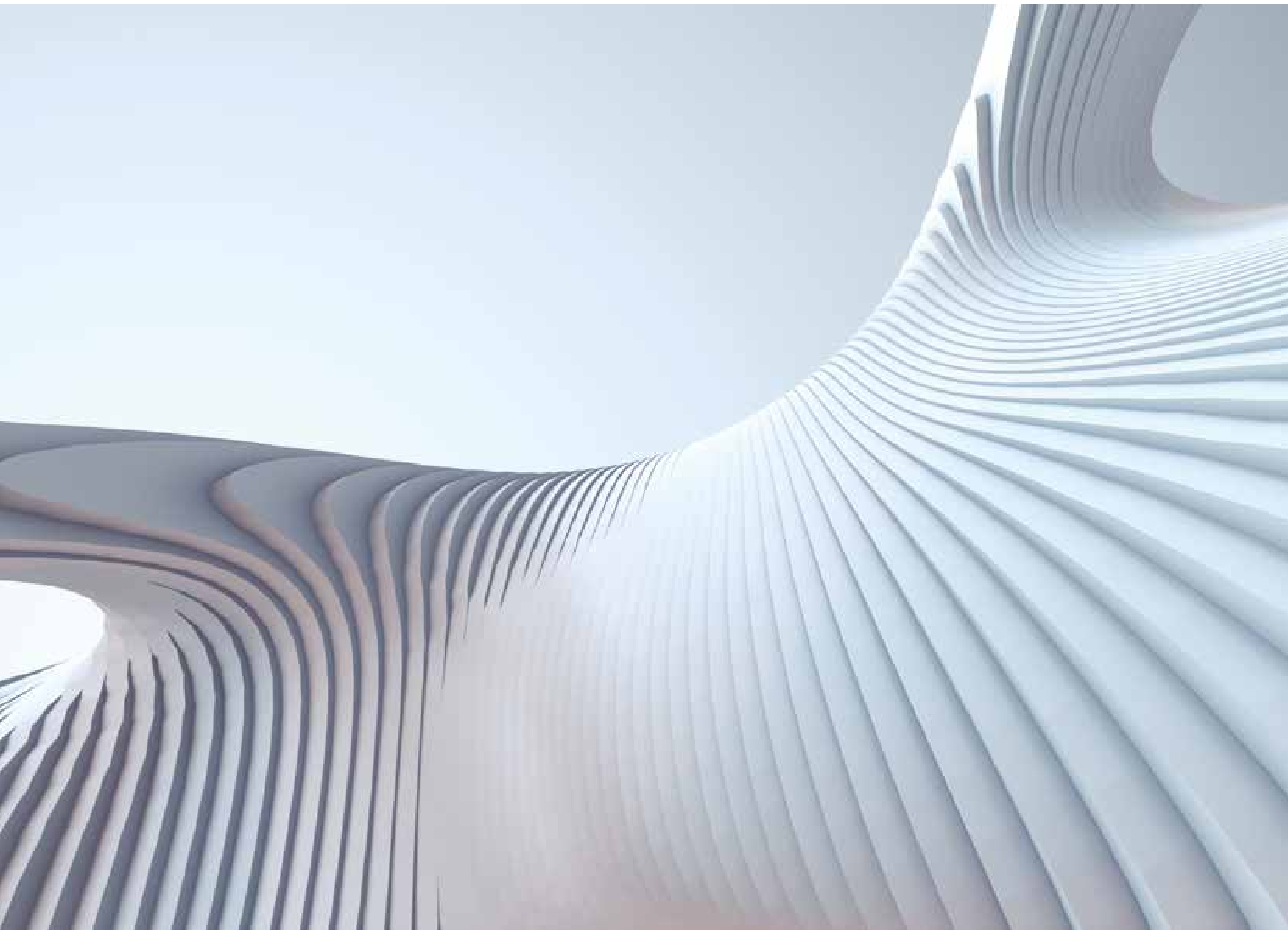
ProduktionNRW
Cluster Maschinenbau/Produktionstechnik

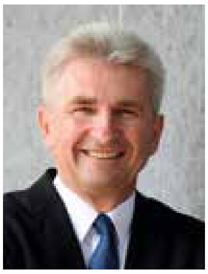


Innovations made in NRW
Potentials of Additive Manufacturing

VDMA

Content

A young technology with a lot of potential



Prof. Dr Andreas Pinkwart
Minister of Economic Affairs, Innovation, Digitalisation and Energy of North Rhine-Westphalia

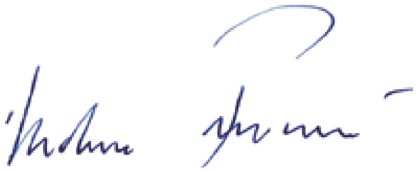
Dear readers,

North Rhine-Westphalia is a leading industrial location that is strong on innovation and has a global impact. Its industry creates value and industrial growth, with a unique mix of specialised SMEs and larger businesses. It provides environmental, economic and social stimuli, assures many good jobs and enjoys a good standard of living.

The mechanical engineering and plant construction industry has a particular role to play. Not only is it the state's largest industrial employer, but it also sets the pace for many other sectors through its role as an equipment supplier. Additive Manufacturing plays a significant part in this regard, since it can be used to develop and manufacture new products so much more quickly. It is thus an important complement to traditional manufacturing processes. This new manufacturing technology has strong roots in North Rhine-Westphalia. Pioneers and prominent corporations in the Rhine-Ruhr-Lippe region have adopted Additive Manufacturing and are thus investing in the future viability of the state.

The state government supports them in this undertaking. We are driving forward research in the area of Additive Manufacturing and ensuring the best preconditions are in place for our enterprises to respond to changing market demands and develop new areas of business. Our objective is to explore the huge potential offered by this technology even further and turn it into a driver of growth in North Rhine-Westphalia.

The series "Innovations made in NRW" published by the state cluster ProduktionNRW highlights the many positive developments in the state, with a particular focus in this issue on the strengths of Additive Manufacturing.



Yours,
Prof. Dr Andreas Pinkwart

Trailblazing products with Additive Manufacturing

Wolf D. Meier-Scheuven
Cluster Spokesman
ProduktionNRW

Dear readers,

One of the reasons the mechanical engineering industry in North Rhine-Westphalia is so strong is its good networking. SMEs and large companies, research institutes and universities work closely together to develop advanced products in line with their customers' needs and find solutions for the challenges of our times. Besides providing an important foundation for the power of innovation of the industry, sharing knowledge and information also leads to trailblazing results in Additive Manufacturing.

This method of tool-free manufacture is taking on an increasingly important role in production in North Rhine-Westphalia. Its benefits are best seen in areas where conventional manufacturing reaches its limits. So, for example, in prototyping, individual spare part manufacture, and components with a complicated geometry, Additive Manufacturing makes efficient and commercially viable production a possibility. It also paves the way for many new business models. As a result, customers can receive the prototypes, tools or components they want, with the same functions, reliability and long service life as those made by conventional means, within a very short timeframe.

The many different examples of application in our innovation magazine "Innovations made in NRW" illustrate the commitment shown by the mechanical engineering industry in NRW. They highlight the huge opportunities offered by Additive Manufacturing, while also showing where the challenges lie. This magazine will provide businesses in the sector with valuable assistance in deciding how to implement their own innovative manufacturing processes.

I hope you enjoy this issue and find it a source of inspiration!

Yours,
Wolf D. Meier-Scheuven

Well networked for Additive Manufacturing

JESSICA GÖRES

Resource-efficient manufacture of complex parts with no need for tools? What is commonly known as 3D printing has long been a topic at the heart of mechanical engineering. More than 140 companies, universities and research institutes have recognised the fact, and have joined VDMA's Additive Manufacturing working community. There is strong representation from players in NRW.

Lightweight design engineers go into raptures when it comes to analysing bird skeletons, mushrooms or trees. After all, nature creates the perfect compromises between stability and weight optimisation. But efforts to translate nature's models into bionic structures have long failed because of the complexity involved. Machining and casting processes reached their limits, especially where low-volume production was involved. It was rarely cost-effective to run to the expense of the forming process.

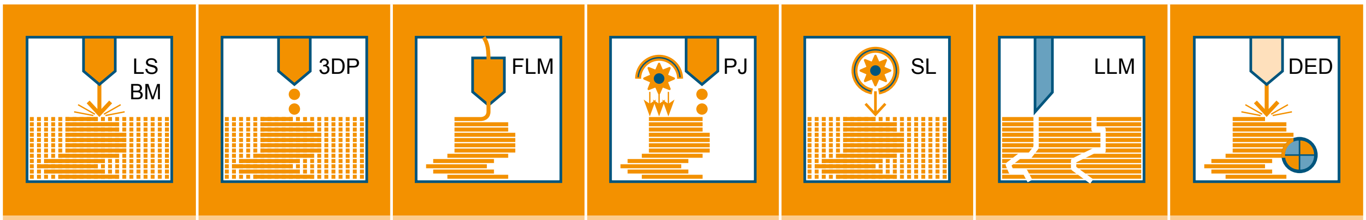
But Additive Manufacturing (AM) is now turning everything on its head. Because components are built up layer by layer using powder, wire or polymer filaments, the result is almost total freedom of design. Wall thicknesses can be varied to suit the intended loads, and hollow areas with stabilising honeycomb and lattice structures can also be included in the components, for example cooling, pneumatic or hydraulic channels. And there are many examples of functional integration, whether cable holders with a clamping function or pneumatic grip systems whose structure is used to direct the air.

Varying wall thicknesses, hollow spaces, honeycomb structures – these are the principles of bionics. And additive process chains put them into practice. It all starts with the interplay between digital design and simulation to determine the ideal component structure. The digital datasets can be printed directly, which involves arranging as many virtual components as possible in the system's build space in the interests of efficiency. At the end of the printing process, they are heat-treated as appropriate, the material residues are removed, the components are separated out and post-processed.

Objective: industrial implementation of additive process chains

There is room for improvement in all stages of this broadly outlined process chain. After all, AM is a young field of technology: it is established in the area of prototyping, but in series manufacturing processes the various additive metal and polymer processes still need to be proven. The good news is that more and more companies and research institutes have decided to give AM processes that opportunity.

Graphics: VDMA



Beam melting / sintering (LBM, EBM, LS, HSS)	**3D printing / binder jetting**	**Fused layer modelling / freeformer**	**Polyjet**	**Stereo-lithography**	**Laminated layer modelling**	**DMD, EBW, MPA, hybrid systems**
Metal, polymer	Plaster, ceramic, quartz, **metal**, polymer	Thermoplastics (+ fillers, including metallic)	Photopolymers (+ fillers), wax	Photopolymers (+ fillers, e. g. ceramic)	Paper, polymer, CFRP	**Metals** (powder, wire)
Prototypes, small series, tools, functional components	Prototypes, models, casting moulds	Models, prototypes, consumer articles	Models, prototypes, casting moulds	Models, prototypes	Patterns, models	Individual components, small series, tools, repairs
And some more: extrusion, screen printing, gel-dispensing...						

The many different processes in Additive manufacturing.

An important meeting place for the growing community is VDMA's Additive Manufacturing working community. Its more than 140 member companies and institutes have come together since it was founded in mid-2014 to drive forward the industrial implementation of additive process chains. These include a number of leading research institutes from NRW, such as the Direct Manufacturing Research Center (DMRC) of the University of Paderborn, the Rapid Technology Center (RTC) of the University of Duisburg-Essen, and RWTH Aachen University, with its Institutes for Laser Technology (ILT) and the School of Production Engineering of E-Mobility Components (PEM). In addition, two dozen suppliers, manufacturing service companies and industrial users from North Rhine-Westphalia also participate in the working community.

"The strength of our open working community lies in the way players from all parts of the value chain work together," says Rainer Gebhardt, who as project manager is responsible for the growing network within VDMA. New members join every month and contribute their own specific expertise. The result is a point of culmination where fresh ideas and new players have the opportunity to meet and share with established industry heavyweights.

Many of the members are applying long years of experience in other industries to additive processes. Because viewpoints of AM plant manufacturers and their suppliers are being brought together with the experience accrued by software and automation specialists, providers of materials, process gases, vacuum and air purification technology, and industrial users and manufacturing service providers, the working groups within the working community gain a quite sophisticated view of the situation.

Driving forward automation and standardisation

The members are aware of the strengths offered by additive processes. They know about freedom of design, resource efficiency compared to machining processes, the opportunities for individualisation and repair by adding new layers, and the short waiting times that a totally new and decentralised spare parts logistics system using print-on-demand processes makes possible. But they also know that there are still a few hurdles to overcome along the way toward efficient additive mass production.

Most recently, they have developed an "automation roadmap", illustrating the ways forward to Additive Smart Factories. And as part of a "printing devices working group", they elaborate standards to make the freedom of design offered by additively manufactured fittings, valves and pipe manifolds usable in line with the European Pressure Equipment Directive in the future. "We are combining our accumulated expertise and experience to make additive methods fully ready for use in industrial processes as quickly as possible," says Gebhardt. And ultimately, it will involve anchoring Additive Manufacturing, free of all hype, as a long-term theme in the German mechanical engineering and plant construction industry, in policy-making and among the broader public.

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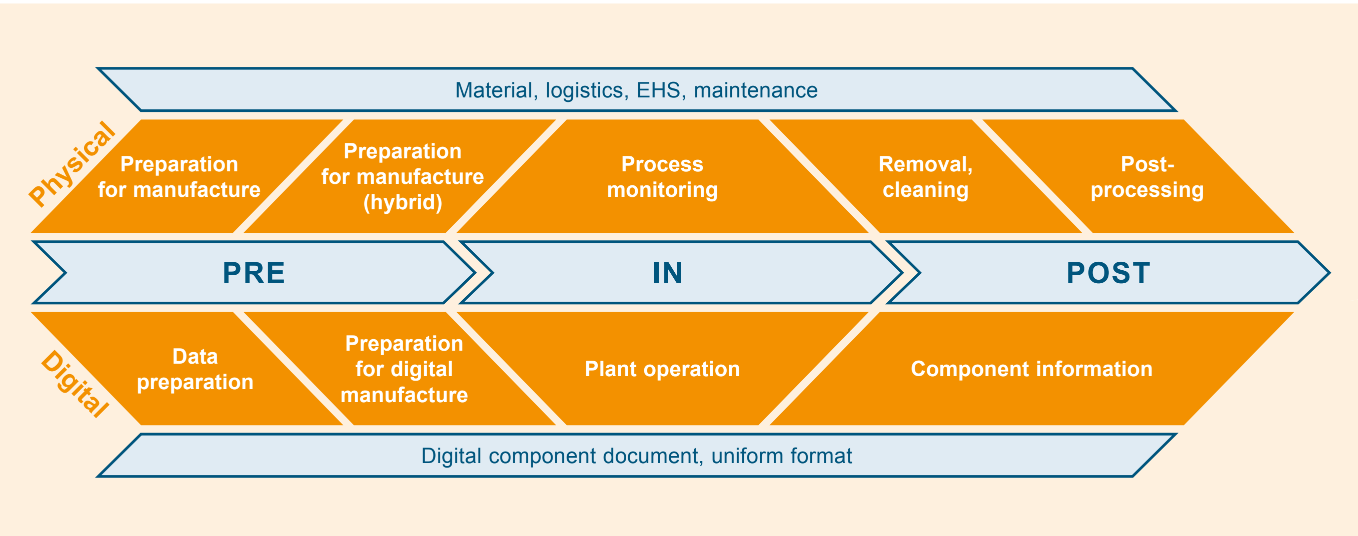


Automation roadmap to the Smart Factory.

LightHinge+, the ultra-light bonnet hinge

ERIC KLEMP AND JENS CHRISTOFFEL

Interdisciplinary collaboration between voestalpine Additive Manufacturing GmbH, EDAG Engineering Group AG and Simufact Engineering GmbH shows how Additive Manufacturing can be made commercially feasible. First, all parts of the process chain from the idea through to the product have to be completely understood and put into practice, and the partners involved in the process must be prepared to share their knowledge in depth.

Additive Manufacturing processes offer a wealth of opportunities, and when the right knowledge for the application in question is available and properly used, significant potentials are the result. In addition to putting lightweight design into practice, this also includes integrating functions that were previously considered impossible. One example of this combination of experience, knowledge and motivation is the LightHinge+ bonnet hinge, which is the result of this kind of interdisciplinary collaboration.

Efficient engineering enabled the weight of the hinge to be reduced by 52 percent, while incorporating a pedestrian protection function. The production and post-production processes were also shortened, resulting in distortion-optimised, tool-free manufacturing with minimal post-processing.

Lightweight design and integration of additional functions

Bonnet hinges are fitted to all vehicles and the standard product made of sheet metal, die-cast or forged, will weigh 1.5 kg. They are subject to very stringent safety requirements. In the event of a collision, state-of-the-art, active bonnet hinge systems provide additional protection for pedestrians by actively raising the bonnet: in a crash, a pyrotechnic actuator that triggers in a fraction of a second will lift the bonnet by a few centimetres.

Complex kinematics are required for this function to work. It consists of up to 40 individual components, with high tooling and assembly costs. Because this is highly labour-intensive, a mass-production solution is not economically possible. Reasons of design and inadequate space at the vehicle's front end also stand in the way of implementation. This was the context in which the project partners began working together to implement a reasonably priced, functional and lightweight solution.

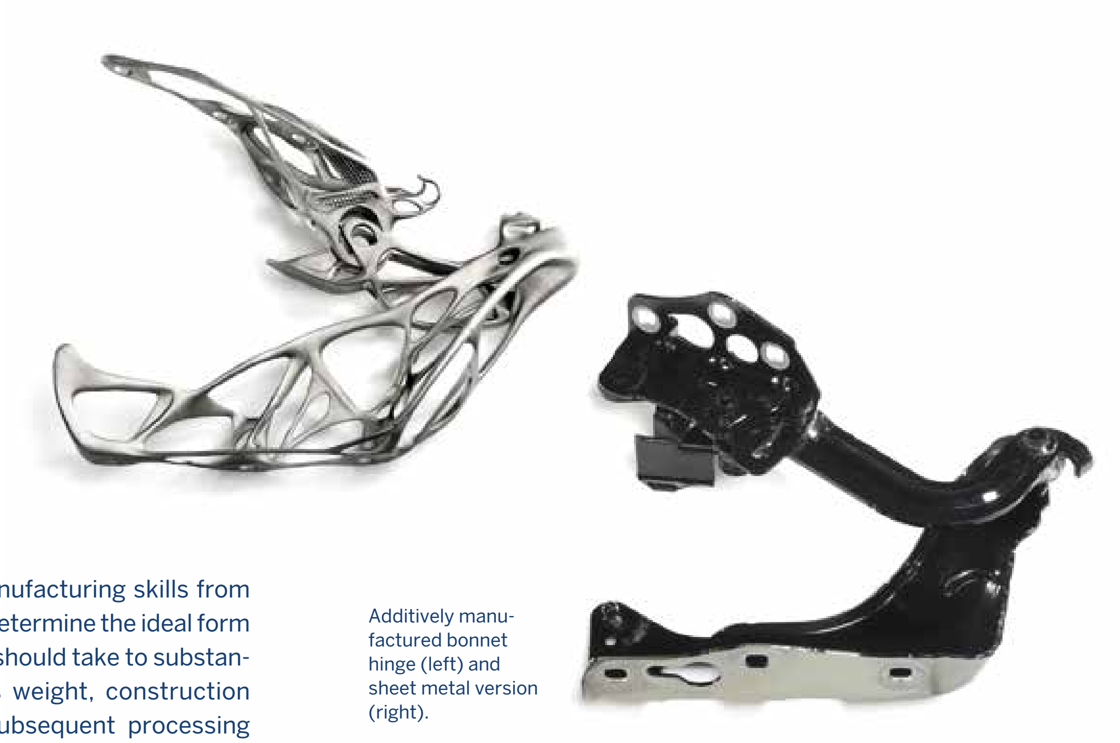
In addition to the technical benefits, the LightHinge+ also offers a design with visual appeal.

Photos: EDAG Engineering

Interdisciplinary team offers a range of perspectives

Using creative methods, an interdisciplinary team applied new conceptual and achievable solutions to create a new component. Input came, firstly, from the automotive expertise of the lightweight design, safety and coachwork experts at EDAG, and the expertise with Additive Manufacturing materials and manufacturing opportunities, and simulation skills, offered by Simufact.

The first step was to select a material that would fulfil the stringent demands in terms of strength and stiffness, while being suitable for use with Additive Manufacturing processes. This was followed by topology optimisation, to produce a strong yet light bionic design. To minimise the requirement for supporting structures imposed by the process, the project partners worked closely on design, development, calculation and testing, with input from



Additively manufactured bonnet hinge (left) and sheet metal version (right).

the Additive Manufacturing skills from voestalpine, to determine the ideal form the component should take to substantially reduce its weight, construction time and the subsequent processing stages.

The efforts paid off: extensive design changes and the use of the bionic approach achieved a weight reduction of 52 percent compared to the reference construction method using sheet metal. In addition to the technical aspects, a visually appealing result including bionic filigree structures was also achieved, making the LightHinge+ a design object radiating sportiness and exclusivity.

A key benefit of Additive Manufacturing is the new geometric freedoms that it offers. For the project, this meant it was possible to achieve a complex set break point structure. The application of a defined force from a pyrotechnic actuator will cause this point to break, offering an additional level of freedom to move. As a result, the bonnet will rise about 5 cm in the event of a collision with a pedestrian.

The free space thus created acts as a crumple zone and cushions the impact on the pedestrian, providing protection from the solid vehicle components. Thanks to Additive Manufacturing, integrating this crucial function involved no extra costs. The connection point for the pneumatic spring, the brackets for the windscreen washer hose and the collar screw guide in the hinge were also integrated into the component. This reduced the number of parts by 68 percent compared to the reference item in sheet metal.

This highly integrated hinge function is also much more compact and can therefore be used in the limited space available in high-performance vehicles. Putting the new technology into practice and the simulation-based prediction using a component test provided confirmation: in the trial, the set break point triggered as planned, providing the necessary level of freedom.

Minimising distortion and residual stresses

The Additive Manufacturing process generates a very concentrated local heat build-up during manufacture of the hinge, with high heating and cooling speeds that can potentially lead to distortion and residual stresses in the component. A software solution developed especially for Additive Manufacturing by Simufact resolved this problem. By simulating the component distortion, the geometry was negatively pre-distorted to minimise final shape deviations. As a result, distortion in the LightHinge+ was reduced to within the required tolerance. This approach avoided the need for costly and time-intensive manufacturing trials. The components can now achieve the required tolerance right from the first manufactured batch.

Design and simulation were performed at the voestalpine Additive Manufacturing Center using the available materials and machine parameters in real time as part of the construction process. Optimising these stages enabled four complete bonnet hinges to be produced in a single manufacturing batch. The next stage of removing the supporting structures under prototype conditions is still performed manually, but an automated process is in preparation.

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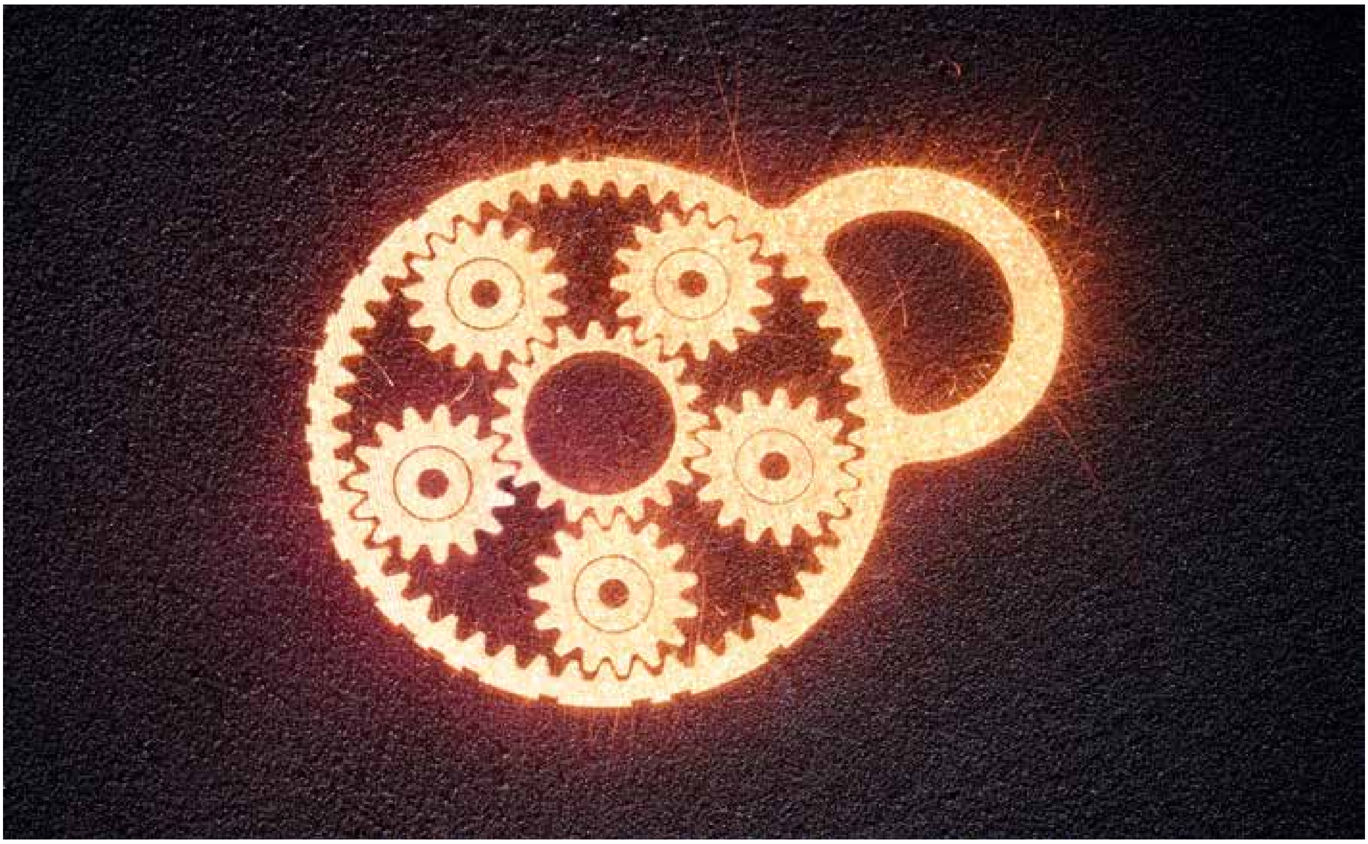
From a commercial viewpoint ...

TOBIAS STITTGEN

Additive Manufacturing technologies previously tended to focus mainly on prototypes and very small series runs, but further adaptations to the technology and the continuous improvements in plant productivity – including in the area of automobile manufacture – have made the manufacture of series components in quantities of more than 10,000 units per year commercially viable.

Photo/Graphics: ACAM



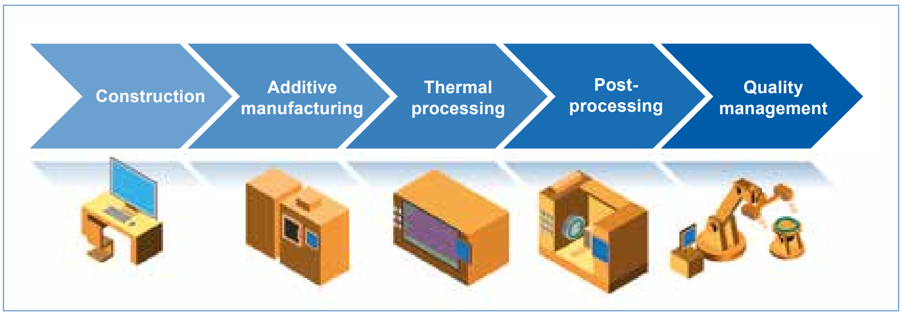
Laser powder bed fusion (L-PBF).

A robust and well founded calculation of manufacturing costs is essential if decision-makers in production, purchasing and product development are to consider Additive Manufacturing options from a commercial perspective, especially in direct comparison with conventional manufacturing processes (e. g. die-casting, milling or forging).

Calculating commercial viability

Established cost models drawn from conventional manufacturing can only partly meet these criteria, since the manufacturing process fundamentally differs from other methods, in the way the parts are built up layer by layer, for example. To be able to compare conventional methods against additive processes and base a decision on the result, the calculation must cover all aspects of the Additive Manufacturing process chain.

The literature includes a number of approaches for calculating the manufacturing costs of 3D-printed components, each with a different focus and treating the relevant influencing factors along the process chain differently. Because the average rates of construction for all the 3D printing processes are still low, manufacturing time has a heavy impact on costs. Conversely, the steps preceding and following the actual manufacturing process, such as designing the components and the subsequent heat treatment, are less important, although they still need to be considered as part of any overall approach. A highly accurate prediction of manufacturing time



Additive Manufacturing process chain.

is therefore essential if a precise calculation of manufacturing costs is to be obtained.

The approaches described above are similar in that, based on the characteristics of the components, such as the volume to be produced, the necessary manufacturing time can only be estimated using mathematical models or heuristics. Because this does not consider the specific geometry, which may involve a filigree lattice structure, for example, the forecast accuracy may vary by more than 50 percent.

Establishing calculation routines

Current studies by ACAM Aachen Center for Additive Manufacturing GmbH in the fields of various research partners are therefore aimed at developing and trialling new approaches to accurately calculate manufacturing time. In the area of laser powder bed fusion (L-PBF), a joint project by the Fraunhofer Institute for Laser Technology (ILT) and the School of Digital Additive Production (DAP) at RWTH Aachen University uses an approach of determining processing time based on a calculation routine upstream of the actual data preparation, which simulates the subsequent path plan depending on the materials and systems used. The individual component layers resulting from this simulation (including the vectors to control the scan system) are then used to calculate processing time.

Initial validations of the simulation predictions using various commercially available systems have produced deviations in the low single-digit percentage range. Because all Additive Manufacturing processes build up the product layer by layer, the above approach can also be applied to technologies such as laser metal deposition (LMD), which provides an uncomplicated way of comparing a range of potentially relevant Additive Manufacturing processes.

Finally, to determine the actual manufacturing costs, the calculated manufacturing time is multiplied by the hourly rate for each machine. Costs of raw materials, power and shielding gases needed for the manufacturing process must also be added. Empirical values for these are available.

Because stages such as heat-treatment, machining and comprehensive quality assurance typically follow the manufacturing process, for metal-based 3D printing processes in particular, the calculation model must be expanded accordingly. Thanks to the unique engineering portfolio and expertise available at the RWTH Aachen University campus, these extra stages can be added in close cooperation with the experts from various specialist areas.

The result is a robust, end-to-end calculation model that stands up to the demands of multiple industries and procedures and can be used as a basis for decision-making by purchasers, production planners and design engineers.

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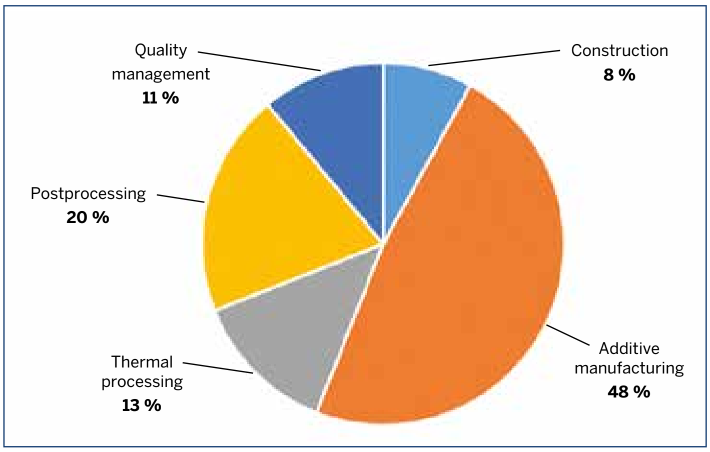


Generic cost breakdown for Additive Manufacturing of a component from the aluminium alloy AlSi10Mg.

In the land of unlimited (design) opportunities

ANKE THEISSEN

3D scanners can be used to transfer sophisticated objects from the physical into the digital world. Once the objects are digitalised, adaptations, changes and reverse engineering pose no problem.

Photos: Murtfeldt

Trial installation of the new bracket to retrofit an emergency doctor's car with wireless and communications technology.

There are no limits – or hardly any, at least – to design when it comes to Additive Manufacturing. In fact, it's more the case that the familiar approaches adopted by designers in conventional manufacturing impose limits on component design. This is where design engineers need to greatly change the way they think: in future, components must be conceived and developed in terms of their function, and no longer from the perspective of cost.

That means a high level of freedom of design – but also a huge amount of responsibility, since responsibility for production now passes to the design engineer. Objects are now manufactured as developed in the CAD program. Reverse engineering can be a good help with some requirements, as the following example of application will show.

Comtec GmbH, a telecommunications company based in Dortmund, receives an order to fit out a passenger vehicle as an emergency doctor's car with wireless and communications technology. The necessary technology cannot be incorporated using the existing onboard system, as this approach would not guarantee the system's security and ability to function. The limited available space in the car and the absence of design data for attaching the required components (touch screen monitor, control panel for the emergency light system, and a wireless on/off switch) pose a particular challenge.

Reverse engineering using 3D scanning

Comtec selected Dortmund-based polymer manufacturer and processor Murtfeldt Kunststoffe to work with it on the project, since Murtfeldt was able to reverse-engineer a structure based on a 3D scan in the absence of design data. This made it possible to attach the monitor and control panel in the emergency vehicle easily, quickly and securely, in line with the objective of achieving a secure fitting combined with very good ease of operation, which must be guaranteed even under hectic conditions.

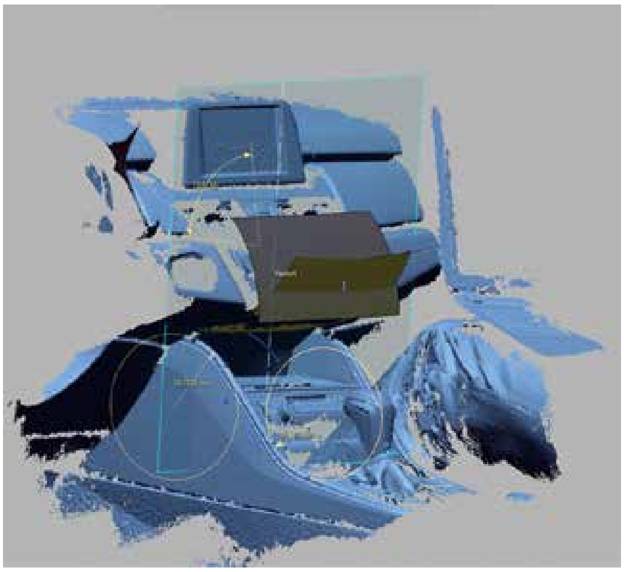
A further major advantage in Murtfeldt's favour is that it expanded its engineering facilities to include 3D printing some years ago. It can offer everything from a single source – not just the reverse engineering but also the design, selection of materials, manufacture, etc.

Comtec's customer therefore supplies the monitor and functional control panel. Murtfeldt uses Eva, a 3D hand scanner from Artec, to scan the monitor, the control panel and the vehicle cockpit in sequence. Reverse engineering in this way generates the key data needed for the manufacturing process from the scan of the intended location.

3D framework delivers geometries for reverse engineering

The scanning process delivers a 3D framework that can be used to reverse engineer the geometries of the individual objects in the CAD system. All with a level of precision that means there is no longer any need to take or check measurements manually. Using this data, the next step is to design the individual elements: the monitor bracket, control panel frame and mounting flange for fitting to the vehicle cockpit.

The high-resolution data and precise measurements make it possible to precisely determine or set the tolerances for the elements that have to be fitted – for example, those of the monitor for the bracket that will hold it – to ensure that the control elements are securely fitted and held in place even when the vehicle is exposed to rough handling.



Reverse engineering approach: 3D scans record the geometry of the monitor, control panel and vehicle cockpit for use in the bracket design process.

Lightweight design structures and integrated mechanical functions reduce cost and effort

The design engineer develops the final product based on the knowledge, data and values obtained in the above process, while keeping a focus on the benefit and functionality of the component at all times. The CAD file forms the basis for manufacturing using 3D printing. Lightweight design structures, such as honeycomb structures in the interior of the component, can reduce the weight of the bracket and panel by up to 75 percent. Internal channels, e. g. for integrated fluid lines, can be incorporated at no extra cost. Additional mechanical functions like joints and snap hooks make additional components within the bracket superfluous, making the work of fitting it to the car easier.

The component is ready for use in just a few days – which would have been impossible for a "single unit batch" using conventional manufacturing methods. Comtec receives a finished solution from Murtfeldt and can fit the component with the intended technology, and then incorporate it into the car with no further assistance, thanks to the high level of accuracy achieved in the manufacturing process.

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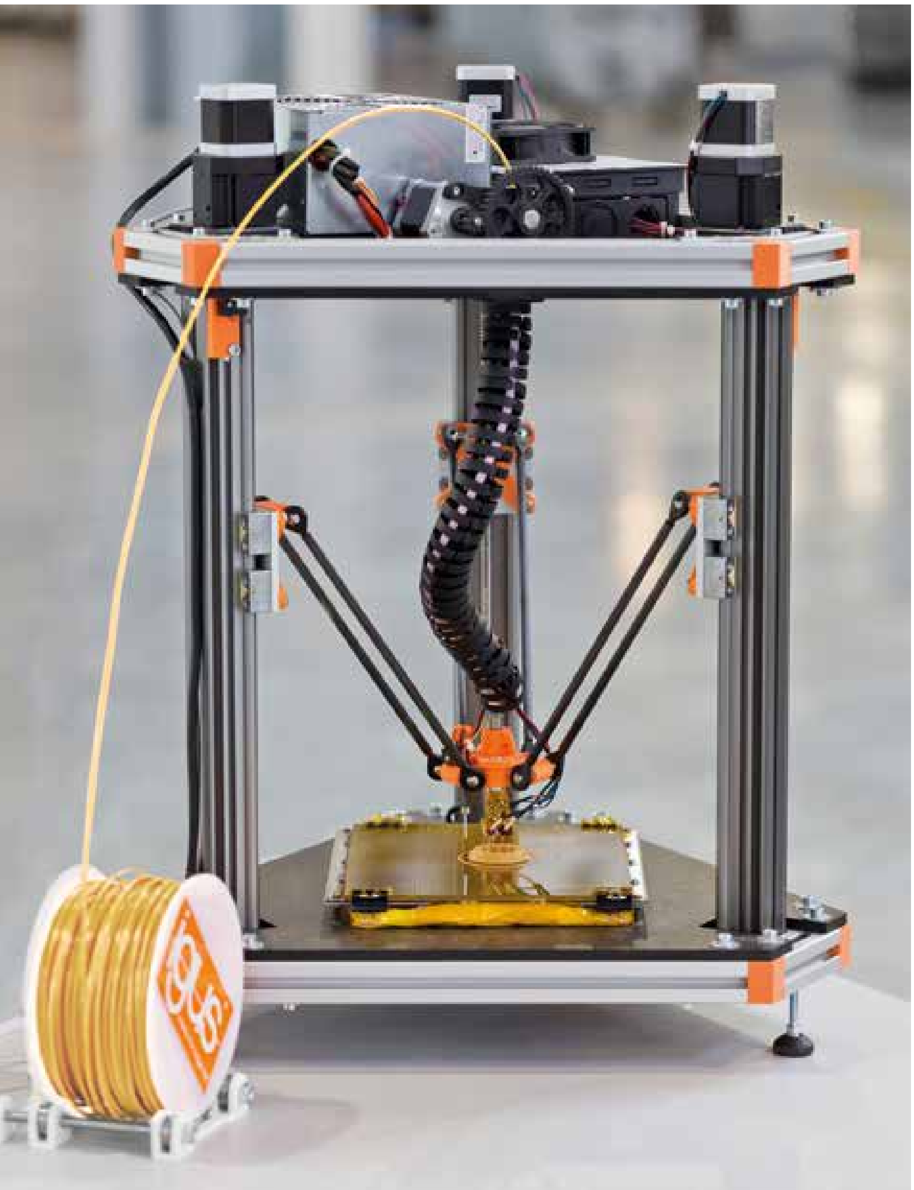
Maintenance-free wearing parts from the 3D printer

GERHARD BAUS

Motion plastics supplier igus provides lubricant-free, maintenance-free wearing parts made of high-performance polymers for its customers. Individual parts can be made of 3D-printed plastics in just a short time.



Photos: igus

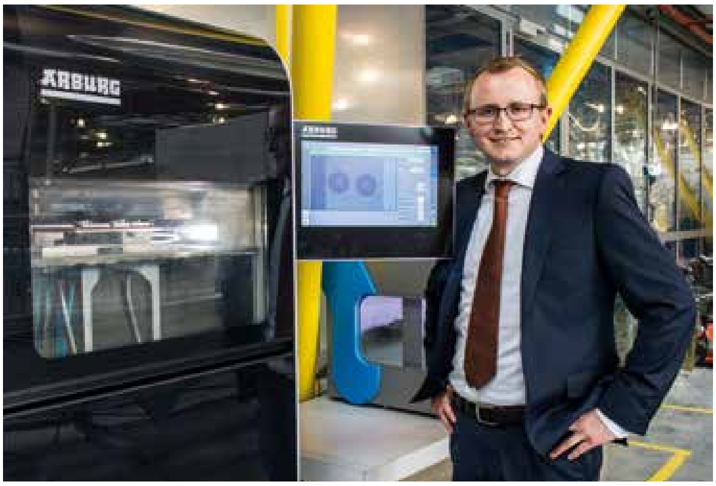
Cost-effective manufacture of individual wearing parts is now possible thanks to Additive Manufacturing.

The focus is on wearing parts such as cog wheels or sliding bearings that must stand up to significant demands in moving applications. Customers can order the appropriate lubricant-free material as a filament from igus in Cologne, and then make the parts they need themselves using their own 3D printer. Those who don't have a 3D printer can also commission the manufacturing stage from the company online. The 3D printing service usually makes a start on production the same day.

There is a strong emphasis on the quality of components that move and are therefore exposed to friction and wear: "Regardless of whether the printing is done here or by the customer, our Tribo-Filaments or SLS powders make these additively manufactured products much more wear-resistant than those made of standard materials like the synthetic polymer acrylonitrile-butadiene-styrene (ABS), for example," says Tom Krause, head of Additive Manufacturing at igus GmbH. "That's why customers who need a fast, straightforward and long-lasting replacement and want to make prototypes or small series runs of moving parts are happy to talk to us."

Parts with a long service life

All printed parts are made at igus using either the FDM or SLS process. For FDM, igus uses seven different filaments that stand out on account of their specific properties. "For example,



Tom Krause and his team use the Freeformer from Arburg for the FDM process. In parallel, the team is investing heavily in expanding its SLS printing capacities.

we have one material in our portfolio that's particularly suitable for high-temperature applications," says Krause. "And another is approved for use in contact with foodstuffs."

The company develops its own high-performance polymers. In addition, the SLS process can be used to make extremely complex special parts quickly in larger volumes. igus uses two different materials for this: the laser sintering material iglidur I3 is a powder that ensures a very low friction value and high wear-resistance in the printed component. The laser sintering material I6, on the other hand, was specially developed for printing cog wheels.

"We demonstrated its high wear resistance and long service life in a series of trials in our 2,750 square-metre in-house test laboratory," says Krause. "That's where we put iglidur I6 up against other standard materials." For a comparison against the previously standard materials for SLS printing, a worm gear was tested with a torque of 5 Nm at 12 rpm. The cog wheel made of the standard laser sintering material PA12 came to a stop after just 521 cycles, as the friction coefficient had risen so high. The wheel made of the new laser sintering material, on the other hand, displayed only very slight wear after a million cycles, and was still fully functional. Milled cog wheels made of POM had totally worn out after 621,000 cycles. "That shows that our material is highly resilient, with a very long service life," says Krause.

Benefits of Additive Manufacturing

Depending on the level of customisation, the material selected and the quantity required, igus has various manufacturing methods available. Additive Manufacturing is an integral component of the manufacturing process, whether for direct 3D printing or production of tool moulds for the injection moulding machines. In principle, any component with a minimum wall thickness of 0.5-0.7 mm can be manufactured, since this is the smallest possible wall thickness the laser diameter will allow. "We even use 3D printing in developing our own prototypes," says Krause. "For linear technology, too, we can print the carriages and end blocks ourselves. That means linear tables that require no lubricants or maintenance can be manufactured at low cost and very quickly to suit the customer's requirements."

Just as with other manufacturing methods, the component costs with Additive Manufacturing depend heavily on the number of components manufactured per hour. "For smaller parts, Additive Manufacturing can still be attractive at unit quantities of up to 10,000," says Krause. "But for very large components, the costs are correspondingly higher. Even so, Additive Manufacturing can still be of interest here if the components can't be made in any other way, or if another method would be very cost- or labour-intensive." And Additive Manufacturing is the option to pick when very fast handling is needed: for example, if parts are required the same day or if machine down-time is on the horizon.

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A dusty business – from Rapid Prototyping to additive mass production

JOHANNES LOHN

New demands on Additive Manufacturing bring Direct Manufacturing and Direct Tooling in their wake. Protiq GmbH describes the particular challenges facing plant engineering and material for series production from a user's perspective.

Additive Manufacturing already offers many new opportunities. Overnight we can create samples, prototypes and functional elements from a range of materials such as plastics, metal and ceramics. In the past, generative manufacturing was used mainly for rapid prototyping.

Direct Manufacturing involves the Additive Manufacturing of end products directly and without tooling. The product and its scope of application therefore define the demands in terms of materials and manufacturing technology. The electronics sector, for example, places great demands on electrical properties of products and their flammability.

From the perspective of Total Cost of Ownership (TCO), additively manufactured, improved tools can drastically reduce the manufacturing costs of the end products. These tools and injection moulds offer the potential for saving weight and shortening process and cycle times. In the manufacture of forming tools, mechanical parameters such as strength, ductility and surface hardness are of primary importance.

Photos: Protiq

New materials such as copper, brass, zinc and new tool steels for direct tooling of high-performance tools and direct manufacturing of end products.

Series production with Additive Manufacturing

The right materials for the task are essential for series production using Additive Manufacturing:

- Examples of application for Additive Manufacturing show that the current selection of materials for these applications is largely inadequate. Quality certification of new materials with tailored properties is therefore a fundamental precondition for the future broad and cost-effective use of Additive Manufacturing in industrial production.

- In selective laser sintering, most of the products are made from the base material PA12, with or without fillers. Many sectors, however, require industrial polymers that will satisfy the demands on the end products. Nylon 6 (PA6), nylon 6.6 (PA6.6) and polybutylene terephthalate (PBT) are of particular importance. The standard polymer polypropylene (PP) is also in very widespread use. Present-day plant engineering was originally developed to manufacture individual prototypes and is of only limited value in processing these engineering-relevant polymers. From the user's perspective, 3D printing technologies need to be refined to meet the enhanced demands of direct production.

- The range of materials is also very limited when it comes to metals. Copper alloys are very important for conductive structures and elements. But processing highly conductive copper using generative processes is a particular challenge. Like a mirror, the red material reflects the wavelength of a traditional red laser, which means most of the laser energy is reflected and not used as intended to melt the material.

- Modifying the process has helped, which means it is now possible in certain circumstances to process highly conductive copper using additive methods. This adapted laser melting process can also be used to work with zinc and brass. While zinc can be used as an addition to traditional die-cast zinc product families with small unit quantities, the ability to process brass creates new levels of freedom for the jewellery industry and the taps and valves industry.

- The processing of high-tensile steels also offers a lot of potential. These require higher process temperatures. Together with prominent research institutes in North Rhine-Westphalia and heating appliance manufacturers, Protiq GmbH is already working on new solutions that will make it possible to add typical tool steels, e. g. 1.2343-grade hot-work steel, to the range of materials in the near future.

"High-tech meets the Stone Age"

Direct Manufacturing requires the automation and networking of plant technology with conventional manufacturing technologies:

- The actual manufacturing process in Additive Manufacturing is well developed and runs fully automatically, but the upstream and downstream processes still require significant manual input for the most part: components are cleaned of powder residues by hand and the residues are manually reclaimed to be fed back into the process. The plants are even set up by hand, with the consequence that it can sometimes be impossible to achieve the ideal capacity utilisation in single-shift operation.

- The latest-generation plants come with interfaces that enable increasing automation along the process chain, from 3D data handling to process planning (positioning and support generation), processing and post-processing, and packaging. The unresolved questions in the area of automation technology offer an opportunity for German special machine manufacturers to cultivate the attractive market for Additive Manufacturing.

Direct Tooling makes it possible to manufacture forming tools and conformally cooled tool inserts with improved performance and in lightweight design.

Digital networking at all stages of the value-added processes

Only digital networking along the vertical and horizontal value-added processes can make the lean, flexible manufacture of customised series products possible. Additive Manufacturing enables a manufacturing time of just a few hours. This speed should not be compromised by slow, conventional ordering processes. Digital data handling is the precondition for automated, vertical integration, from the customer through to production.

Initial Internet platforms are making the ordering process leaner, and at the same time make it possible to link with established SAP systems. This includes 3D model analyses, including 3D data repairs, online price calculation for the services and materials offered, including configuration, scaling and post-processing, the selection of the relevant logistics service and payment provider, and commissioning the digital shopping carts.

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Additive Manufacturing of individual units and small batches pays off

ULRICH KLOSE

Systec GmbH manufactures and develops automation systems and special-purpose machines, and has built on its own automation and control products to develop fully industry-ready 3D printer solutions for the FFF/FDM process.

Photos: Systec

The large-scale industrial 3D printer has a build area measuring 625 x 625 x 625 millimetres.

While a product is in the development stage, patterns regularly have to be manufactured, tested, altered and re-manufactured. That was the experience of Jochen Keuschnig, product developer at Systec in Münster, a few years ago. For a plastic housing, he needed large, individually shaped parts with an edge length of about 40 centimetres.

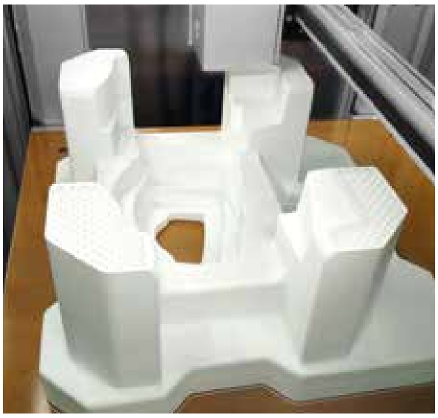
Large-format industrial FFF/FDM 3D printer

Injection moulding during the development stage would have been too expensive. Additive Manufacturing using the low-cost FDM process seemed an efficient solution. But to his surprise, Keuschnig was unable to find a supplier. Although FDM 3D printers for small parts are now available from electronics discounters, the range of scalable, large-format printers suitable for industrial use is negligible. Systec recognised a promising niche market at that point and began developing its own large-scale industrial 3D printers.

In an industrial environment in particular, there is often a need for large components produced using FDM or the similar FFF process, whether for special-purpose solutions, as product samples, for development parts, or for small batch runs. FFF/FDM 3D printing using low-cost, versatile filaments such as PLA or ABS is a worthwhile alternative in cases that do not require large unit quantities and high production speeds.

Using existing expertise from automated gluing processes

Systec was able to draw on existing expertise for the development of its 3D printers. Experience had already been gathered in the control of dosing systems for numerous gluing applications. With the FFF/FDM process, a polymer filament is melted in the hot end and applied via the pressure nozzle in layers, in the same way as hot glue, and a three-dimensional object gradually



Using Additive Manufacturing to produce this transport block allows for product properties that would not be possible using a method such as milling.

It all started with this plastic housing component. Because no suitable supplier could be found, Systec constructed its own FFF/FDM 3D printer.

takes shape. With the ready-to-use DriveSets positioning systems, Xemo positioning control, a complete manufacturing cell concept, an NC software solution for machine operation, and a wealth of mechanical engineering expertise, Systec was ideally equipped to integrate the 3D printing application as part of a plant design suitable for industrial use.

“Industrial-scale FFF/FDM 3D printing relies on precisely controlled movement and high-precision, even temperature control,” says Systec 3D printing consultant Marcus Schwegmann. In customer meetings, he regularly observed that the customers are not looking for “one” complete 3D printer. Instead, many customers want a sturdy, flexible, moving system with a heatable cabin, all the necessary industrial interfaces, and a build area that is not too small. “Our customers often want to integrate the actual 3D printing technology themselves,” says Schwegmann. In many cases, it’s the know-how with large-scale mechanical engineering that is the key factor for the customers. They want sturdy machine solutions that will stand up to all day-to-day industrial pressures and be fully set up for use as 3D printers.

That’s also the situation with a current project. A customer was looking for a base system it could use to develop its own granulate 3D printer head. Systec manufactured a 3D printing cell with a printing area of one cubic metre, together with all the motion, control and safety technology, and prepared it for the extruder to be incorporated. Everything else was the customer’s responsibility. “Our 3D printing systems are an open platform,” says branch manager Jan Leideman. “Our customers have total control and complete access to all system components.”

Additively manufactured transport block saves 18 kg

The demand for customer-specific, large-format 3D printers is there. That’s clear from many of the application enquiries that Schwegmann receives. One manufacturer of crane systems needs special transport blocks for its intralogistics systems, for example. Previously, these parts, which have a limited number of useful cycles, were milled from massive polymer blocks. That led to a lot of waste and correspondingly high material costs. Using the Additive Manufacturing method tested by Systec to make the transport blocks from “Colorfab XT White”, the customer was able to reduce the weight of the finished component from more than 25 kg to around 7 kg.

The printing process itself took just over three days. But that didn’t matter, since only about ten such parts were needed each year. Another advantage is that the details can be improved each time a new one is printed. The transport block acquired a carry handle, for example. That would not have been possible with milled components.

The company also works together with Dutch technology developer Demcon to make its mechanical engineering skills in the 3D printer segment available for the Euregio “Smart Production” project. For this project, Systec is providing Demcon, which has developed a 3D printer head for viscous materials, with a 3D printer base cell for use in integrating its innovative technology. The goal is to be able to manufacture large-scale sealing lips, for example, using a 3D printer.

“The availability of 3D printers in-house is one of the reasons why our own production itself has become more flexible. Covering caps that are needed only infrequently, housings for electrical wiring, sample parts and much more besides can now be printed off quickly”, says Leideman.

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Printing ceramic components using light

IN CONVERSATION WITH MICHAEL STEINBACH

Michael Steinbach,
Head of Technical Ceramics.

Steinbach AG, based in Detmold, uses the Additive Manufacturing method LCM to make tiny ceramic components with ultra-high precision. We talk with Michael Steinbach, head of the company's Technical Ceramics division.

The Technical Ceramics field is a relatively new one for Steinbach. Tell us how it came about.

Steinbach: In 2015, we were looking for a new business area. We were already working as part of a Joint Venture in Taiwan to manufacture precision parts using ceramics – although we already produce precision parts using ceramics the conventional way. We kept receiving enquiries for small batch runs from customers there, but they would not have been commercially feasible. That's when we thought about how it could be done, and we began looking at 3D printing for ceramic components. We made the actual start in early 2016.

How does Steinbach's Additive Manufacturing process work?

Steinbach: We use the LCM process. It stands for Lithography-based Ceramic Manufacturing. The printing uses a liquid that includes ceramic powder and a photopolymer, a light-sensitive polymeric material. The building platform is lowered into this thick slurry from above. Below the glass slurry container is a lighting unit that radiates UV light. The photopolymer reacts to the light and hardens each individual layer. Nothing happens to the ceramics at this stage: only the polymer reacts and this cures the ceramics.

In this way, we build up several hundred, or several thousand layers, one at a time. At the end, the component is about 20 percent larger than required. Following the printing process, it is cleaned and heat-treated. The polymer is then carefully burned out in a furnace over a period of several days. This makes it lose around 20 percent of its size again. It is then sintered at 1,600° to harden the ceramic component. The printing process is performed using only light. The exposure cures the liquid and forms the body of the component.

What is the target market for these printed ceramic components?

Steinbach: We serve markets where the properties of ceramics have never previously been a good fit, and where different materials have been used until now. But these tend to wear rapidly and have to be replaced, unlike the situation with ceramics. In medical technology, analytical equipment or sensor technology, for example, where the required device quantities run into the thousands rather than the millions. This means that only a few thousand ceramic components are needed. That's our global market. And it's where we can offer products made using our 3D method that are better and cheaper.

What sort of products are they?

Steinbach: We specialise in very small components, micro-components for medical devices.

Additive Manufacturing enables the finest structures, as the coil shows.

There is also demand from the mechanical engineering industry for our products. We are often involved in small batch manufacture or single-part products here. While plastic or metal parts used to be used, they had to be changed frequently because of the high ambient temperatures involved. Ceramics have not been suitable for this process to date, because only small unit quantities were needed. This has now changed. Printed ceramic components are commercially feasible, and they do not wear.

What is the competition like?

Steinbach: The market for additively manufactured ceramics is very clear, which is one of the reasons why we chose to go in that direction. Throughout Europe, there are just a handful of locations that offer the same service as we do. Most entities that use this kind of printing system are research institutes. But the market is growing. At Ceramitec, the leading trade fair for ceramics, you would find only two or three suppliers active in 3D printing three years ago. This year the total was much higher.

You said that making components in small batches using 3D printing is commercially feasible. What other advantages does it offer?

Steinbach: You can manufacture internal geometries. Using conventional methods, you would have to manufacture several parts and then join them together. There is also a big saving in time and costs, since you no longer have to make tooling to produce the parts. And that tooling would suffer wear and tear over time. Because we generate almost no production waste, our environmental footprint is also much more positive. Another advantage is that you can try more things out. You can produce the components the way you need them, whereas previously, you always had to draw on standard components.

Are there any disadvantages?

Steinbach: I would say the method has its limitations, at least for the moment. One is wall thicknesses. We are currently limited to a maximum wall thickness of four millimetres, but soon we will be able to produce eight millimetre thicknesses. If the component walls get any thicker, the debindering process – the separation of the polymer from the ceramics – no longer works. The thicker the wall, the longer the path needed by the polymer to escape. There is a risk that it will destroy the component in the process. A solution to this will be found at some point, and it will be possible to make thicker component walls, but at the moment we can only make wall thicknesses of up to four millimetres with no risk.

Will Additive Manufacturing processes replace conventional methods sooner or later?

Steinbach: Development in this area is moving very swiftly. When we first started looking at this field in 2015, we very quickly concluded that this was not just hype that would fade again after a period. We were already convinced that Additive Manufacturing would be a part of future production systems. It will not replace conventional manufacturing methods, but will be used alongside them. We are not driving out existing systems but, instead, we can offer additional solutions and thus also cultivate new markets. Our main driving force at the beginning was to build up expertise and use it to help shape a new industry. It was very exciting for us to be part of the process right at the beginning, and it still is.

www.steinbach-ag.de

Photos: Steinbach

Complex geometries for different applications: gas exchanger, fluid reactor, nozzle.

Additive Manufacturing: Looking at the whole process chain as a key to success

RINJE BRANDIS

Today, Additive Manufacturing offers a wide range of potentials for innovative solutions. The successful use of this technology requires all steps in the process chain to be coordinated and considered as a whole, from the first conceptual design to final machining. This is demonstrated here on the basis of a practical example.

Graphics: DMG Mori

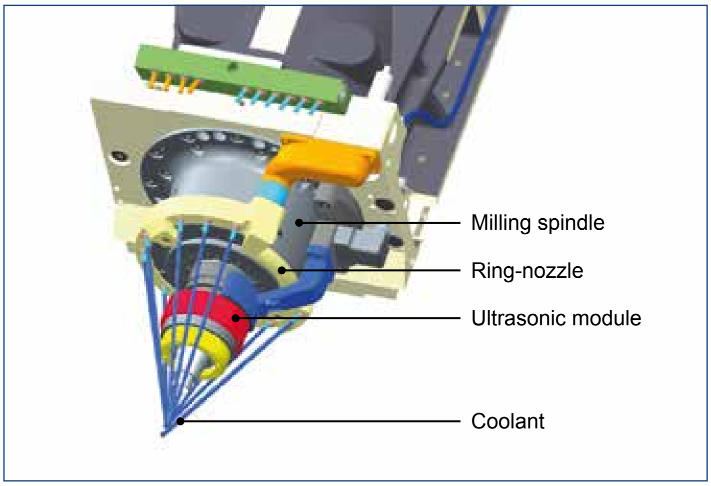
Considering all aspects of the Additive Manufacturing process chain.

Additive Manufacturing technologies (AM) for metallic materials have reached the point where they can be put to practical use in mechanical engineering and plant construction. The advantages are obvious: complex geometries, small batch volumes and a fast response to design adjustments offer great opportunities for innovative solutions. However, poor technological knowledge and a lack of confidence in “printed” components are still often obstacles to their use. These printing systems are often perceived as stand-alone methods, and as a result are not sufficiently integrated in the processes of an industrial production environment.

DMG MORI Academy GmbH supports external customers and its own plants in the introduction and use of Additive Manufacturing. These consulting and engineering services focus on a comprehensive consideration of the product development process, from the first conceptual design to the finished production component. This end-to-end approach and the linking of design, additive manufacturing process and final CNC machining is key to successful application of the technology.

The challenge

Our ring-nozzle for the cooling process in an ultrasonic milling system is a good example to illustrate the potentials of Additive Manufacturing in mechanical engineering and considering all aspects of the process. The ultrasonic technology enables efficient grinding, milling and drilling of advanced materials that may be hard and



Ring-nozzle in use in an ultrasonic milling system by Sauer.

brittle, super alloys that are difficult to machine, and fibre composites. An ultrasonic process overlays the rotational movement with a longitudinal oscillation. In our example, removing swarf and the process heat that develops in the system posed a challenge. This is where the conventional approach of supplying a coolant reached its limits, necessitating a new solution.

The coolant must be applied directly, preferably to the entire tool, at a very low angle to the spindle axis. The interference contour of the ultrasonic module would make a conventional solution very difficult. Furthermore, the range of components to be processed imposed significant limitations on the size and shape of the new nozzle, making a compact design essential.

Considering the process as a whole and the self-imposed goal of manufacturing the components in an industrial environment generate further requirements. The widespread practice of manual post-processing of a printed part is no longer an option. Only a consistent and stable manufacturing process from printing to final machining can produce components reliably, safely and efficiently. This also applies to small batches involving fewer than 100 units per year.

The Additive Manufacturing solution

The conceptual design consists of a ring-shaped part with several nozzles around its circumference. An integrated channel supplies the nozzles with coolant. A bridge is incorporated in the area of the ultrasonic module to close the main channel. This is necessary to ensure uniform pressure distribution for all nozzles. Two mounting holes at the front provide the connection to the milling spindle.

The design follows the function and the overall production process. First, the printing direction is determined and the part is designed accordingly. To ensure easy separation at the downstream cutting stage, it is constructed flat on the building plate. Furthermore, the inner channels are designed with a curved roof geometry to prevent them from being obstructed by the support structures. These supports are constructed as fine-filigree lattice structures of the same material, and allow the dissipation of process heat from overhanging geometries. In addition, the massive parts of the component are replaced with an internal honeycomb structure to reduce the overall weight. Wall thicknesses are based on the working forces of the chuck during final turning and milling.

Professional from start to finish

Final machining of the part is done on a CTX beta 800 TC. Here, the main spindle initially clamps the part on its outer surface. The first stage involves removing the supports and milling the seat on the inlet. Then the inner surface is turned, which will later form the seat of the component. The part is then automatically transferred to the counter spindle and clamped on the inner surface to enable milling of the nozzle seats. This allows the component to be fully processed on six sides with full process stability.

This example clearly illustrates the potentials offered by Additive Manufacturing and the need to consider all steps in the product development process as a whole. In mechanical engineering, the acceptance threshold for the use of such printed parts is still very high. This is often due to a lack of confidence by the engineers in stressed parts made from a powder. However, this scepticism is not justified.

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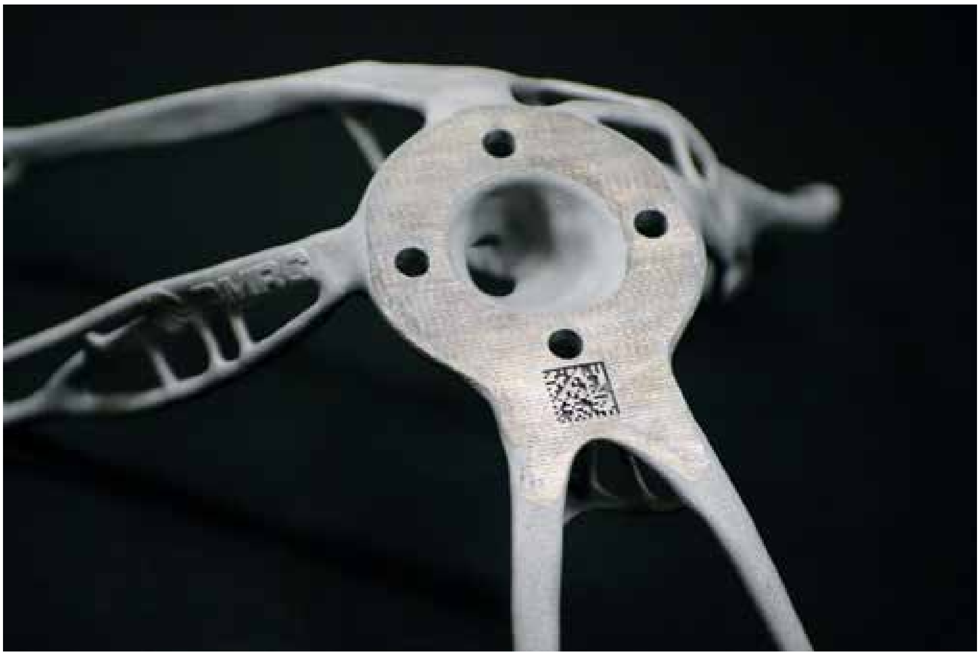
Filling the gap between industry and research

CHRISTIAN LINDEMANN

Additive Manufacturing processes offer huge potentials for businesses to make technological progress, and not only in NRW. So far, however, the technology has not yet gained a foothold in the production facilities of small and medium-sized enterprises (SMEs). This can be attributed to the many challenges that the technology still has to overcome. The reasons for this, in turn, lie in a lack of design knowledge, a limited selection of materials, and inadequate training for engineers to master the technology.

Photos: DMRC

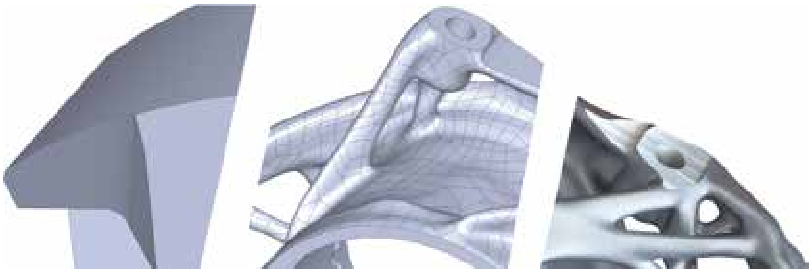


Optimised and marked structural component for a satellite. Additive Manufacturing reduced its weight by 50 percent.

In the heart of Ostwestfalen-Lippe, specifically at the University of Paderborn, 15 professors and 30 research assistants are working on making Additive Manufacturing technology available to SMEs. The Direct Manufacturing Research Center (DMRC) was created at the University for this purpose in 2008, at the initiative of aircraft manufacturer Boeing. With a current total of 29 industry partners covering the entire process chain, the DMRC has been initiating research projects for more than ten years now. The network focuses on research, innovation and teaching. Its themes include researching new materials for electric mobility, as well as bioresorbable implants for the human body. Starting in 2019, in addition, the University of Paderborn will develop customised materials for the industry in NRW. It has three production facilities available for metal and polymer powders. The project “iAMnrw – Materials” is sponsored by the European Regional Development Fund (ERDF).

The continued success of the German economy depends on its future workers. The University of Paderborn has offered a broad range of teaching events on the subject of Additive Manufacturing for ten years now, and was one of the first in Germany to do so. The DMRC offers many professional development courses and industrial seminars to provide further training opportunities for the current generation. It works with entities such as the Association of German Engineers (VDI) in providing training to the level of VDI-approved Additive Manufacturing Engineer. The goal of the qualification course is to gain an overview of the entire Additive Manufacturing process: from selecting the component, deciding on the manufacturing method and design, to putting Additive Manufacturing into practice in the company.

Three new startups have been established by former employees in the meantime. “AMendate GmbH” focuses on making future products lighter and



Step-by-step transition from a solid base body to an ideal lightweight structure for a wheel carrier.

more bionic, while "Additive Marking – Produktionsintegrierte Kennzeichnung GbR" works to ensure that the manufacturing stages of 3D printed components remain easy to follow throughout. And "AMproved GmbH" is the first professional online market for Additive Manufacturing, offering pragmatic solutions for industrial use. Like the DMRC itself, the goal of all these startups is the industrial implementation of this technology.

- AMendate is developing a fully automatic topology optimisation software for Additive Manufacturing. This technology considers the rules of design for Additive Manufacturing and greatly simplifies the optimisation process. Developed from the user's perspective, this software meets all engineering requirements. High resolution guarantees detailed structures, and stress optimisation creates bionically shaped geometries with an even distribution of stresses. An automatic, intelligent smoothing algorithm efficiently transfers the result into geometries that can be printed directly. With the automatic retransition into CAD-models the need becomes redundant to further process the resulting product using additional, special software. AMendate gives design engineers an error-free, printable component that meets every requirement, all in super-quick time.

- Additive Marking addresses the challenge of labelling additively manufactured components to ensure they are traceable throughout the entire product lifecycle. The digital process chain, which may be assured using Blockchain technologies, for example, can be combined with the physical world in this way. This is of interest for spare parts that have previously been made using injection moulding or similar procedures, and were marked by the mould used in the process. As the moulds succumb to wear and tear and demand declines, these parts are now increasingly being made as required using 3D printing. But also for research and development, test units, for example, must be clearly allocated for the purpose of positioning and orientation in the Additive Manufacturing system. In the case of safety-critical components, e. g. in aerospace, for medical applications or in automobile manufacture, the need to mark components to ensure traceability goes without saying.

- AMproved is the contact for all operators of Additive Manufacturing technologies. As an online marketplace, it offers not only I/O devices, spare parts and accessories, but also innovative solutions to improve quality and efficiency. It offers everything needed in day-to-day production. As a highlight, the company will exhibit its solution for safe, contamination-free and traceable powder handling at the Formnext Trade Fair. A container system developed especially for Additive Manufacturing, with leak-free valves, makes it possible to store and handle the powders used in the process, keeping them away from oxygen and moisture, and using RFID tags to guarantee clear traceability. It is also developing air-conditioned, mobile manufacturing cells as part of a collaborative arrangement with a manufacturer for industrial construction purposes. In addition to providing the ideal conditions for installing AM plant technology, gas sensors and an air purification system will also achieve a substantial improvement in industrial safety.

When a number of skills are pooled and interdisciplinary collaboration is the result, as in the case of the startups described above, for example, the results speak for themselves. One result was a 50 percent reduction in the weight of a satellite component. The required topology optimisation for this was provided by an algorithm from AMendate, while Additive Marking looked after the product labelling, and AMproved ensured the production processes themselves flowed smoothly. The project was coordinated and implemented at the DMRC, with industry input. This showed how joint, interdisciplinary collaboration creates a bridge between industry and research to foster the industrialization of the technology in the long run.

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4D textiles: morphing hybrid textile structures for medical, automotive and aerospace applications

DAVID SCHMELZEISEN AND THOMAS GRIES

3D printing deals solely with generating static objects. Creating structures that change over time is the task of an entirely new research discipline, which has developed under the name of 4D printing.

Photos: ITA

Morphing 4D textiles with button surface for human-machine interaction.

Opening the blinds, opening the windows, getting dressed, driving cars, working on the computer, going cycle racing... our day-to-day activities are characterised by the manipulation of static objects. The digital transformation of our environment is already helping the way we interact with everyday objects. Small, digitally controlled motors are increasingly taking over our daily tasks. We refer to “intelligent systems”, which define the fourth industrial revolution. But employees at the Institute of Textile Technology (ITA) at RWTH Aachen University are already aiming well beyond the fourth industrial revolution. The question they are asking is: “How can we breathe life into the static objects that surround us?”

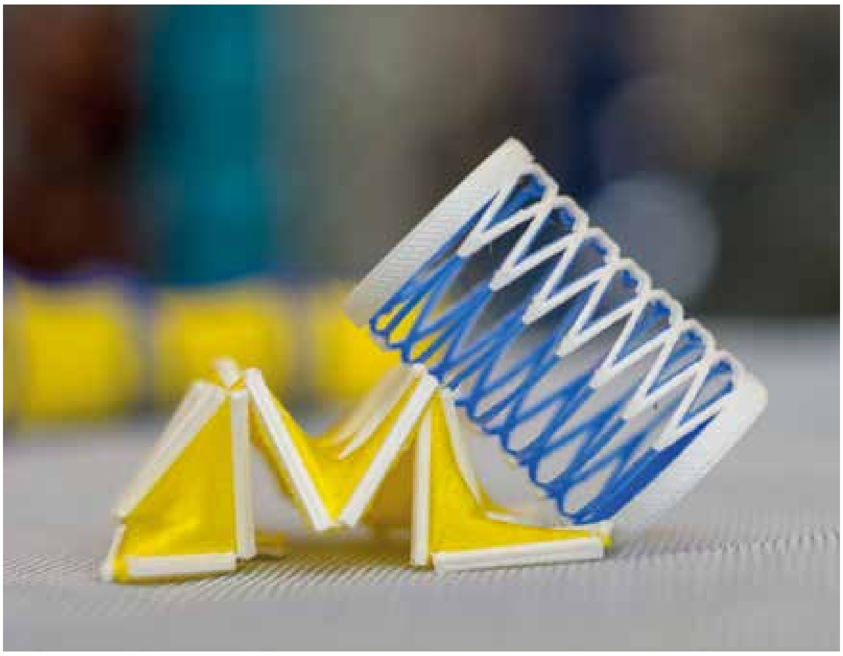
The answer lies in the fourth dimension: time. If we give dynamic properties to three-dimensional objects, what we get as a logical consequence is four-dimensional structures. The expression “4D printing” was coined in 2013 by Skylar Tibbits, architect and leading thinker, at the Self Assembly Labs at MIT. Tibbits works with 3D printed structures that change form in response to external stimulation. He uses polymers that swell in response to humidity, or expand in response to temperature, to build layered structures. These bases constitute interesting approaches toward realising objects that change over time. One difficult aspect is the scalability of the structures, in terms of their geometry as well as the effect being sought.

Multi-material systems that change over time

This is why the Institute of Textile Technology (ITA) has been working with prominent industry partners not just from NRW but from Germany as a whole to implement multi-material systems that change over time. These hybrid materials consist of highly elastic textile and additively manufactured smart materials: 4D textile.

An early example of this vision is the BMW GINA Light Vision concept car. A revolutionary aspect was its "flowing" flexible textile bodywork. The textile bodywork was intended to combine form and function in a single component. It was designed to respond to stimuli, for example, opening and closing doors, headlights or the bonnet. The vision of textiles that change with time was born. At the moment, the GINA model still remains a vision.

ITA applied for the first patent for the hybrid material "4D textile" in 2016. In early 2017, the interdisciplinary research group headed by Prof. Gries was honoured with the Innovation Prize of RWTH Aachen University for the 4D textile hybrid material. This was followed by the 2018 Creativity Award of the German Textile Machinery Industry, presented by the VDMA Industry Association for the Textile Machinery Industry.



Programming the textile surface for acoustic properties and rotary printing for orthotic applications.

Textiles that change over time represent the next stage of evolution of textile materials, from functional, industrial textiles to living components.

In 2016, therefore, the Institute of Textile Technology first combined elastic textiles with what are known as 4D-printed structures. Working with industrial partners from NRW, ITA expanded the concept of 4D textiles to cover a range of fields of application: examples include morphing display systems and touch pads, self-regulating façade elements, and programmable implant systems.

Living structures – 4D textiles

Textiles combine a high level of strength, elasticity and drapability with low flexural strength. At the same time, they can be manufactured in large volumes with a high level of customisation at low cost. These properties make them the ideal basis for 4D structures. Functional enhancement with autoreactive materials can take place during the textile manufacture process at a fibre, yarn and surface level, or during subsequent refining stages. In their research, the employees of ITA benefit from the full process chain of one of the largest of the RWTH institutes, from fibre manufacture to the functionally enhanced end product. The manufacture of form-changing fibres and filaments is scaled at ITA using industrial process technology to create a commercially viable process. Fibres and filaments of this nature are made into fibre-based products on more than 400 machines in the process development unit of ITA.

The first combination of 3D printing and knitted textiles to form autoreactive multimaterials created something of a sensation. The first prototypes are autoreactive surfaces that provide support for users in automobile interiors. For the future, the researchers at ITA, in conjunction with industrial partners from NRW, can see many applications for multimaterials of this nature: three public projects are currently focusing on the use of multimaterial systems in the area of automotive interiors, medical technology and architecture.

The Alive Automotive Interior project, with input from prominent partners in NRW, aims to develop textiles that will later assist users to operate their digital environment in the age of self-driving cars. In the field of medical technology, work is being performed on tubular structures that can actively change shape. One benefit of these is that implants can move independently and combine at the point of application. And in architecture, active textile outer shells can reduce energy consumption via a control system that incorporates sun-dependent materials. Design effects that interact with the immediate environment are a further possibility with this technology.

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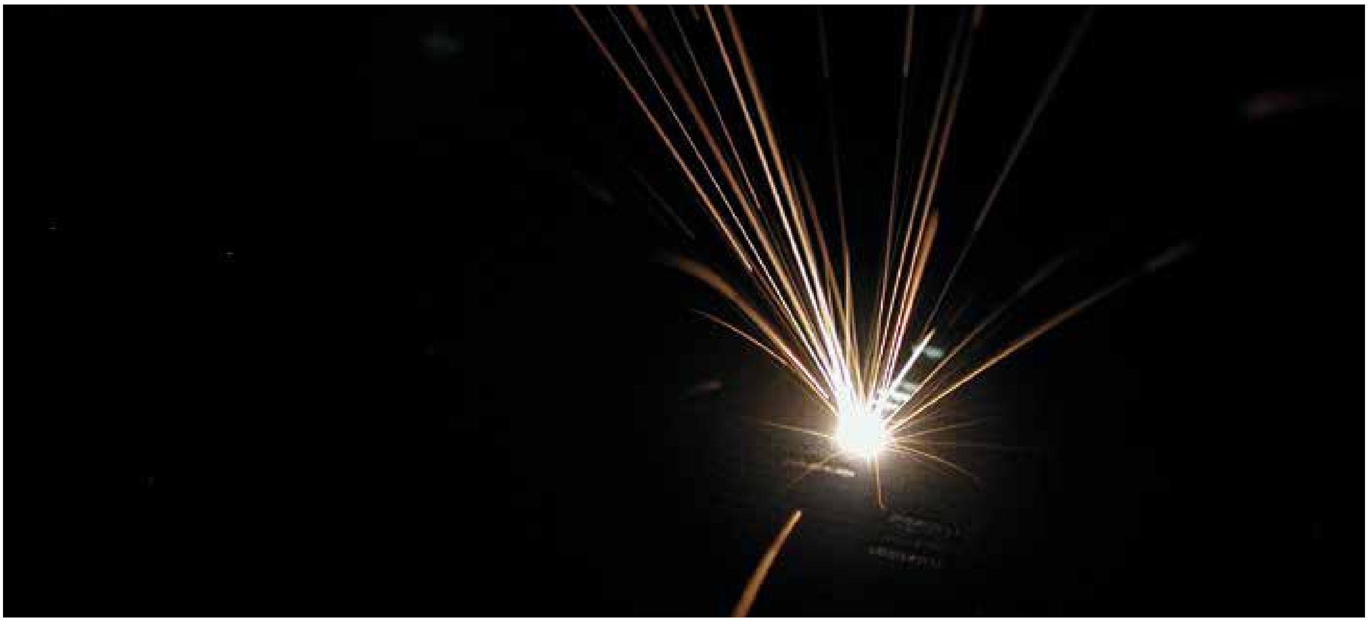
Additive Manufacturing goes hybrid: metal combined with ceramics

CHRISTOPH KAMMANN AND JAN T. SEHRT

What if a 3D printer could prepare the desired powder mix for the laser beam melting process and feed it into the printer, all at the push of a button? This is the vision that the chair of Hybrid Additive Manufacturing (HAM) at the Ruhr University of Bochum is working toward, as it seeks to develop the potential for Additive Manufacturing technology in the area of laser beam melting and expand the range of materials that can be used.

Photos: Ruhr University Bochum



Exposure of the powder bed surface at laser beam melting.

Laser beam melting is an Additive Manufacturing process that is used to produce highly complex metal components, either directly as prototypes or as ready-to-use end products. It involves melting a metal powder layer by layer with a laser beam and consolidating it into a solid material. At the moment, the range of metallic materials that can be used for processing in this way is much narrower than for conventional procedures. In some cases, the materials currently available have been specially adapted for use in Additive Manufacturing. Nevertheless, the trend is toward adapting the properties of the materials to suit the intended application in the end products.

The chair of Hybrid Additive Manufacturing (HAM) at the Ruhr University of Bochum is researching ways in which the properties of metallic components produced using 3D printing can be altered through the targeted inclusion of ceramics. This involves deposition of ceramic particles into the powdered metal source materials, for example, and then performing the laser beam melting process. The mixability of the powdered source materials opens up entirely new opportunities in Additive Manufacturing technology to generate product-specific material properties.

Work originally began at the chair of Manufacturing Technology at the University of Duisburg-Essen, and is now continuing at the newly established chair of Hybrid Additive Manufacturing at the Ruhr University of Bochum.

Magic powder

Imagine being able to tell a machine the desired material composition for a particular product. The machine automatically prepares the desired powder mix and runs the 3D printing process using the right settings for the combination of materials in question. The powder mix can be used to set many different properties, whether a particular alloy is desired that offers advantages under particular conditions, or hard ceramic phases that can improve the wear-resistance of a given material.

Optimised mixing

The properties of the powder mixes are vital elements in the laser beam melting process, to enable the powder to be applied evenly and consolidated using the laser. To manufacture homogeneous powder mixtures based on metal powder and ceramic microparticles, an automated Turbula mixer was designed, constructed and put into operation. This mixer was used to develop a deposition process that can be used to create homogeneous metal-ceramic mixtures. Turbula mixers are known for achieving good results when mixing powders at low speeds. With a combination of rotation, translation and inversion, they achieve an extremely high level of efficiency. Optimising the Turbula mixer parameters and introducing mixing aids made it possible to develop a suitable procedure for metal powder with ceramic microparticles and create powder mixtures for 3D printing.

Modified materials

In all cases, the goal must be to ensure the material properties ultimately satisfy the criteria required of the component, such as resistance to wear, stability and functionality. The distribution of the ceramic particles in the component and the associated material properties depend greatly on the 3D printer settings. To this end, test pieces were produced using the modified metal powders with different ranges of process parameters, which were then examined and compared using microscopic analysis and measurement of mechanical and tribological properties. The objective was to see how the ceramic particles are distributed within the component and to establish the effects in terms of strength and resistance to wear.

Adapt material properties to stresses

During 3D printing, the material properties are generated along with the geometry, and are open to local influence. Unlike traditional methods, it is possible in this way to deliberately generate different strengths on the inside of the component compared to its other areas, for example. This creates the opportunity of ensuring greater strength values along the component's power flow lines. It would be conceivable to generate very strong bionic structures surrounded by a more ductile metal matrix, in other words a sort of composite material composed of a substance with different strengths. This would make it possible to create new material properties that have previously been impossible to manufacture.

There is still a need for further material tests on the use of these new materials in end products before the list of potentially marketable metal powder mixes can be further expanded.

KNOW-HOW

Inversion Kinematics

Inversion is a new fundamental kinematic movement that was discovered through the invention of an invertible cube in 1929 by Paul Schatz, who used it as the basis for the development of inversion kinematics. The elegant geometries and movements that result were adopted by artists and architects, and found a technical application in the Turbula mixer and Oloid technology.

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The Turbula mixer.

Creating a turbine layer by layer

RALF DAHMEN

Additive Manufacturing (AM) processes permit totally new component geometries and functions, and make small series runs commercially feasible. This makes AM ideal for metal components in gas turbines, as a project by Solidteq GmbH in Neuss shows.

Solidteq components made using 3D printing.

"We need metal components in fairly small numbers, with a high level of functional integration, optimum mechanical and thermal properties, and flow-optimised gas flow control." That was the request received by Neuss-based company Solidteq GmbH from a gas turbine manufacturer. This specifically involved elements such as the compressor and impeller housings for a small, compact gas turbine with a power range of a few hundred kilowatts.

Flow-optimised design

Solidteq drew on the opportunities provided by Additive Manufacturing to square this particular circle. In this process, laser beams are used to melt metal powder layer by layer at predefined points to build up the required component. The metal powder that is not heated is removed at the end of the process, leaving behind the finished component. The manufacturing process requires no costly tool moulds, just a precise, three-dimensional dataset and a 3D printer.

This recipe suited the customer's needs, since it is expecting to sell about 30 gas turbines in 2018, and 100 to 200 next year. Expensive tools and moulds are not cost-effective for such low unit quantities. The customer also wanted the components to come with a flow-optimised design for gas flow control. This would have been very difficult to achieve with conventional forming and processing methods.

For the material, Solidteq opted for the corrosion-resistant nickel-based alloy Inconel. This is particularly well suited for the components in a gas turbine that are exposed to high thermal and mechanical stresses. Because the compressor housing in the gas turbine measures 300 x 300 x 200 mm, the three-dimensional printing process takes about 80 hours. Solidteq must guarantee the largely automatic operation of the plant and the high-accuracy melting of the powder at very high temperatures throughout this quite lengthy timeframe.

No negative impact on the unmachined part

The heat applied during the melting process, in particular, must not negatively impact on the component geometry and the narrow tolerances that are required. Solidteq assisted the customer with the intelligent design of the components, to ensure that the required support geometries minimised component distortion, but without impacting on the flow-optimised design of the gas channels and the further processing of the part itself.

The fine planning work on the components took just a few days, at which point the final dataset was available and the actual Additive Manufacturing could begin. The total time from awarding the contract to production of the final additively manufactured components took only about ten weeks – much less than conventional forming processes would have required. If any minor functional or geometrical changes to the components are required later, amendments to the simulation and design data are all that will be required. There will be virtually no changes to the Additive Manufacturing process itself.

The company's services – consulting during component design and the Additive Manufacturing – are rounded out with mechanical post-processing of the components and comprehensive documentation. Solidteq provides the finishing touches in the form of any necessary turning, drilling, milling, honing and spark machining, and services such as quality management, material testing, coating and painting. Comprehensive documentation of all processes from job planning to on-time delivery of the components is available on request. These end-to-end services also impressed the customer, and have already led to further discussions about new orders for additively manufactured components.

Solidteq views Additive Manufacturing as a practical technology for prototypes and very small series runs that do not involve critical cycle times. The same applies to lightweight design, functional integration and complex component geometries. Because a large part of Solidteq's team has an automotive background, they are used to dealing with stringent demands and

Photos: christophschuhknecht

sophisticated processes. This unique expertise, covering the entire process chain, is something that Solidteq, as a start-up, can now offer to potential customers in the mechanical engineering and plant construction industry.

Solidteq can draw on a solid foundation when it comes to the further refinement of 3D printing in metal. The company grew from the prototyping unit of automotive supplier Rheinmetall Automotive AG, and is able to benefit from the lean structures and agility of a newcomer, combined with the practical experience built up over many years by a global technology firm.

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Additive Manufacturing methods in special-purpose machine manufacture

VOLKER ZÜSCHER

The rapid development being seen in the field of Additive Manufacturing (AM) opens up totally new opportunities for manufacturing in many industries – and that also goes for special-purpose machine manufacture. Cologne-based turbomachine manufacturer Atlas Copco Energas GmbH describes its experience with selective laser melting (SLM) in impeller manufacture.

Photos: Atlas Copco Energas


Expansion turbine for natural gas applications.

Atlas Copco Energas is part of the "Compressor Technique" business area of the Atlas Copco Group. At its Cologne location, it develops and manufactures single and multi-shaft compressors and expansion turbines that are used in the oil and gas and chemical/petrochemical industries, for industrial gases and the energy industry.

Different but established manufacturing processes for impellers

An important focal point for Atlas Copco Energas is impeller design development to suit individual customer processes and the associated requirements. The impeller is a rotating component that is subjected to major centrifugal forces. The material used here is specially designed and appropriately quality-tested for each individual application. A basic distinction is made between open and enclosed impellers, which can have diameters ranging from about 60 mm to 1,500 mm.

The rapid development being made in AM opens up new opportunities for making metal components directly using SLM. Initial trials have been performed to produce various components using SLM. It was clear that a number

Integrally-geared turbocompressor from Atlas Copco Energas.

Open impeller.

of components are not yet suitable for production using AM, since they are too large or their geometries are not complex enough to offer worthwhile cost savings (for example, by combining separate assemblies to form a single component).

Atlas Copco Energas has concentrated on enclosed impellers with complex geometries and small diameters (below 300 mm), and has established that enclosed impellers of this type are suitable for AM. Two components can also be combined into one this way.

A look at the process

One challenge is to remove support structures in areas that are hard to access. An emphasis on post-processing is therefore essential. The objective is to investigate a process that can mechanically remove support structures in a single pass. Atlas Copco Energas has examined and tested a number of manufacturing methods in its "Polishing" department. This involved investigating a special electrochemical pulse method that concentrates on removing support structures in hard-to-reach areas. Initial tests with this method have shown that, in general, the support structures can be easily removed.

This pulse method is suitable for all 3D-printed metal components. Since no other operating consumables are required, this method substantially reduces the cost and effort involved. In addition, there are significant demands in terms of surface quality, since the impellers must be highly efficient. This necessitates a subsequent polishing stage. A selective mechanical/physical surface treatment process in several stages can achieve values of less than Ra 1 µm. At present, this appears to be a practical way to remove support structures and achieve defined surface quality values. All the manufacturing processes described here can be requested on a contract manufacturing basis.

The next step in this process is to manufacture a complete enclosed impeller and perform detailed surface measurements and structural examinations of the impeller segments.

Promising potentials in special-purpose machine manufacture

In parallel with surface treatment, overspeed tests are also performed on additively manufactured enclosed impellers. Overspeed tests are a quality testing process at Atlas Copco Energas, and are performed for all impellers: they involve running the impeller up to an overspeed in a protected vacuum chamber and then braking again after a set time. The initial overspeed tests on impellers produced using AM were positive.

Summary and outlook

The next step will involve validating the material, which will probably prove to be the greatest challenge. AM technology offers many new opportunities to change component design. This can include functions that would otherwise be possible only with multiple manufacturing stages: in other words, component complexity will generally have minimal impact on the cost of manufacture using Additive Manufacturing (i. e. the SLM process). The first cost comparisons against conventional manufacture of enclosed impellers show that AM is cheaper. Even so, the post-processing stages, such as machining or polishing, may reduce the cost advantages.

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