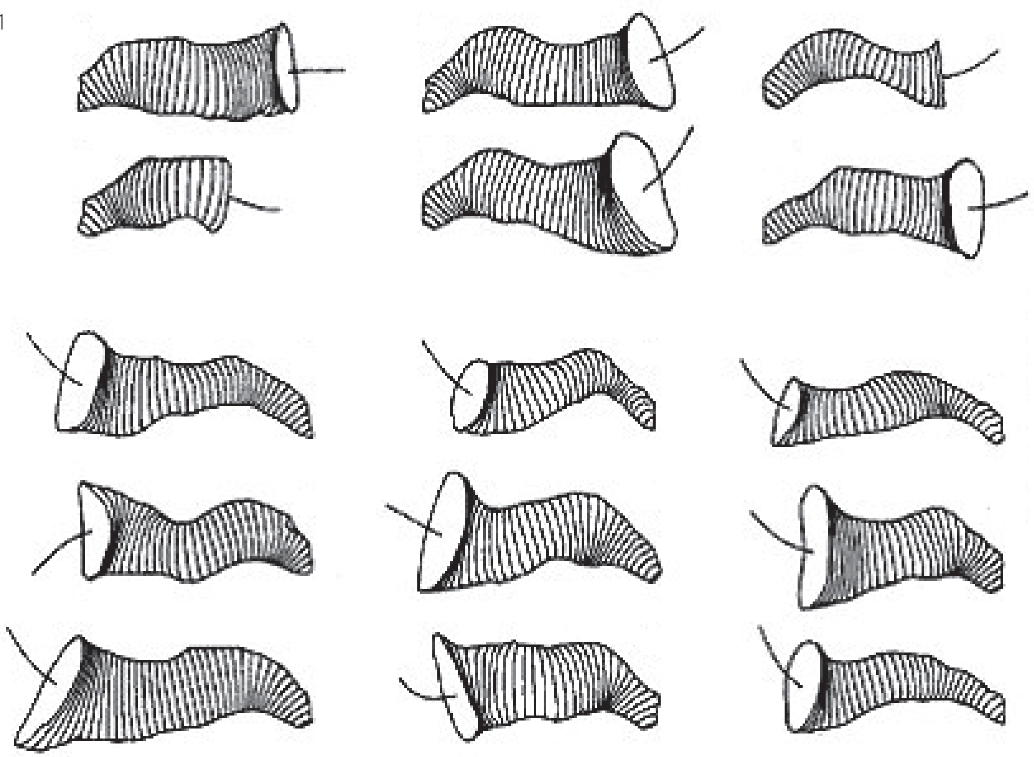

1 Variety of different ear channel geometries

After designing the shell of the hearing aid, it is manufactured using Direct Light Processing (DLP) based on vat polymerization. The technology uses a light source to cure and harden acryl resin. In comparison to stereolithography (SLA), the resin is not cured by a single beam but by projecting a single image at once for a given layer. DLP printers have the advantage that they can produce parts in a short build time and at reduced costs with a high level of precision, process stability and good material properties. Typical wall thicknesses of the shell range from 0.5 to 0.7 mm. Moreover, DLP allows for a wide range of colors. As a result, Sonova AG offers over ten different materials for hearing aids. For a given material, multiple shells can be printed in a few

hours. After the printing process, the shells are separated from the build plate and support structures removed. A post-curing step causes the final curing of the resin. A quality check ensures the integrity of the printed shells.

For the final assembly of the hearing aid, an operator places the specified electronic components in the shell. Prefabricated electronic kits and layout instructions accelerate the manual positioning. After all components are integrated in the shell, it is closed and sealed. Applying a transparent varnishing improves the optical appearance and makes it possible to fine-tune the retention of the hearing aid. The marking with a serial number allows the traceability of the medical device. A final quality check

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tests the acoustic and visual characteristics of the device. In this regard, it is worth mentioning that it is not only the geometric personalization of a hearing aid but also the acoustic settings which are tailored to a customer's degree of hearing loss and the assessment of a hearing care professional. The final product is delivered to the customer within one to five days.

To achieve such a fast delivery, Sonova AG makes use of a distributed production network consisting of several manufacturing facilities in different parts of the world. Each local facility possesses multiple DLP printers to deliver hearing aids with the

2 and 4 Customized hearing aids from Sonova AG

3 Silicone impression from ear channel

described process chain to regional customers. To attain a more continuous production flow and increase, production flexibility orders are printed in small batch jobs using multiple small-sized DLP printers. In general, the printer size and number need to match the required local capacity. Overall, a worldwide, decentralized network of local production facilities offers a high degree of flexibility, simplifies logistics and enables a short turnaround time for customized hearing aids.

5

5 Selection of customized hearing aids for various ear channel shapes and in different colors

6 Shell of hearing aid showing integrated components

More recently, Sonova AG announced the release of new solutions for hearing aids with a metal shell. These shells are made of titanium through laser melting. The material's excellent biocompatibility allows its use for customers who are allergic to typical acrylic otoplastic materials. Fabricating the shell out of metal enables a decreased wall thickness of only 0.2 mm, thereby allowing the integration of larger components such as loudspeakers or batteries at constant size or making hearing aids even smaller and discrete. In the future, it will be interesting to see how advancements in additive manufacturing will affect and further improve hearing aid applications.

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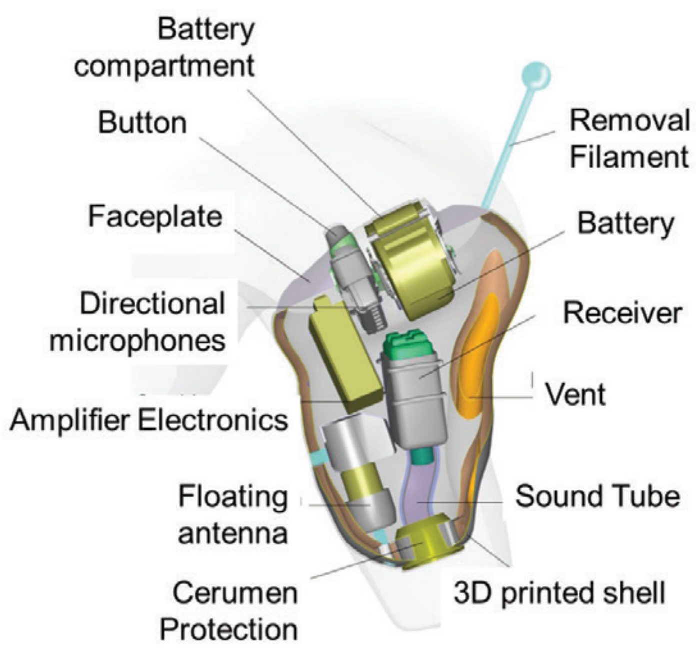

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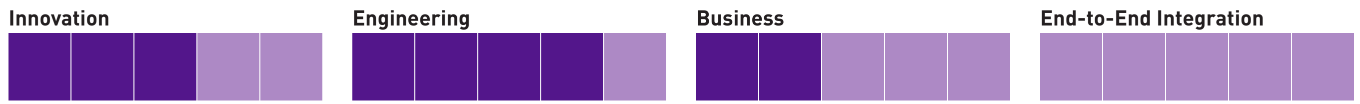
Optimized ball check valve for fluid filling system



A so-called check valve or non-return valve is a component that allows a fluid or gas to flow only in one direction of the component. If the fluid tries to flow in the opposite direction, the valve blocks it. As a standard component, such a one-way valve is employed for many applications in fluid technology, pneumatic systems and process engineering. The simplest form of check valve is a ball check valve, which consists of a housing with two openings, a ball, and a spring.

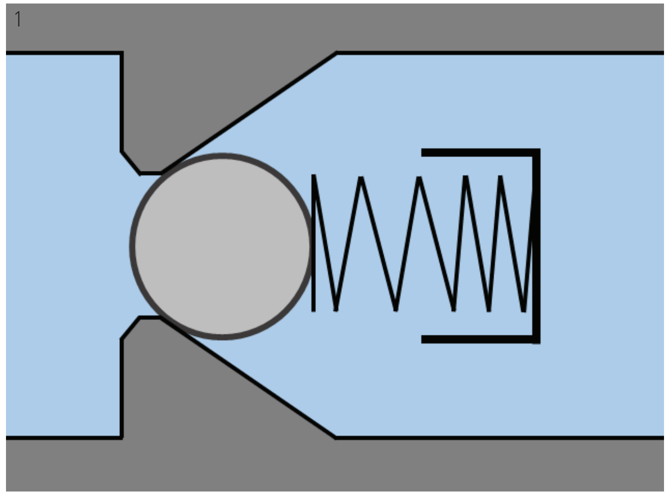
In the closed state of a ball check valve, the pre-tensioned spring presses the ball against the constriction meaning the narrow part of the housing. In case fluid tries to flow from the right opening to the left opening, the ball blocks a possible flow. In the open state of the valve, fluid flows from left to right. Due to the dynamic pressure of the fluid, the ball is pushed to the right and a gap is formed at the narrow section, allowing the fluid to pass through the check valve.

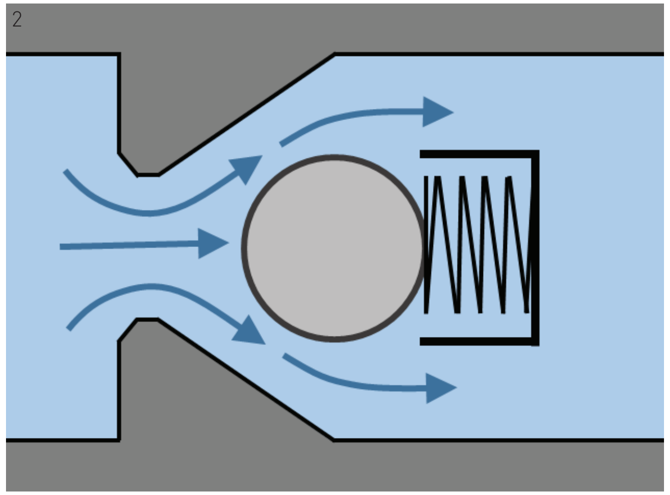
3D Druck Tech AG had the task to develop a ball check valve for a small series production of a filling system in which a chemical solution is transferred from a larger container to smaller devices. In the filling system, a non-return valve allows air to flow from the outside into the container during the bottling of the solution, thereby preventing a compression of the container. The valve only permits fluid to flow into the container and the chemical solution itself cannot escape through the valve.

In the development of the check valve, 3D Druck Tech AG had to meet several requirements. To ensure the tightness of the valve in the closed state, a high surface quality is needed at the constriction where the ball contacts the housing. As the valve is exposed to a chemical solution, the durability of its components must be ensured. The specified available design space corresponds to a relatively small size of 9 X 9 X 25 mm. As the check valve is employed as a final component, a cost-efficient and reproducible manufacturing concept is required.

A check valve permits a fluid to flow in one direction only. The application of 3D Druck Tech AG demonstrates how an iterative development process and consideration of trade-offs regarding additive manufacturing lead to an optimized ball check valve.

Customer **–**
Manufacturer **3D Druck Tech AG**
Technology **Laser melting**
Material **Stainless steel CL 20**
Machine **Concept Laser M1**
Produced quantity **400 in one batch job**





1 and 2 Ball check valve in closed state (left) and open state (right), allowing fluid flow from left to right

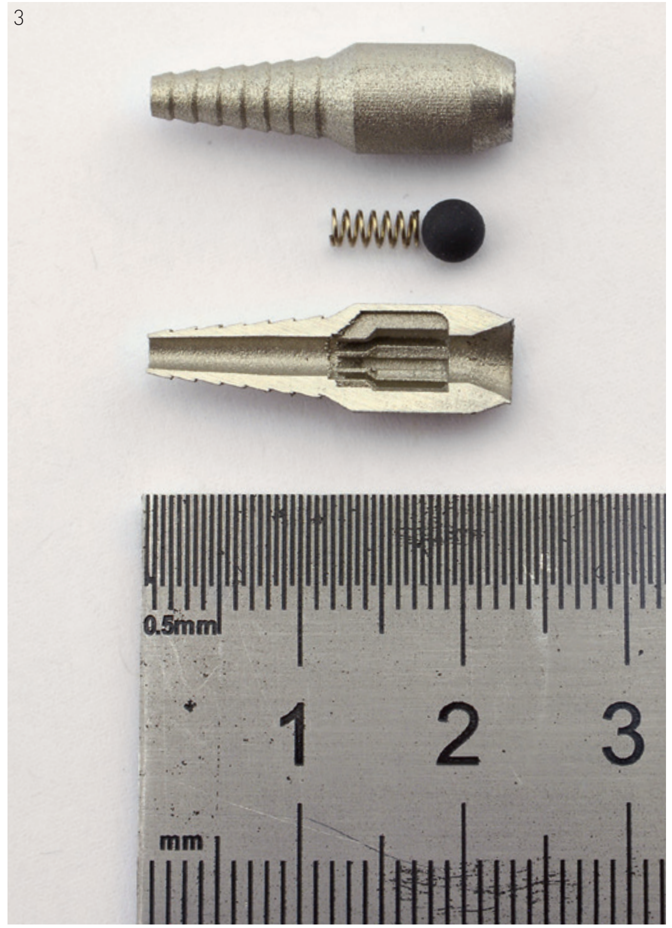
3 and 4 First design iteration of check valve consisting of valve housing, rubber ball and spring

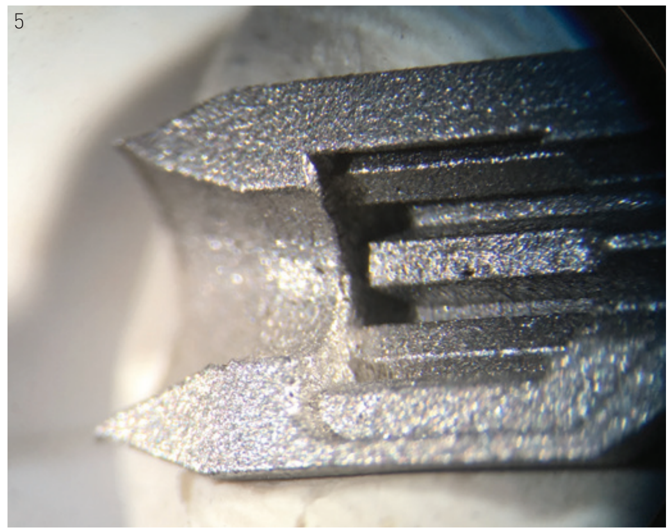
5 and 6 Microscope image showing surface roughness at constriction

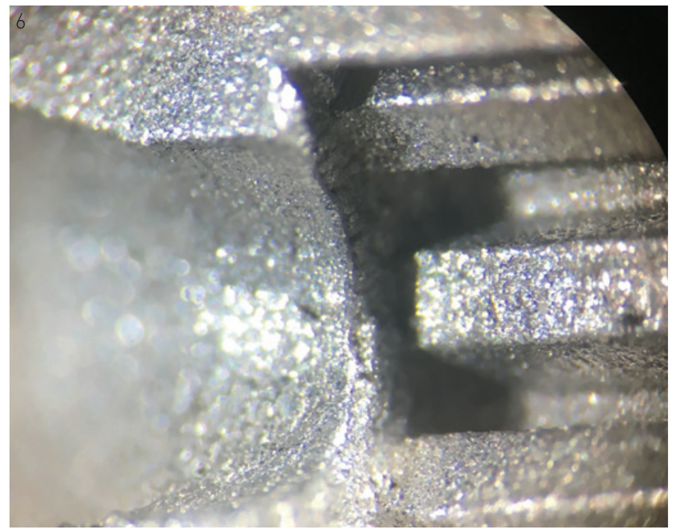
Additive manufacturing was chosen by 3D Druck Tech AG because it allows the fabrication of small-sized components with complex, thin-walled geometries in an economically viable, small series production. Laser melting was therefore selected to manufacture a chemically resistant check valve made of stainless steel.

For the first design iteration, the basic idea was to build an integral check valve consisting of three parts – a rubber ball, a spring and an additively manufactured valve housing. The valve housing corresponds to a rotationally symmetric body with a conical connection for tubes of different diameters. If the housing is fabricated in longitudinal direction, no additional support structures are needed. Laser melting makes it possible to realize a wall thickness of 0.4 mm. During post-processing, the housing is removed from the build plate and sandblasted. The check valve is assembled by inserting the spring and pushing the rubber ball through the larger opening. The advantage of this first design iteration is a reduced number of parts and thus lowered assembly effort. However, as the constriction, meaning the contact surface between rubber ball and valve housing, is not further post-treated, it is not optimally sealed against fluid flow. As it can be seen in a microscope image, the surface is rough and contains unmolten powder particles. Further post-treatment of this functional surface is possible but difficult for conventional machining due to insufficient accessibility, and expensive in case of more advanced post-processing technologies such as electropolishing.

The second and final design iteration achieves an improved sealing of the check valve with a concept consisting of five separate parts – a metal ball made of stainless steel, a spring, a sealing ring, a valve housing and a valve plug. The valve housing and plug are additively manufactured. The upper edge of the plug is turned for a high surface quality and seals the check valve together with the metal ball. During assembly, the spring and the ball are first inserted into the valve housing. The plug is then pressed into the housing plug together with the sealing ring. Although the number of individual parts is higher in comparison to the first design iteration, the tightness of the valve is now ensured. Only a low pre-tensioning of the spring is necessary and the post-processing of the constriction as a functional surface is simplified. The assembly of the valve consists of standard components in addition to the two additively manufactured parts. Compared to the first design iteration, the valve housing has a more conformal and space-saving shape with a diameter of only 7 mm and a length of 22.5 mm.







The two design iterations represent only an excerpt of the overall development process in which 3D Druck Tech AG has continuously developed and improved the original design concept for the check valve. The application example illustrates well that the development of additively manufactured components is an iterative process, in which the interplay between design, manufacturing and post-processing needs to be considered as a whole to achieve optimized results.

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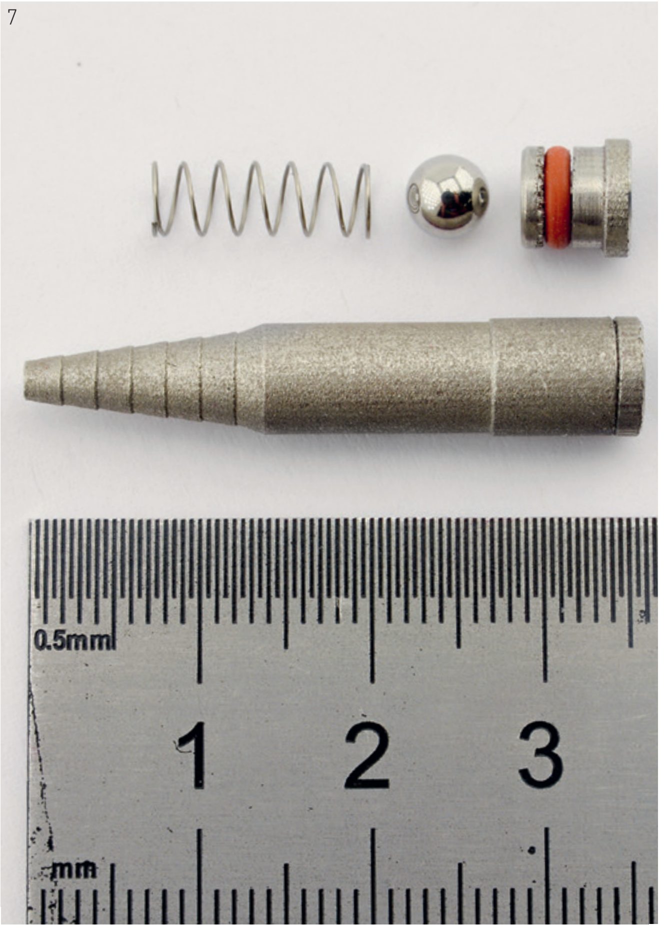

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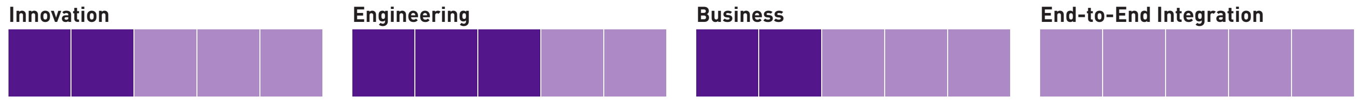
7 and 8 Second design iteration of check valve consisting of valve housing, valve plug, metal ball, spring and sealing ring

In this application, it is the combination of additive manufacturing, standard components and conventional post-processing which enables the fabrication of the check valve for the specified requirements. Due to the space-saving design, approximately 400 valve housings can be fabricated in a single batch job for a small series production. The final assembly of the valve is carried out using standard components such as metal balls, springs and sealing rings. In this way, a cost-efficient production of check valves is possible which meet the necessary requirements such as chemical resistance and fulfill the specified functionality with an optimized sealing.

Injection molds made in PEEK for silicone parts



Besides hobbyists, makerspaces and laboratories, fused deposition modeling (FDM) can be employed for professional applications with a variety of different thermoplastics. Fabru GmbH demonstrates the use of FDM to manufacture injection molds in PEEK.

Customer	**Application example**
Manufacturer	**Fabru GmbH**
Technology	**Fused deposition modeling**
Material	**PEEK**
Machine	**Plastjet 3C-855**
Produced quantity	**–**

3D printers based on Fused Deposition Modeling (FDM) are commonly employed by hobbyists, makerspaces and laboratories for the fast and cheap manufacturing of prototypes. Print material in the form of filament is heated in a nozzle and applied layer by layer to form a part. Frequently used materials are PLA and ABS. These materials represent, however, only a small fraction of the available thermoplastic materials in the field of modern plastics processing.

There exists a large number of thermoplastics with various properties that can be utilized for different applications. The targeted use of such materials results in professional applications for FDM. In this context, the company Fabru GmbH is developing printers and filament for FDM. The goal is to be able to process a wide range of thermoplastic materials without the necessity to make changes on a 3D printer, including its printing head. An application example of Fabru GmbH demonstrates the use of FDM for processing PEEK (polyether ether ketone). In this case, molds are made of PEEK for injection molding of silicone parts, in this case a sealing ring.

There are several reasons for manufacturing the molds in PEEK within an FDM process. In order to crosslink the silicone part, the injection molds have to be heated to a temperature of up to 200 °C. In this temperature range, almost all thermoplastics fail due to their heat resistance. In addition, the molds are exposed to high mechanical stress during injection molding. Therefore, prototype molds are often produced from metallic materials instead. However, this results in long lead times and high manufacturing costs. The use of PEEK within an FDM process avoids these disadvantages. The material has a high mechanical strength and heat resistance. Using the FDM process, molds can be fabricated comparatively quickly and cheaply with a sufficiently good surface finish. This approach is therefore particularly advantageous for prototyping and small-series production.

The Plastjet 3C-855 printer from Fabru GmbH is employed for processing PEEK. The challenge lies mainly in the high processing temperatures required for printing PEEK filament. The heating bed is heated up to 210 °C and the nozzle set to 420 °C to bring the filament into a thermoplastic state. By heating the build space, which has a dimension of 800 X 500 X 500 mm, shrinkage effects of the plastic are minimized. In this case, the temperature of the filament must not be too low, as otherwise the layer adhesion is insufficient and individual layers will then separate from each other. However, the filament must also not be heated up too much, as the material will then not be applied in a sufficiently defined manner.

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1 and 2 FDM printer Plastjet 3C-855 from Fabru GmbH

To control the temperature in the printing head and achieve thermal separation, an internal water cooler with a closed cooling water cycle is utilized. As adhesion between building base plate and PEEK filament is relatively high, removal from the base plate represents another challenge within the manufacturing. Advantages of processing PEEK are that the material possesses a good layer adhesion and shows relatively low distortion values.

The fabrication of the PEEK molds for a sealing ring takes a few hours. The required tolerances are within a range of +/– 0.05 mm. Further post-processing of the surface can be done, but is optional. To save material, the molds use integrated honeycomb structures. Although the honeycombs are enclosed, such a geometry can be implemented with the FDM process, since no openings are required in comparison to powder-based or liquid-based additive manufacturing processes.

The high mechanical properties of PEEK and its high temperature resistance lead to tough molds. Injection molding can be used to produce a small series of components. Further improvements of the material properties of PEEK are possible if short fibers are added to the filament. All in all, applying PEEK in combination with the FDM process allows producing complex and robust molds for prototypes or a small series in a fast and cost-effective way.

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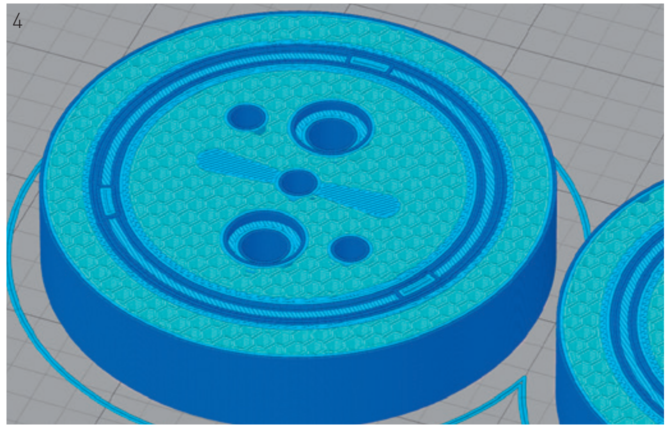

In the area of modern plastics technology, PEEK is used in addition to many other thermoplastic materials. Several other plastics are nowadays also produced as filament for additive manufacturing and processable with FDM. For instance, in comparison to expensive PEEK, PEI (polyetherimides) or polycarbonates (PC) are also suitable as temperature-resistant materials for molds. These materials can also be processed with the Plastjet 3C-855 printer from Fabru GmbH. In principle, depending on the application, the right material has to be combined with the right design for FDM in order to achieve an added value. In this respect, FDM offers many advantages and besides the common materials PLA and ABS, it offers a wide range of other plastics for innovative applications.

3 FDM-printed PEEK molds with silicone sealing ring

4 Honeycomb structures integrated in injection molds

Additive manufacturing for high-end cameras – a success story continued

Innovation

Engineering

Business

End-to-End Integration

ALPA Capaul & Weber AG develops high-end medium-format cameras. Starting from customized lens shades, the company successfully implemented additive manufacturing in a step-wise manner into its product portfolio.

Customer	**Professional photographers**
Manufacturer	**ALPA Capaul & Weber AG**
Technology	**Laser sintering**
Material	**Various polymers like polyamide (PA), thermoplastic polyurethane (TPU)**
Machine	**–**
Produced quantity	**100 – 1,000 per year**

ALPA Capaul & Weber AG from Zurich specializes in the development of high-end medium-format cameras. The previous report released in 2016 had already presented this company with its products. At that time, the focus was on high-variety lens shades for modular camera setups. Lens shades are mounted at the front of the camera lens in order to prevent reflections in the lens during complex lighting conditions.

Using additive manufacturing enables many advantages of this kind of application. The design freedom allows fabricating modular, individually adapted lens shades. These are customized according to the lens and digital back of the camera. Different configurations are created based on parametric CAD models. The production is carried out by laser sintering of thermoplastic polyurethane (TPU). The comparatively light material has flexible, rubber-like properties. In addition, its durability and water resistance makes TPU perfect for the regular use of the cameras. Furthermore, a rough surface due to additive manufacturing further decreases reflections.

In this way, the company was able to offer its customers a wide range of easy-to-handle lens shades, of which the shape is precisely adapted to the individual camera setup. This allowed the company to add a number of variable products to its portfolio without having to make major investments in advance. Such a degree of flexibility would hardly be possible with another production method.

Since the last report, ALPA Capaul & Weber AG has been working consistently on expanding the use of additive manufacturing in its product portfolio. Over the last two years, several further developments have been implemented, which are outlined in the following. From the company's point of view, it is described what experience was acquired by successfully implementing additive manufacturing.

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ALPA managed the introduction of AM technologies in a step-wise manner. Such an approach aims at raising the complexity of targeted applications with an increasing understanding of the whole AM ecosystem. It is important to emphasize that lens shades represented the first step into additive manufacturing. Similar parts tackled in the early phase include modules such as covers, handles, or other accessories. Such type of components are not function critical or highly loaded, nor do they have a very complex interface or critical requirements on tolerances. For such parts, additive manufacturing is advantageous and offers a clear application case with customer benefit. In this first step, the aim was to gain initial experience, generate basic expertise and establish a first process chain. Besides knowledge in "design for additive manufacturing", this includes choosing a suitable manufacturing process with the right material and post-processing technology as well as establishing a collaborative relationship with suppliers.

1 and 2 Customized lens shades for high-end cameras

3 – 5 Laser-sintered accessories like covers and handles

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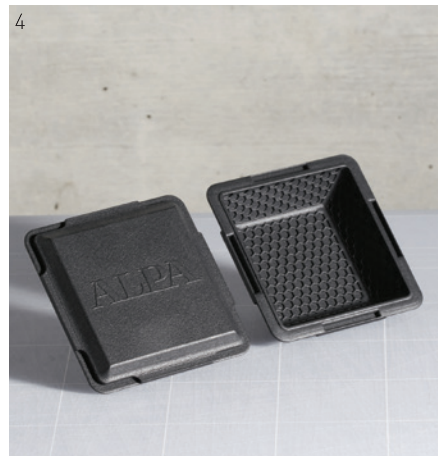

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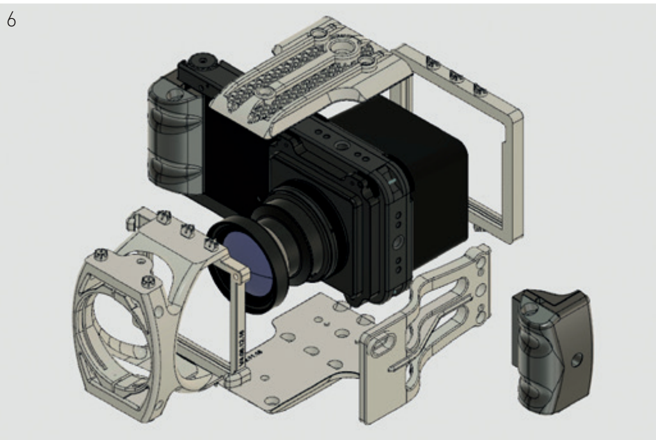
This first process chain covered three important areas, namely identifying the right application with a suitable design, production with a robust supply chain together with partners, and validating the business case. Based on this, the second step of implementing additive manufacturing was to increase the complexity in all three areas and further improve the process chain.

For instance, regarding design, functional assemblies with a higher degree of complexity than in the first phase were developed and additively manufactured. An example is the photogrammetry camera ALPA 12 FPS add|metric. Photogrammetric techniques allow fast, contactless and precise acquisition of complex geometries. For this purpose, photogrammetric applications require increased mechanical stability. Using laser sintering of reinforced polyamide, digital medium format cameras were adapted and optimized for such applications. The ALPA 12 FPS add|metric was successfully tested and resulted in a high accuracy for photogrammetric applications. The development process benefited not only from the design freedom of additive manufacturing, but also from short innovation cycles and cost advantages in small series production. Further details on this application were recently presented at the AMPA conference at ETH Zurich.



6 and 7 Photogrammetry camera ALPA 12 FPS add|metric with assembly

Based on the success and acquired expertise in the first and second phases, the aim of the third phase was to systematically integrate additive manufacturing into the product development processes and adapt them accordingly. The company recognized that the design approach could be further improved by implementing agile hardware development principles. In this context, it is also important to respond to new market requirements. Trends include the emergence of new markets such as the increased demand for customized products, the rapid development and adaptation of components for various camera setups, and the increased use of video in addition to photography in advertising.

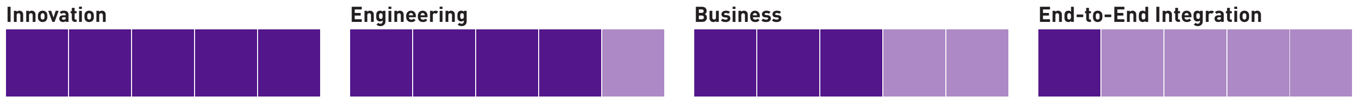
One example is the agile development of a high-end video camera for a Hasselblad H6D-100c digital back. In several short sprints the video camera with its features like mounts for camera and battery was developed. Several different prototypes were fabricated by means of laser sintering. After each sprint, lead users tested the developed

product features. Based on usability tests, these were further improved and retested. Product improvements are thus incrementally released and quickly validated. The feedback was used to fine-tune the product. As a result, a better product-to-customer fit was achieved. In addition, the total time-to-market accounted for only around six months.

8 and 9 High-end video camera for Hasselblad H6D-100c digital back

In retrospect, the showcase successfully demonstrates how additive manufacturing can be introduced in a company within three phases. The first step is to set up a complete process chain for rather simple designs and non-critical applications (one material, one process), which offer a clear value-adding benefit for additive manufacturing. The second step is aimed at gradually increasing its complexity regarding the relevant areas, e.g., new materials, more complex designs, different post processing combinations, order processing. Based on the acquired knowledge, the third phase seeks to adapt the underlying product development processes and systematically make use of additive manufacturing in order to identify opportunities for new products and business cases. In this context, the uncertainty, risks and capital investments required for the launch of new and innovative product concepts is also reduced. In the near future ALPA Capaul & Weber AG aims at advancing their products employing the advantages of additive manufacturing. Just recently, the company was granted a CTI project to develop further design practices, supply chain processes and business models.

Parts featuring built-in electrical wires



AMAR relates to a novel AM-based design concept enabling the development of parts featuring built-in electrical wires. The concept is successfully applied to redesign the rotor of a Slip-Ring Assembly leading to drastic product simplifications.

Customer	**RUAG Space Switzerland Nyon and CSEM SA**
Manufacturer	**3D Precision SA and ProtoShape GmbH**
Technology	**Laser sintering, laser melting**
Material	**Aluminum and copper**
Machine	**Concept Laser GmbH, SLM Solutions Group AG**
Produced quantity	**More than 10 prototypes**

The following showcase describes the outcome of AMAR, a project related to the redesign of a SlipRing Assembly rotor (SRA rotor), based on additive manufacturing. This project was carried out by RUAG Space Switzerland Nyon (RSSN), jointly with CSEM, each partner bringing its own expertise, respectively the design of SRAs and the re-design of an existing product based on advanced manufacturing technologies. AMAR was funded by the SERI's Swiss Space Office (SSO).

SRAs are electrical continuity devices intended to transfer electrical signals from a stationary member to a rotating member. SRAs are used on earth for a broad range of applications such as video surveillance, machine-tool, motion simulators and many others. In space, SRAs are recurring elements in satellites where they can be found in Solar Arrays Drive Mechanisms (SADMs), Antenna Pointing Mechanisms, Momentum Gyroscopes and other instruments. In its current state-of-the-art physical architecture, the rotor of an SRA consists of a stacking of high-precision insulating and conductive rings, each conductive ring being manually soldered to an electrical wire, itself routed to the extremity of the rotor. The stack is interfaced to a structural central shaft, and the whole assembly is mechanically stabilized by a matrix of casted resin.

Today, the production of SRA rotors is a long and delicate process involving a large number of components and production operations. As a rule of thumb, the number of components increases with the number of electrical channels to be included in the rotor, following a multiplicative factor of three. In other words, each channel to be achieved involves three components: an insulating ring, a conductive ring and an electrical wire. Unsurprisingly, the manufacturing and assembly efforts tend to increase accordingly, as well as the probability of reliability issues. In this context, the motivations to undertake a development project such as AMAR were obvious. SRAs being among RSSN's flagship products, a set of strategic objective was defined, namely to reduce the manufacturing and assembly costs by more than 40%, whilst improving the

overall reliability and repeatability of the end product. The redesign was also expected to enable a mass decrease of the rotor and to avoid the use of cables, which are part of the current physical architecture.

To fulfill these objectives, CSEM developed a new design and manufacturing concept, which makes it possible to merge the two essential features of the SRA rotor: the mechanical structure and the electrical conductors, including their electrical connection interfaces. The parts being produced can take various 3D shapes and therefore accommodate to a broad range of product specifications. Thanks to the suppression of cables, monolithic designs of electromechanical components featuring built-in conductive wires can be envisioned, enabling significant simplifications of the assembly sequence.

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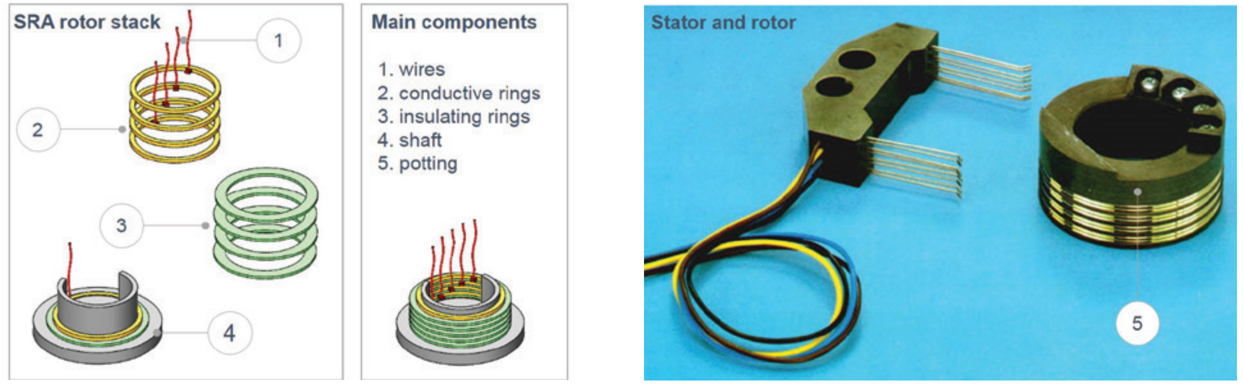

1 State-of-the-art architecture of a SlipRing Assembly rotor (SRA rotor)

The design concept relies on the AM production of a monolithic structure comprising a structural hull and a plurality of electrical wires mechanically linked to the hull by means of sacrificial bridges. Various AM technologies can be applied, depending on the application requirements. As a second step, the structure is filled with insulating material. The insulating material is cured and finally, the sacrificial bridges are removed by means of a conventional subtractive process. The resulting component is a mechanical part featuring a built-in electrical conductor. The termination of the wires can take various shapes to achieve the function of electrical connection interfaces, such as pin, crimping, spring or slip ring contact. The shape of the wire terminations "A" and "B" can be directly achieved during the AM fabrication step or reshaped during the post-AM remachining already mentioned, when high precision is requested. The structural hull may comprise additional features such as mechanical interfaces, reference surfaces, flexure elements, lattice structure and many others, all of them being achieved "by design" during the AM fabrication or during the post-AM remachining.

The displayed figure describes the new physical architecture of the SRA rotor part in a simplified way. For more clarity, the built-in wires are all gathered within a 2D imaginary plane. The design includes 12 annular shape slip ring interfaces on the wire termination "A" and 12 soldering interfaces on the wire termination "B." As depicted, the slip rings are intrinsically comprised into the monolithic structure, as built during the AM process. After casting and curing, the external shell of the structural hull is remachined and the separated rings appear encapsulated in the resin. The structural stiffness of the rotor is henceforth provided by the remaining metallic structure, or by the resin volume if the structural hull is completely removed.

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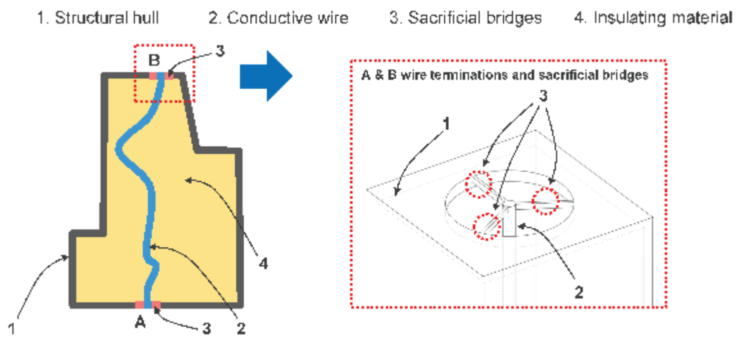

2 Design concept of parts featuring built-in electrical conductors

The detail design was jointly elaborated between RSSN and CSEM. During this phase, the geometries were defined so that the use of support material could be completely avoided. Depending on the prototype versions, the diameter of the built-in wires was set in a range of 0.5 to 1 mm and two wire termination alternatives were implemented at "B": axially oriented remachined soldering pin-holes and radially oriented AM-made soldering cradles. The external diameter of the rotor after final machining is a cylinder of 33 mm diameter and 44 mm height.

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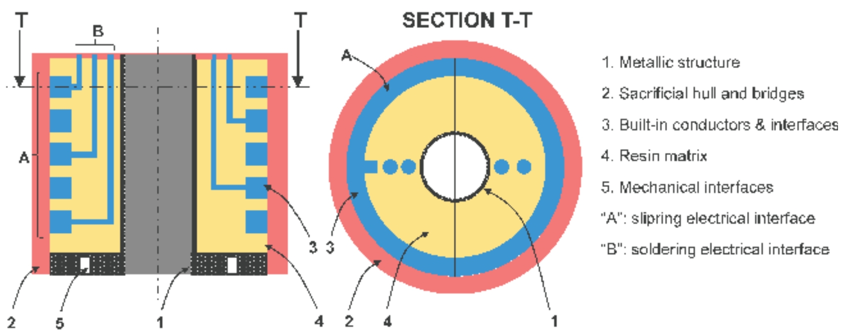

3 Design concept implementation for SRA rotor

The final design was manufactured by means of laser melting, using the standard AlSi10Mg aluminum alloy. After the additive fabrication, the usual post-process steps of stress relief annealing, part separation and precision cleaning were executed. The part was then filled with an epoxy resin, cured and remachined in order to remove the external shell of the structural hull and the sacrificial bridges. After remachining, a gold layer is selectively applied to the surface of the slip rings in order to improve the tribological and electrical performances of the SRA rotor during operation. At the end of the sequence, cables were soldered to the final part which was then mounted on a performance test bench.

The electrical properties of the rotor prototype were fully validated in terms of electrical continuity, insulation resistance and dielectric strength. The dynamic electrical noise and lifetime performances were also verified, showing satisfying results for SADM

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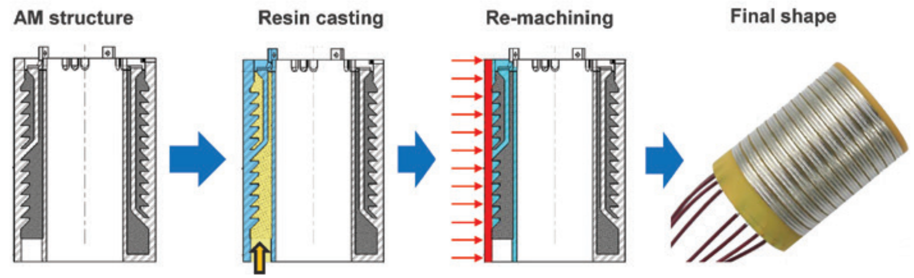
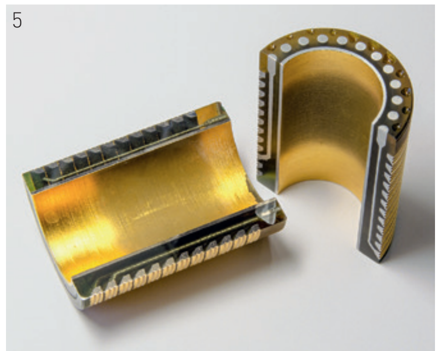
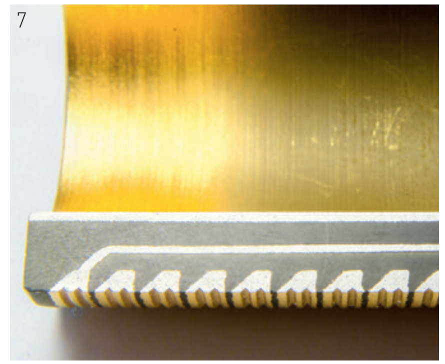


4 Manufacturing route for SRA rotor

applications intended to Low Earth Orbit (LEO) and Geostationary Orbit (GEO) operated missions. A set of improvements was implemented to the next generation of prototypes in order to further improve some key characteristics such as dynamic electrical noise and rotor compactness, targeting a broader range of applications. Considering a number of 24 electrical tracks to be implemented, the new concept enables a reduction of the components from more than 70 parts to a single one, inducing a drastic decrease of the manufacturing and assembly efforts. The new concept also allows a significant reduction of the overall mass, since the central shaft can be removed or optimized. As wished, the new physical architecture of the rotor does not include cables anymore, which contributes to improving the reliability of the system. Based on a preliminary analysis performed at the end of the project, the cost reduction objective of 40% is considered as realistic. To consolidate this value, the development shall be further continued in order to fully define the design geometries and the process parameters. The final prototype shall then be fully qualified with respect to the application requirements foreseen. These very positive results pave the way for a continuation of the development, possibly in the framework of the European Space Agency (ESA) programs.





5 - 7 Final SRA rotor prototype

During this 14-months project, a number of prototypes and design implementation tests were performed, thanks to the very short delivery time for the parts produced by laser melting. These multiple iterations allowed us to deeply understand the relevant parameters for a successful implementation of the design concept. The very successful outcome of AMAR does not only confirm the applicability of the concept to the SRA rotor application, but also to other products which could advantageously benefit from the same improved redesign. RSSN and CSEM would like to thank 3D Precision SA and ProtoShape GmbH for their active participation in the project.

Production of casted spare parts in reduced lead-time

Innovation **Engineering** **Business** **End-to-End Integration**

The application of Benninger Guss AG demonstrates how a digital process chain can be combined with binder jetting and sand casting to produce spare parts in a fast and cost-efficient manner for complex and large geometries.

Customer	**ABB Turbo Systems AG**
Manufacturer	**Benninger Guss AG**
Technology	**Binder jetting**
Material	**Silica sand**
Machine	**ExOne S-Max**
Produced quantity	**1**

Long-lasting components have the requirement to operate over a long period without failure. In the event of damage, the manufacturer usually guarantees the supply of spare parts – in some cases for decades. Fast production of spare parts is essential to continue operations as quickly as possible. Particularly for larger components with complex geometries, it is important to supply spare parts quickly and cost-efficiently. With older cast components, there is often no longer a model (tool) available and drawings are no longer valid or not available anymore. Nevertheless, the spare part should meet today's quality requirements.

Such a scenario applies, for example, to turbochargers of marine diesel engines. For this application, Benninger Guss AG was commissioned to produce spare parts for turbochargers. In this particular case, the original component was produced in the early 1980s using a conventional sand casting process with a model. The dimensions of the component are 1200 X 800 X 640 mm with a mass of approximately 200 kg. For the part, the customer provided a reference part as well as 3D data created from the original drawings. On this basis, Benninger Guss AG was commissioned to produce a completely machined, ready-to-install spare part. In order to solve this problem quickly and cost-effectively, Benninger Guss AG applied the following process.

The existing drawings and the 3D model from the customer served as a starting point for the reconstruction of the part geometry. Using a contactless and portable 3D scanner, Benninger Guss AG captured the geometry of the reference part without having to destroy the component. For reverse engineering, the 3D model generated from the scan data and the 3D model provided by the customer were superimposed and compared to each other. The deviations and inaccuracies displayed with a color map were compared and corrected in several steps. The 3D model resulting from this process was released by the customer for production.

Based on the reconstructed part geometry, the casting technician created the mold filling and feeding system. The challenge was to produce a flawless casted part right the first time. For this purpose, mold filling and solidification simulations were carried out to analyze the casting process for the complex geometry. The obtained results led to the final design of the casting system. Based on the part geometry and the final casting system, the individual molded parts were then designed. In this case, four partial molds were necessary, a base plate, an intermediate piece, a lid and a core.

1

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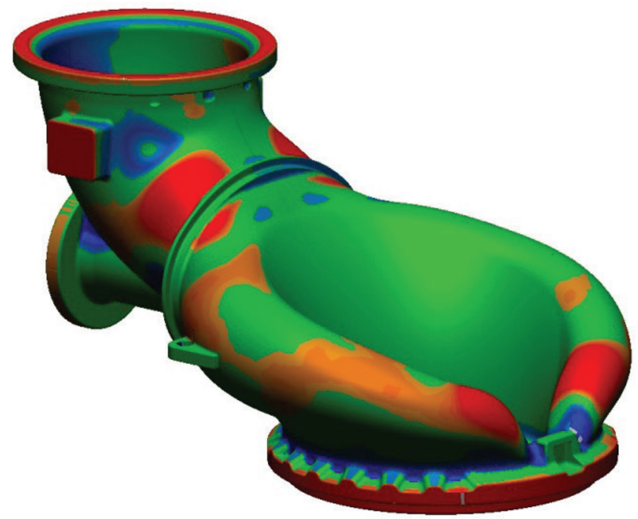


1 Casted spare part for turbocharger of marine diesel engine

2 Comparison between 3D scan data and reconstructed CAD model

An ExOne S-Max printer with a maximum build volume (job box) of 1,800 X 1,000 X 700 mm was used for the production of the individual partial molds employing binder jetting of silica sand. In this additive manufacturing process, a binding agent is applied to selected areas of the silica sand through a print head. After the printing process, the individual molded parts were removed from the build volume and the molded parts had to be separated from loose powder material.

The cleaned molded parts were then joined together and assembled to form a complete mold. The subsequent production steps are the same as those of the conventional sand casting process. Melt was poured into the prepared molds. A special temperature-resistant alloy is used for turbocharger parts. For the final treatment, the raw castings were blasted, plastered, primed and mechanically processed. The ready-to-install spare part could then be delivered together with the test certificates.

The described process offers many advantages in the production of spare parts. The use of the binder jetting process makes it possible to fabricate components with complex geometries quickly and cost-effectively. In the above example, the lead time was reduced by 26 working days to 70 working days compared to the conventional procedure. This time saving is particularly important when it comes to the supply of spare parts. In this particular case, a cargo ship could be put back into service much earlier.

3 ExOne machine used to fabricate sand casting molds through binder jetting

Assuming that a model (tool) is no longer available for the production of a complex component, the described additive process offers considerable cost advantages compared to the conventional manufacturing process. In the present case, the savings amount to CHF 54,000.00 compared to the conventional method (total CHF 80,000.00, of which the model costs CHF 67,500.00). The break-even point, i.e. the quantity at which the conventional process becomes cheaper, would in this case occur with approximately 16 spare parts!

Rapid prototyping of turbocharger turbines made in Inconel 718

Innovation **Engineering** **Business** **End-to-End Integration**

For the development of turbocharger turbines, ProtoShape GmbH shows how rapid prototyping can be used to quickly and cost-effectively produce prototypes for testing. The turbines are made in Inconel 718 and possess thin-walled fins.

Turbochargers are employed in combustion engines to increase their performance and efficiency. The basic principle works as following: exhaust gases produced by the combustion drive a turbine whose energy is used to compress the intake air at the engine inlet. As a result, the airflow rate is increased and the suction work of the engine pistons is reduced. Exhaust gas chargers are utilized in engines of construction vehicles, locomotives, generators, power plants or ships. A turbocharger includes compressor and turbine wheels which rotate at high speed and are exposed to the high temperatures of the exhaust air. To achieve a high fatigue strength of the components, commonly used materials include nickel-based super alloys and titanium alloys.

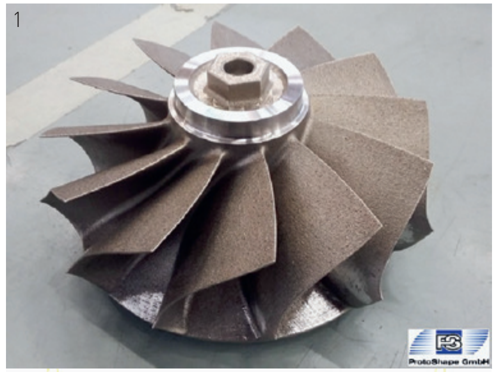
Customer	**ABB Turbo Systems AG**
Manufacturer	**ProtoShape GmbH**
Technology	**Laser melting**
Material	**Inconel 718**
Machine	**SLM 250 HL**
Produced quantity	**<10**

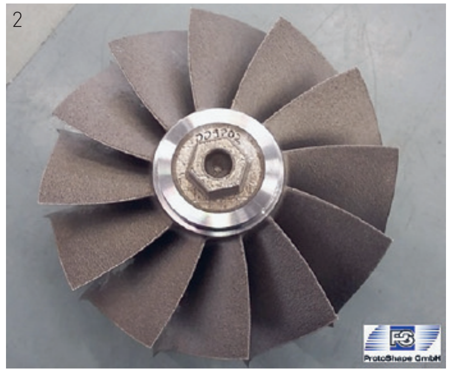
ProtoShape GmbH was assigned by ABB Turbo Systems AG to fabricate turbine wheels applying additive manufacturing. In particular, the task was to manufacture it in the nickel-based super alloy Inconel 718 using laser melting. Inconel has the advantage that it is very durable, especially for cyclically loaded and rotating components. Although this alloy has been used in additive manufacturing for a longer period of time, the challenge for ProtoShape was to fabricate the more complex geometry of the turbine wheel with its relatively thin fins with a wall thickness of only about 1 mm.

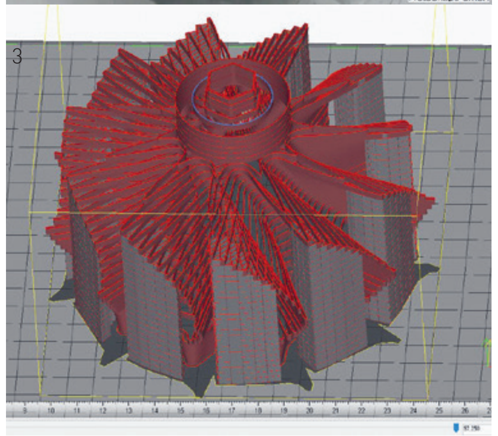
Manufacturing the turbine wheel in the specified material innovation required ProtoShape GmbH to solve three main problems. Essentially, these are the definition of support structures for the build process, the selection of a suitable set of process parameters and the preparation of the geometry for post-processing steps.

Support structures were applied between the build plate and the turbine wheel. These support structures are comparatively massive to allow a sufficient heat transfer between the part and base plate. Thinner structures would lead to high thermal deformations, either resulting in larger inaccuracies or a cracking of the support structures. Besides supports at the bottom of the part, additional struts are also applied at the lower side of the fins to transfer heat generated during the build process to the base plate. The support structures were created in the software Autofab. The relative orientation of the part results from the basic geometry of the turbine wheel.

Besides the definition of support structures, ProtoShape GmbH had to fine-tune the process parameters to fabricate the turbine wheel with the thin-walled fins in Inconel 718. Basic parameters that can be changed are, for instance, the velocity, hatch distance and power of the laser beam during the laser melting process. In this respect, the objectives are to attain an accurate part geometry with a sufficiently high material density, to avoid hot cracks due to an increased local heat accumulation, and to achieve a stable build process with a reduced build time. Identifying optimized trade-offs was possible by ProtoShape GmbH using tests with different parameters and based on prior experience. The final build time of a single turbine wheel with an SLM 250 HL machine amounted to 32 hours.



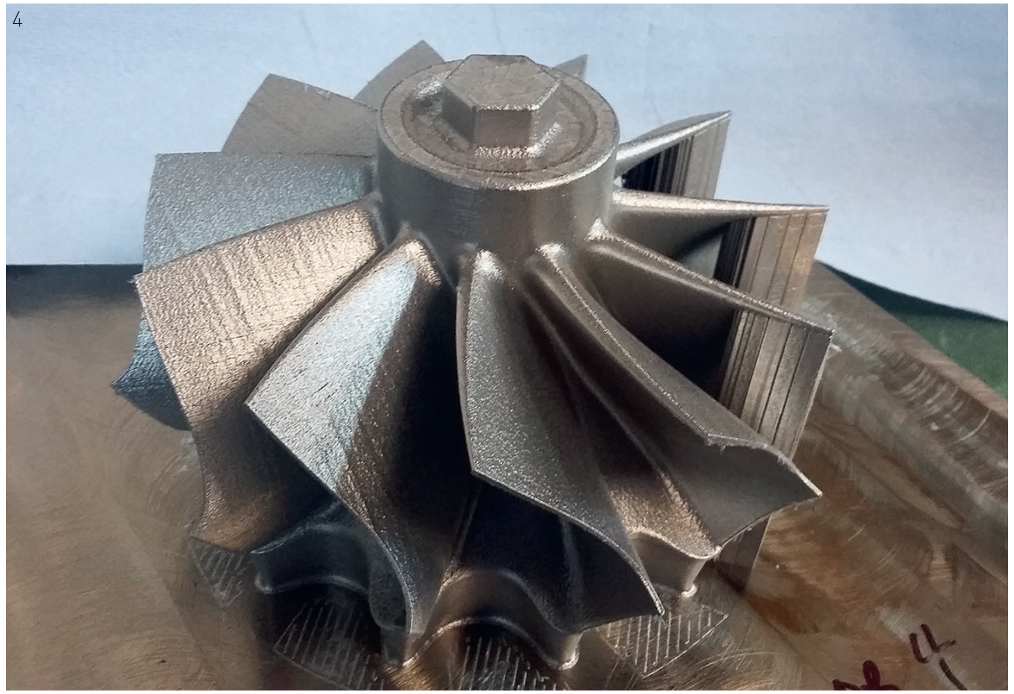


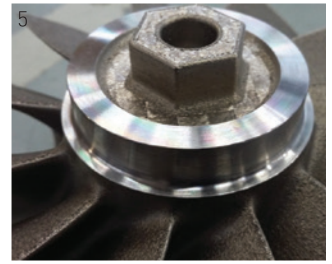


1 and 2 Laser melted turbine wheel made of super alloy Inconel 718

3 Support structures for turbine wheel generated in Autofab

In order to post-process the additively manufactured turbine wheel, the original geometry was modified prior to the build process. This includes machining allowances and production aids to clamp the part. After the build process, support structures are removed and the part is detached from the base plate employing wire cutting. After sand blasting, the part is clamped and functional surfaces are turned. After the post-processing step, ProtoShape GmbH delivered the final turbine wheel to ABB Turbo Systems AG after about four weeks. ABB Turbo Systems AG successfully tested the final turbine wheel part.





The showcase demonstrates well how additive manufacturing can be used to fabricate functional prototypes for testing in a short period of time. In this particular case, a robust fabrication of a more complex geometry was accomplished in Inconel 718 by applying a suitable combination of support structures and process parameters. In comparison, the fabrication can take up to several months using conventional manufacturing methods. In summary, additive manufacturing allows a rapid fabrication of complex parts, also with special materials, thereby enabling a fast, flexible and cost-efficient testing.

4 Fabricated turbine wheel with attached support structures

5 Post-processing of turbine wheel by means of turning

Swiss institutions with research focus in additive manufacturing

FHNW University of Applied Sciences Northwestern Switzerland
Brugg-Windisch, Muttenz

BFH Bern University of Applied Sciences
Biel-Bienne, Burgdorf

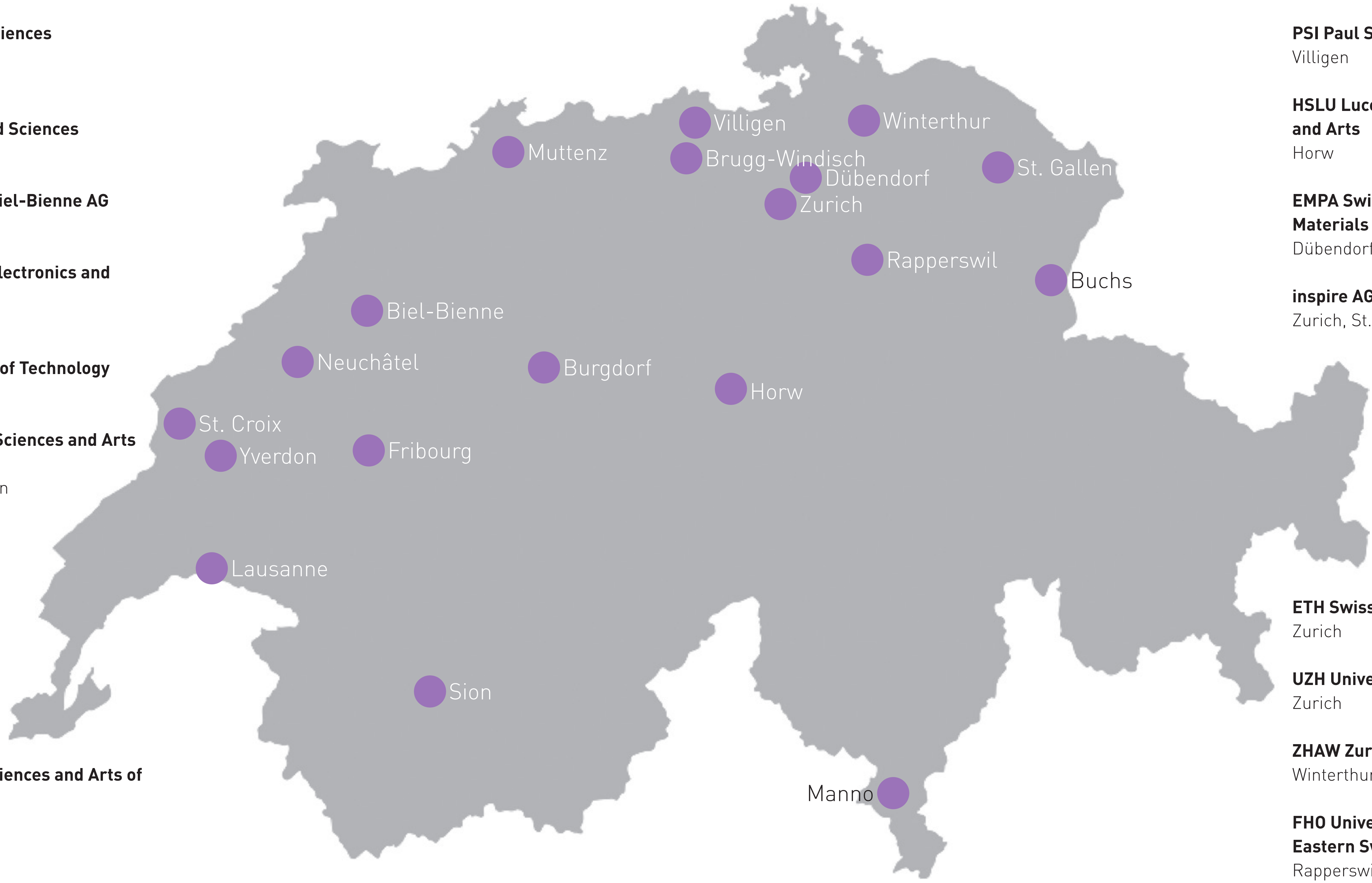
Switzerland Innovation Park Biel-Bienne AG
Biel-Bienne

CSEM Swiss Center for Microelectronics and Microtechnologies
Neuchâtel

EPFL Swiss Federal Institutes of Technology
Lausanne, Neuchâtel

HES-SO University of Applied Sciences and Arts Western Switzerland
Fribourg, Yverdon, St. Croix, Sion

SUPSI University of Applied Sciences and Arts of Southern Switzerland
Manno



PSI Paul Scherrer Institute
Villigen

HSLU Lucerne University of Applied Sciences and Arts
Horw

EMPA Swiss Federal Laboratories for Materials Sciences and Technology
Dübendorf, St. Gallen

inspire AG
Zurich, St. Gallen

ETH Swiss Federal Institutes of Technology
Zurich

UZH University of Zurich
Zurich

ZHAW Zurich University of Applied Sciences
Winterthur

FHO University of Applied Sciences of Eastern Switzerland
Rapperswil

Specialized institutes in additive manufacturing research

BFH Bern University of Applied Sciences
Engineering and Information Technology

BFH Bern University of Applied Sciences
Engineering and Information Technology, Print Technology

BFH Bern University of Applied Sciences
HKB Bern University of Arts, Materiality in Art and Culture

CSEM Swiss Center for Microelectronics and Microtechnologies

EPFL Swiss Federal Institutes of Technology Lausanne
Competence Centre for Materials Science & Technology (CCMX)

EPFL Swiss Federal Institutes of Technology Lausanne
School of Engineering, IMT Institute of Microengineering Lausanne

EPFL Swiss Federal Institutes of Technology Lausanne
School of Engineering

EPFL Swiss Federal Institutes of Technology Lausanne
School of Basic Sciences, ISIC Institute of Chemical Sciences and Engineering

EPFL Swiss Federal Institutes of Technology Lausanne
Laboratory of Thermomechanical Metallurgy (LMTM)

EMPA Swiss Federal Laboratories for Materials
Sciences and Technology

ETH Swiss Federal Institutes of Technology Zurich
D-MATL Department of Materials, Complex Materials

ETH Swiss Federal Institutes of Technology Zurich
D-MAVT Department of Mechanical and Process Engineering, IWF Institute for Machine Tools and Manufacturing

ETH Swiss Federal Institutes of Technology Zurich
D-MAVT Department of Mechanical and Process Engineering, IDMF Institute of Design, Materials and Fabrication

ETH Swiss Federal Institutes of Technology Zurich
D-MTEC Department of Management, Technology and Economics

FHNW University of Applied Sciences Northwestern Switzerland
School of Engineering, IBE Institute of Business Engineering

FHNW University of Applied Sciences Northwestern Switzerland
School of Engineering, IPPE Institute of Product and Production Engineering

FHNW University of Applied Sciences Northwestern Switzerland
School of Engineering, IPN Institute of Polymer Nanotechnology

FHNW University of Applied Sciences Northwestern Switzerland
School of Life Sciences, Institute for Medical and Analytical Technologies

FHNW University of Applied Sciences Northwestern Switzerland
School of Life Sciences, Institute for Chemistry and Bioanalytics

HES-SO University of Applied Sciences and Arts Western Switzerland
School of Management and Engineering Vaud, AddiPole, Advanced Manufacturing Center

HES-SO University of Applied Sciences and Arts Western Switzerland
School of Engineering and Architecture of Fribourg, Institute for Printing (iPrint)

HES-SO Valais/Wallis University of Applied Sciences and Arts Western Switzerland
School of Engineering, Institute of System Engineering

FHO University of Applied Sciences of Eastern Switzerland
HSR Rapperswil School of Engineering, IWK Institute of Materials Technology and Plastics Processing

HSLU Lucerne University of Applied Sciences and Arts
Lucerne School of Engineering and Architecture

inspire AG
icams Innovation Center for Additive Manufacturing Switzerland

inspire AG
inspire pdz – Design for New Technologies

PSI Paul Scherrer Institute

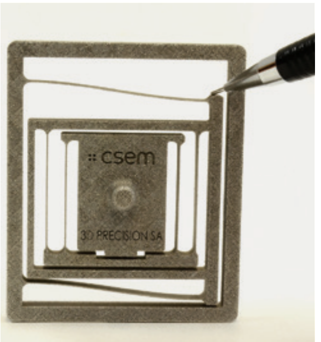
SUPSI University of Applied Sciences and Arts of Southern Switzerland
Department of Innovative Technologies

Switzerland Innovation Park Biel-Bienne AG

UZH University of Zurich
Department of Informatics

ZHAW Zurich University of Applied Sciences
School of Engineering, Centre for Product and Process Development, Advanced Production Technologies (ZPP)

ZHAW Zurich University of Applied Sciences
Institute of Mechatronic Systems (IMS)



The example above is a high-performance stainless steel compliant structure offering lifetime above 15 million linear motion cycles of +/– 5 mm. The European Space Agency acknowledged the relevance of this internally founded development and selected CSEM to design and produce a functional compliant mechanism dedicated to space applications

CSEM Swiss Center for Microelectronics and Microtechnologies

Institute

CSEM is a national innovation accelerator – a catalyst for the transfer of technologies and know-how from fundamental research to industry. This role involves four principal tasks: we develop and maintain technology platforms, we integrate and combine technologies into workable systems, we mature those technologies until using them, we add value to our industrial clients, then we support the process of transferring those technologies to industry.

Main research topics

- Optimized redesign of existing customer products and design of new products, based on AM technologies
- Advanced manufacturing of high-precision components with embedded functionalities (sensors and actuators) by combination of manufacturing technologies
- Optimization of SLM process parameters and quality control
- Qualification of the raw material (initial powders) and SLM-fabricated parts

Offer

- Combination of AM technologies with microfabrication, surface treatment/grafting and functional printing
- Characterization and optimization of material properties based on the developed protocol (applying post-processing such as HIP). Selection of the initial materials based on the developed characterization protocol (particle size, flowability, residual humidity, crystalline phase, microstructure, chemical composition ...)
- Integration of electrical connections, sensors (resistive, capacitive, piezoelectric) and/or actuators on 3D objects, by the combination of various AM technologies
- Technology transfer and licensing

Product development offer

- Customer products in-depth system analysis to identify potential improvement areas based on AM
- Product design, multiphysics simulation and multiobjective optimization (Solidworks, Comsol, Optistruct)
- Prototyping and production of high-precision components
- Product performances and metrological characterization

Technologies

Selective laser melting (SLM), UV stereolithography (SLA), UV micro stereolithography (uSLA), multimaterial platform: combination of different technologies within 1 system with up to 24 materials
Inkjet printing (single and multe-inozzle), aerosol jet printing, screenprinting, gravure printing, photonic sintering, characterization systems

Contact

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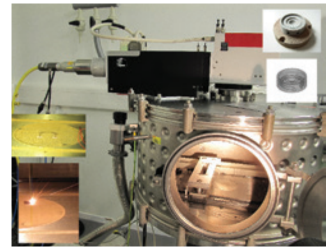
EPFL Swiss Federal Institutes of Technology Lausanne Laboratory of Thermomechanical Metallurgy (LMTM)

Institute

The LMTM has expertise in the domain of additive manufacturing of metallic components. The focus is mainly on Selective Laser Melting and on its application in micromechanics, watchmaking, jewelry and medical industries. The LMTM is a research partner in the field of additive manufacturing technology in many projects funded by the Swiss Confederation.

Main research topics

One of the research axis at LMTM concerns a better understanding of the metallurgical and physical aspects of Selective Laser Melting (SLM) and the control and design of microstructures in metals and alloys manufactured by this process. Specific research topics are optimization of process parameters for new materials and alloys and in situ combination of processes like Laser Shock Peening with SLM (3dLSP patented by LMTM) for the 3D control of residual stresses, distortions and cracks.



Experimental SLM station and some application

Offer

- Development of SLM process window for metallic materials (stainless and tool steels, nickel-based alloys, precious metals, high-entropy alloys, metallic glasses)
- Combination of SLM with thermo-mechanical treatments to improve the mechanical properties, the wear resistance, the tribological performances and/or the fatigue life of parts
- Thermomechanical testing of materials (Gleeble 3800 Physical Simulation System)
- Characterization of microstructures (FEI XLF30 scanning electron microscope with EDS and EBSD detectors)
- Characterization of mechanical properties like hardness by microindentation (Qness Q10A)
- Evaluation of residual stresses by hole drilling (SINT Technology MTS3000 Restan)

Technologies

Selective Laser Melting: powder bed process for metals: The LMTM operates an open SLM station: 500 W per laser, 3-axis scan head, infrared thermometry, powder preheating up to 300 C, controlled atmosphere, powder characterization sensors for thermal conductivity or laser absorptivity
Laser Shock Peening: surface treatment for metals: The LMTM is equipped with a SAGA HP laser (wavelength: 1.064 m, high energy per pulse: 2.3 J, low repetition rate: ← 10 Hz with pulse duration: 6.3 ns)

Contact

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+41 (0)21 695 42 69, roland.loge@epfl.ch, www.lmtm.epfl.ch

EMPA Swiss Federal Laboratories for Materials Sciences and Technology

Institute
Empa conducts cutting-edge materials and technology research, generating interdisciplinary solutions to major challenges faced by industry, and creates the necessary scientific basis to ensure that our society develops in a sustainable manner. Advanced manufacturing and in particular additive manufacturing is one of the focus areas of Empa's Department for Advanced Materials and Surfaces. As part of the ETH domain, Empa is committed to excellence in all its activities.

Main research topics
The AM research activities at Empa focus on the materials science aspects in the additive manufacturing of metals, ceramics and polymers at different length scales (nm–cm). In particular Empa is active in the following three areas:
- New materials for and by additive manufacturing
- Powder processing and functionalization
- Insitu monitoring and modeling of additive manufacturing processes

Prof. Dr. Patrik Hoffmann monitoring a lab equipment at Empa in Thun

Offer
Research collaborations:
- Joint research with industry partners where the tasks and the results are shared
- Public research that ais supported by research programs, e.g., from SNSF, Innosuisse or the EU
- Contract research where the industry partner pays for the work of Empa and receives the results

Analytical services, e.g., material or product characterization and measurements
Conferences, seminars, workshops or trainings

Technologies
Metals:
- Selective Laser Melting (SLM) powder bed
- Laser Metal Deposition (LMD) powder feed

Polymers and composites:
- Stereo Lithography (SLA)
- Direct Ink Writing (DIW)

Ceramics:
- Fused Deposition Modeling (FDM)
- Selective Laser Sintering (SLS)
- Stereo Lithography (SLA)

Dr. Christian Leinenbach operating an SLM machine in Empa's Coating Competence Center in Dübendorf

Contact
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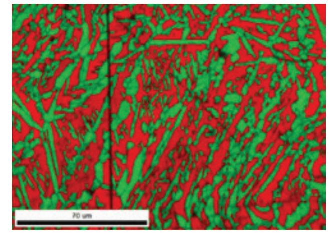
+41 (0)58 765 47 87, lars.sommerhaeuser@empa.ch, www.empa.ch

FHNW University of Applied Sciences Northwestern Switzerland School of Engineering, Institute of Product and Production Engineering IPPE

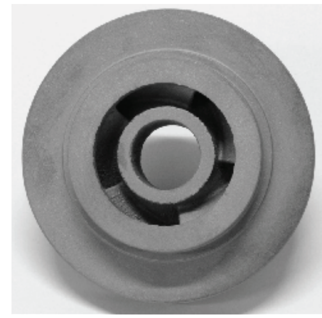
Institute
The Institute for Product and Production Engineering (IPPE) at the School of Engineering of the FHNW performs research and development in the field of metallic additive manufacturing (AM) with special focus on industrial applications such as, e.g., aeronautics and turbomachinery. It features a Selective Laser Melting machine on which parts are 3D printed in aluminum, steel and nickel-based superalloys.

Main research topics
The faculty and staff at IPPE have broad expertise in the entire product development cycle from design, simulation, optimization and validation for AM, to the AM process itself where experts in laser physics and materials science ensure the stability and quality of the manufacturing process. Research projects are always collaborations with industrial partners, often cofunded by the Swiss government, and have a typical duration of 1–2 years. The institute, however, is also at the industry's disposal for rendering short-term services.



Austenitic-ferritic microstructure of Duplex Stainless Steel processed by SLM at IPPE (project funded by CTI)

Offer
- Design for additive manufacturing
- Finite element simulation
- Topology optimization
- Selective laser melting process simulation
- 3D scanning
- Mechanical testing (static, fatigue, random vibration)
- Material characterization (metallography, electron microscopy including EDX)
- Large machine shop



Pump impeller designed and produced by SLM at IPPE (project funded by CTI)

Technologies
- Selective Laser Melting
- Photopolymer Jetting

Contact
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FHNW University of Applied Sciences Northwestern Switzerland
School of Life Sciences, Institute for Medical and Analytical Technologies

Institute

The Institute for Medical and Analytical Technologies at the School of Life Sciences of the University of Applied Sciences Northwestern Switzerland in Muttenz has long-standing experience in medical additive manufacturing. In the context of applied research and development, the close cooperation between the FHNW and regional, national as well as international commercial enterprises facilitates access of public institutions to state-of-the-art research results and the transforming of ideas into practice-oriented products and processes.

Main research topics

The IMA has committed to AM for medical application, using various printing technologies and materials. The application of SLM enables us to realize metallic implants and instruments. We have established the planning, modelling, production and characterization of titanium implants. Printing materials such as magnesia and shape-memory alloys expand the technology towards novel printed material offering unique properties. Bioprinting focusing on AM of biological material like extracellular matrices and cells, for medtech and pharma applications.

Implants from the 3D printer made of titanium and hydroxyapatite

Offer

- ISO 13485-conform process chain for patient-specific implants from image up to sterile packaging, including planning, modelling, production and characterization, as well as microstructural, surface analytical, static and dynamic mechanical and computational analyses
- Porous structures with anatomically adapted gradients with adjustable lattice type, microarchitecture and porosity to adjust the Young's modulus according to the biomechanical needs
- First patient-specific implants placed in a trauma and an oncology patient. A spin-off (Mimedis) was founded, aiming to commercialize patient-specific implants for better clinical outcomes and was sold to Medartis AG
- Process development and application of AM for novel printed materials like metals or ceramics
- Process development for vital materials like cells and 3D structures like extracellular matrices

Technologies

Various Selective Laser Melting systems for metallic implant materials; printing system for bioceramic materials; multijet printing system for plastic-like and rubber-like materials; inkjet-based printing platform; extrusion-based bioprinting for combined avital-vital structures; complete testing and characterization environment.

Contact

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HES-SO University of Applied Sciences and Arts Western Switzerland
School of Management and Engineering Vaud, AddiPole, Advanced Manufacturing Center

Institute

AddiPole is a joint center gathering the competencies and resources from 3 public institutions. Based on more than 10 years of experience in various fields surrounding advanced manufacturing, AddiPole has built a strong expertise helping regional industries developing new products. AddiPole offers services in every step of the value chain, with the possibility to involve various research institutes within our organizations.

Main research topics

AddiPole is at the crossroads of applied research and services for the industry, with specific skills regarding 3D scanning and process engineering. Current research areas focus on process engineering for mixing conductive and non-conductive layers for additive manufacturing.

3D scanning helps in controlling products, either with laser or probe measurement. It is also a key technology for the reverse engineering of products, pieces, tools or artifacts

Offer

AddiPole is active in 3 fields :

- Applied research: we are digging to find new and better use of the existing technologies surrounding additive manufacturing. When needed, we collaborate with other academic institutions to pursue a common goal where each partner finds their valuable output
- Education: the professors taking part in AddiPole are teaching the next generation of technicians and engineers how to use advanced manufacturing technologies at the CFC, technician ES, bachelor and master levels. In addition to that, AddiPole offers continuing education for professionals and nonprofessionals, as well as tailor-made workshops within companies, to answer specific needs and ensure privacy
- Services: AddiPole is a relatively small structure, offering a fast and flexible service to the industry. From the functional analysis to the market study, we offer in situ 3D scanning with high-end machines, CAD modeling, moulding or additive manufacturing

Technologies

AddiPole handles 3 additive manufacturing technologies: FDM, SLA and SLS (metal and polymer). The center has mobile and static 3D scanning technologies (accuracy 0.05 mm to 0.01 mm). AddiPole enjoys as well the presence of a traditional mechanical workshop in the same building, where precision is in everyone's mind.

Contact

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HES-SO Valais/Wallis University of Applied Sciences and Arts Western Switzerland
Powder Technology and Advanced Materials Research Group

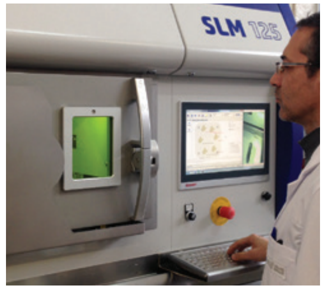
Institute

The research group hosts competencies in the manufacturing of metal and ceramic parts from powders by a number of advanced techniques. It has extensive experience in powder handling, shaping and characterization. It has state-of-the-art infrastructure for particulate materials processing, tailoring powders for shaping and consolidation, debinding and sintering and post-processing operations, mechanical testing and materials characterization. It conducts R&D projects in collaboration with the industry, financed by both private and public funds.

Table-top machine for "Solvent on granule 3D printing" of metals and ceramics

Main research topics

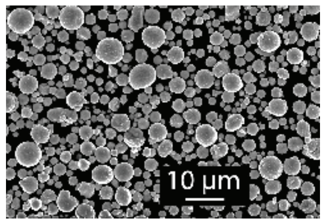
The research activities focus on the manufacturing of parts from powders, including stainless steels, soft magnetic materials, titanium alloys, copper alloys, aluminum alloys, precious metals, superelastic and shape memory materials and advanced ceramics. In the AM field, the group manages standard binder jetting and laser melting technologies. In addition, it has developed its own technology of solvent jetting on metal- or ceramic-based granule beds. The handling and sintering of reactive metals is also a key competence.



SLM 125 machine (laser power 400W)

Offer

- Deep know-how on powder technology
- Powder-bed AM facilities: laser melting, binder jetting, solvent jetting
- Powder characterization: size distribution, flowability, apparent and tap density, gas pycnometry, morphology
- Powder preparation: handling under protective atmosphere, sieving, granulation
- Materials characterization, optical and scanning electron microscopy, EDX and XRPD, mechanical tests, heat treatments
- Process optimization for AM classical materials
- Development of emerging materials for powder-bed additive manufacturing



Gas atomized powder

Technologies

- Solvent on granule 3D printing
- Binder jetting 3D printing
- Selective laser melting
- Powder compaction, debinding and sintering
- Powder injection moulding (MIM and CIM)
- Tape casting
- Hot isostatic pressing

Contact

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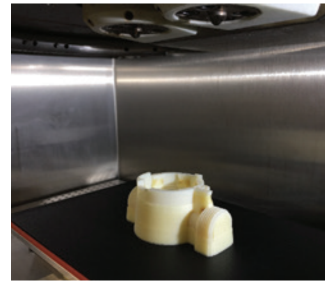
FHO University of Applied Sciences of Eastern Switzerland
HSR Rapperswil School of Engineering, IWK Institute of Materials Technology and Plastics Processing

Institute

The IWK makes innovative and professional contributions to application-based research and development about material, manufacturing technology and plastics processing. It combines science and practice to develop modern materials, multilateral technologies and production processes. In the IWK team, experienced specialists and university graduates cooperate in a straightforward, professional and project-oriented manner to work on industrial tasks in bilateral and publicly funded research projects.

Main research topics

One of our research programs in IWK is oriented on additive manufacturing (AM) which covers a broad variety of interdisciplinary topics includes design, manufacturing and materials processing technologies as well as materials science. Our focus is to apply AM in industrial applications both for plastic and metal parts and components to create innovative and disruptive products. The two main topics are material extrusion processes like APF and FDM/FFF as well as laser metal deposition LMD in combination with machining.



ABS part with water-soluble support structure in the build chamber of Arburg Freeformer

Offer

- Design and manufacturing of AM parts made from serial thermoplastic resins or metals
- Material selection and experimental material characterization for AM
- Measuring of material and part properties
- Processing, preparation and production of filaments for FDM/FFF
- Development of water-soluble support materials
- Integration of endless fibers in FDM/FFF process
- Coating of metals and abrasive on metals (surface engineering)
- Repair any types of metal components (repair engineering)
- Providing features by LMD on the parts which conventionally manufactured

ABS part made with Arburg Freeformer after the water-soluble support structure has been removed

Technologies

- Arburg Plastic Freeforming (APF): material extrusion process by means of plastic pellets
- Fused Deposition Modeling (FDM)/Fused Filament Fabrication (FFF): material extrusion process by means of plastic filaments
- Hybrid machine: Laser Metal Deposition (LMD) together with grinding and milling processes

Contact

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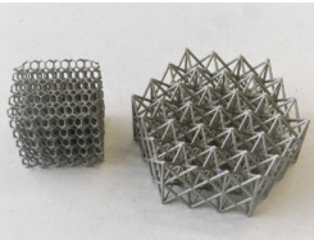
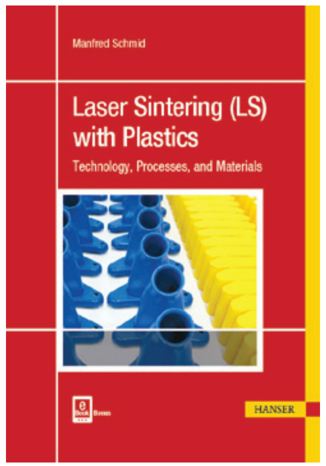
inspire AG
icams Innovation Center for Additive Manufacturing Switzerland

Institute
Inspire is an initiative of Swissmem, the ETH Zurich, and the State Secretariat for Education, Research and Innovation SERI. It is a competence center for the Swiss machine manufacturing industry, with close relations to ETH in Zurich, and is a non-profit R&D partner for the industry, mainly focussing on production technologies. The icams institute has performed R&D for industrial additive manufacturing technologies since 1996, and focusses on quality management systems for the AM process chain, for which the complete process chain is investigated.



Insight into icams' laboratory



Main research topics
Inspire icams focusses on R&D for metal and plastic AM. Research areas are the development of appropriate materials dedicated to the AM processing characteristics, and the definition of requirements for AM powder materials and the characterization of the consolidated materials. Furthermore, the fundamental understanding of the SLS and SLM processes, and the optimization of machine components and concepts are in the main focus. The development of added value for AM parts complements R&D, focussing on lightweight parts and sensor integration.

Offer
All types of projects: bilateral services, nationally and internationally funded projects.
Research covers quality management systems for the AM processing chain, including:
- Powder characterization: flowability, spreadability, particle size distributions, chemical compositon etc.
- Material development for SLS and SLM processes (in cooperation with partners)
- Development of optimized processing windows
- Characterization of the consolidated material properties:
  - Material density, microstructure and phases etc.
  - Development of heat treatment procedures
  - Static and dynamic mechanical testing
- AM machine component optimization for improved process and part quality
- AM part qualification: 3D scanning, and advanced surface characterization
- AM part optimization: lightweight applications, sensor integration and advanced tooling concepts

Technologies
Powder bed fusion: Selective Laser Melting (SLM) and Selective Laser Sintering (SLS)
Blown powder: Direct Metal Deposition (DMD)

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inspire AG
inspire pdz – Design for New Technologies

Institute
Inspire Design for New Technologies addresses the challenges of new technologies like additive manufacturing imposed on the product development process. Engineers in industry need to understand new technologies with their advantages and disadvantages to identify the right applications and design parts with respect to AM's opportunities and restrictions. inspire AG is a strategic partner of ETH Zurich for technology transfer in the field of manufacturing technology and a research partner in various projects funded by the Swiss Confederation.

Main research topics
Design for New Technologies research focuses on the three main challenges of implementing additive manufacturing in series products:
- identifying the parts of a conventional design that will result in the most benefit in a redesign for AM
- breaking the rules of conventional manufacturing to exploit the full potential of additive manufacturing's design freedom
- incorporating this new approach into company processes

An interdisciplinary team develops tools and methods to implement new technologies into industrial applications.

Book on design and development for additive manufacturing

Offer
Integrating new technologies into a company requires a change process to build up knowledge and trust. We assist in these processes by transferring knowledge and supporting engineers in gaining first experiences in a learning-by-doing approach:
- Workshops for SMEs and corporations to identify and validate parts and business models
- Agile development of new solutions with additive manufacturing
- Technology transfer through trainings, events and books like "Entwicklung und Konstruktion für die Additive Fertigung (ISBN: 978-3-8343-3395-7)"

These offers are not limited to additive manufacturing. New technologies like the digitalization of products and services (Internet of Things, Industry 4.0), although based on completely different technologies, bring similar challenges to product development: identifying the right applications and creating additional value for the company and the customer. We are therefore able to apply our experience in design for AM on other new technologies.

Technologies
- Applications of additive manufacturing in the production of series products
- Post-processing of complex structures
- Design automation for additive manufacturing

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University of Applied Sciences and Arts of Southern Switzerland
SUPSI

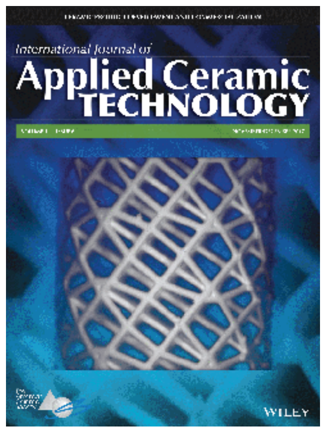
SUPSI University of Applied Sciences and Arts of Southern Switzerland
Department of Innovative Technologies

Institute
SUPSI-DTI focusses on engineering sciences for the industrial sector, training and applied research. The department has been for years very active in the AM sector through various applied research projects, at national and European level, in the areas of ceramic, polymeric and metallic materials, new processes and machine tools, design of innovative products and services, in particular for the medtech and aerospace sectors as for many other industrial applications.

Main research topics
The activities focus on the entire AM value chain, considering materials, product design, processes and systems. Two key topics are:
– Integration of multiple subtractive and additive technologies in hybrid solutions; operating by monitoring and adapting the deposition or subtraction processes, by relying upon a closed automatic in line CAx chain bound to the CNC to select the best processing strategy and machine settings
– Design and additive manufacturing of complex porous ceramic structures (e.g., engine exhaust filters)


4-axis redundant deposition head designed by SUPSI for the EU project BOREALIS (Advanced Concept of Flexible Machine for Additive and Subtractive Manufacturing, 2015–2017) in which SUPSI also acted as technical coordinator

Offer
– AM process design and optimization for metal-based alloys (mostly: titanium and aluminum alloys, Inconel 719, Steel 890, AISI 316 L)
– Hybrid process implementation based on AM and subtraction of material
– Redundant machines and robotic solutions for AM
– Process control and adaptation based on a closed loop monitoring system for AM
– Mechatronic equipment design for multimaterial deposition (i.e. nozzle, primary and secondary deposition systems, vacuum systems, auxiliary gas ejection, gas-powder mix chamber)
– Preparation and characterization of photopolymeric ceramic pastes for AM
– Design, AM and characterization of complex ceramic components
– Mixing and blending equipment
– High-temperature equipment for AM porous materials thermofluid characterization
– Furnaces for thermal treatments (standard and microwave)



Ceramic catalytic support designed and produced by AM at SUPSI

Technologies
– Direct energy deposition of small-medium-large parts (up to 800 X 800 X 800 mm envelope)
– Cold spray for coating and repairing of parts
– Laser ablation and texturing with nanosecond laser source
- Femtolsecond laser source (soon available)
– Peek deposition
– Stereolithographic devices for ceramic AM

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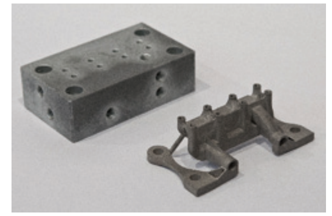
ZHAW Zurich University of Applied Sciences
School of Engineering, Centre for Product and Process Development, Advanced Production Technologies (ZPP)

Institute
The ZPP carries out product and process development from the initial idea all the way to realization. We carry out applied R&D in the fields of innovation playground & development, 3D experiences and advanced production technologies, mainly in additive manufacturing.

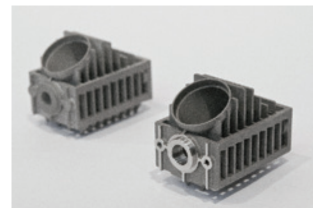
Zürcher Hochschule für Angewandte Wissenschaften
zh aw School of Engineering
ZPP Zentrum für Produkt- und Prozessentwicklung

Main research topics
– Research into additive manufacturing (AM) processes
– Analysis and optimization of AM processes for metals, ceramics and sustainable materials
– Implementation of AM technology, e.g., new design rules for product development
– Development of innovative 3D printing systems (e.g., ceramic 3D printer) and components

Offer
– Adapted product development for AM incl. topology optimization
– Economical and technical feasibility studies in AM
– Development of 3D printer and components
– aR&Dprojects for product and process development for AM
– Supporting companies in introduction of AM with workshops and education
– Common and customized teaching and training in AM



Technologies
– SLM Selective Laser Melting, powder bed process in metal
– FDM Fused Deposite Modelling
– SLA Stereolithography
– SLS Selective Laser Sintering



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ZHAW Zurich University of Applied Sciences
Institute of Mechatronic Systems (IMS)

Institute
As a leading national institution for applied research and development in mechatronics, the Institute for Mechatronic Systems (IMS) specializes in projects for innovative products at the interface of mechanics, electronics and computer science. The know-how of over 50 employees from various fields and a modern research infrastructure make us a flexible and efficient partner in the realization of projects in research and development.

Main research topics
Our strengths lie especially in the following areas: Robotics & Automation, Control Technology & Advanced Control, Drive Technology & Power Electronics, Medical & Systems Engineering. In the field of additive manufacturing the focus lies on the development of advanced hardware and processes and as well as on optimizing material properties for the FDM process, to close the gap between 3D printing and injection moulding. This also includes the qualification of material properties itself and the properties of printed parts.

6-axis FDM printer with tiltable bed (developed by IMS)

Offer
The activities of the laboratory of rapid prototyping (RapLab@IMS) include the complete development process of functional prototypes:
- 3D scanning of parts for geometry capture
- 3D modelling with CAD tools
- Structural analysis of parts and components using state-of-the-art CAE-tools
- Embedding of actuatory and sensory components
- Manufacturing of parts with various AM-processes

The IMS supports the complete development process chain for new mechatronic products with adaptive integration of additive manufacturing techniques.

Technologies
- Fused Deposition Modelling – FDM (incl. fiber reinforcement, multimaterial)
- Selective Laser Sintering – SLS
- Stereolithograhy – SLA
- MultiJet Printing – MJP

Hand prosthesis manufactured with AM (developed by IMS)

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Partner
Swiss AM Guide 2018

AM Expo and Additively

A successful duo that will work even closer together in the future

Producing companies who want to make full use of the potential of additive manufacturing need to get to know the right project partners. AM Expo and Additively have together developed a comprehensive concept to ensure that this works as well as possible.

The purpose of the concept is to make relevant information relating to additive manufacturing accessible to wide circles in the form of events, online and in print – with the aim of enabling them to understand how they can benefit from the various methods of additive manufacturing and helping them locate the right project partners. This second AM Guide is a part of this concept.

Showcases are at the heart of the concept: interested parties can draw inspiration from numerous concrete examples that have been successfully implemented in practice. These showcases are presented and discussed at the booths of exhibitors taking part in the AM Expo. This report portrays the ten most innovative showcases on display at the AM Expo and impressively demonstrates the innovative capacity of additive manufacturing.

New launch of a digital meeting place for additive manufacturing by Additively

Today, the exchange between companies and solution providers takes place mainly at industry events such as the AM Expo. These events are now supplemented by a digital platform to enable the discussion to continue 365 days a year: the Additively platform will be launched during the AMX Night on March 6 as a digital meeting place for additive manufacturing and the technologies for the production of tomorrow. Additively gives people searching for new technologies and solutions a place where they can find inspiration as well as answers to their specific questions.

As coinitiators, partners and sponsors, we are looking forward to a successful second edition and thank the authors and industry for their commitment.

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The Institute of Machine Tools and Manufacturing, IWF

The Institute of Machine Tools and Manufacturing (Institut für Werkzeugmaschinen und Fertigung, IWF) of the Swiss Federal Institute of Technology, ETH Zurich, conducts research in the field of additive manufacturing in three technologies: SLS, SLM and DMD. In all three additive manufacturing (AM) technologies the institute covers research in materials and material behavior, research on the process and process chains for and with AM, research in machines and special applications as for instance lightweight parts and functionalized parts.

In SLM (Selective Laser Melting – powder bed fusion with metal powders) the group investigates the solidification process and the resulting metallurgic microstructure that is generated by rapid solidification after laser-material interaction. Of special interest are the simulation and experimental analysis of the melt pool and warpage due to the thermal contraction during the cooling process as well as the determination of the risk factor micropores, hot cracking and cold cracking. The achieved material strengths are carefully investigated. New processes are being developed such as laser pre- and post-heating to influence the cooling process positively, and to avoid weld splatters that lead to micropores or to a too fast cooldown. The aim is to increase the process robustness, the build-up speed (currently 100–200 g/h) at constant or improved material quality with minimum warpage and thermal stress in the workpiece. Quality management and process monitoring are vital research fields.

In DMD (Direct Material Deposition – material build-up with feed of metal powder or wire to the hot spot) the main focus is the increase of the build-up speed (currently 1,000 – 4,500 g/h), and the generation of large structures. An important application field is the laser cladding of thermally and mechanically highly loaded components such as turbine blades and the development of wear-resistant coatings by Co- or Ni-based materials and even material matrix composites (MMC). As a vision, the group will target new processes with higher build-up rate to overcome todays lack of productivity. Other research topics are similar as in SLM.

In SLS (Selective Laser Melting of polymers) IWF works closely together with inspire icams. In addition to the research in AM processes, successive processes are investigated in order to get the desired form and surface properties or to improve the workpiece quality. For this additional process steps the broad knowledge of other IWF groups is available.

The AM group of IWF works closely together with inspire icams group in St. Gallen. Both are under the scientific supervision of Prof. K. Wegener, IWF ETH Zurich.

Prof. Dr. Konrad Wegener

SATW
Swiss Academy of Engineering Sciences

The Swiss Academy of Engineering Sciences SATW is the most important network of experts for engineering sciences in Switzerland and is in contact with the highest Swiss bodies for science, politics and industry. The network is comprised of selected individual members, member organisations and experts. On behalf of the Swiss Federation, the SATW identifies industrially relevant technological developments and informs politics and society about their importance and consequences. As an expert organisation with high credibility, it conveys independent and objective information on technology – the basis for establishing well-founded opinions. SATW also promotes the interests and understanding of technology in the population, particularly young people. It is politically independent and non-commercial.

Advanced manufacturing has been a SATW focus topic since 2013. Our analysis showed that more resources are required to maintain Switzerland's competitiveness in this field. As stated in our "Technology Outlook 2017" various studies predict significantly higher growth rates for additive manufacturing compared to conventional manufacturing technologies. Thus, one aim of the initiative is to convince politics to provide more funding for this promising field.

In 2016, the SATW established the Advanced Manufacturing Research Alliance to coordinate research activities and foster collaboration among existing research bodies in Switzerland. The alliance focuses on additive manufacturing and industry 4.0. It wants to improve the utilisation range and rate of its partner existing infrastructures, prevent redundancies and thereby reduce operating costs. The alliance further raises awareness of the significance of precompetitive research and development in the realms of politics and business, and campaigns for increased research funding. Current members are the Bern University of Applied Sciences, CSEM, Empa, EPFL, ETHZ, FHNW, FHO, HES-SO, inspire AG, the Lucerne University of Applied Sciences and Arts, Switzerland Innovation Park Biel/Bienne and ZHAW Zurich University of Applied Sciences.

The SATW is in constant exchange with other national initiatives in order to identify and exploit synergies. In the field of advanced manufacturing, the SATW focuses mainly on the research aspects and ensures knowledge and technology transfer to industry through its partner organisations and collaborations. To ensure its long-term competitiveness, a close collaboration with research bodies is crucial for the Swiss industry.

Rolf Hügli
Managing Director

Swissmem
SAMG Swiss Additive Manufacturing Group

Swissmem is the leading association for SMEs and large companies in Switzerland's mechanical and electrical engineering industries (MEM industries) and related technology-oriented sectors.

Swissmem enhances the competitiveness of its 1,100 member companies both at home and abroad by providing needs-based services. These services include professional advice on employment, commercial, contract and environmental law, energy efficiency, and knowledge and technology transfer. In addition, Swissmem offers market-oriented training packages for employees working in the sector.

Swissmem operates a number of strong networks: twenty-seven specialist groups – one of them being the Swiss Additive Manufacturing Group (SAMG) –, various experience-sharing groups and forums give member companies the opportunity for dialogue on technical questions or work on joint projects.

Swissmem is committed to the concepts of competition and entrepreneurial freedom, rooted firmly in a strong sense of social responsibility. Drawing on its broad-based knowledge of the sector, Swissmem advocates the best-possible economic and political framework and a liberal labor market in its dealings with politicians, government and the public. It also supports constructive social partnership.

The Swiss Additive Manufacturing Group (SAMG) is a specialist group of Swissmem. Any Swissmem member company being active in the field of additive manufacturing as a developer, planner, engineering company, manufacturer, supplier or service provider can join the SAMG.

The aim of the group is to foster the exchange of information among the members as well as with national and international organizations and associations. Furthermore the network shall be enlarged and contacts shall be established to universities and other research organizations. Special attention is paid to the basic and continuing education in additive manufacturing as well as to the development of international standards and to the certification of processes. Last but not least the group aims to foster the image of the branch in the public.

Beat F. Brunner
Member of the Executive Board

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Top performances and innovative solutions, as documented in the current Swiss AM Guide, require the courage to search for new ways. New paths are usually complex, unexpected and unknown. Only those who consistently follow their paths reach the top.

Illustration: Different routes to Mount Everest (8,850 m)
Source: Swiss Foundation for Alpine Research

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