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SPOTLIGHT

Additive Generation

face to face with Johannes Gartner

VP of Additive Manufacturing Austria

Additive Manufacturing (AM) and big industry: the state of play and a glimpse of the future

by Kathleen Grant, EnginSoft

Research[1] published last year by Statista predicts that 3D technology will be a highly disruptive force for global manufacturing, with the emphasis shifting from the production of prototypes to full-scale manufacturing of parts and accessories. Statista's research states that AM will enable finished products to be manufactured on a large scale by 2030. Given its growing importance, Futurities decided to dedicate its "Spotlight" to exploring the different facets of this production disruptor, beginning with this interview with Johannes Gartner, VP of Additive Manufacturing Austria.

> "Many think that simulation should be a competitor to AM, yet it isn't; it is facilitative and supportive. The need to create prototypes before the physical realization of new products is greater than ever.

References

[1] www.statista.com/statistics/560323/worldwide-survey-3d-printing-top-technologies

Q. Can you give us an overview of the Additive Manufacturing approach at present?

A. Additive manufacturing (AM) is not one homogenous technology – it is a production paradigm, similar to subtractive manufacturing (that removes materials from a whole block to shape a certain structure or product by means of drilling, milling, or planing) or to forming manufacturing (that uses heat and/or pressure i.e. moulding, bending, and pressing to shape a structure).

The ISO and ASTM standards organizations currently define additive manufacturing simply as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”.

There are currently at least seven basic processes defined by the ISO and ASTM to combine, melt, sinter, polymerize and bind materials. Beneath each of these processes are multiple companies offering different technological solutions which results in a wide variety of niche technologies all being gathered under the umbrella title of AM.

When the public thinks of additive manufacturing many have simple consumer devices (based on fused lamination) in mind and believe that it is quite a recent technology. However, the first AM technology, stereolithography, was already invented in the mid-80s by Chuck Hull from 3D Systems. He successfully combined technologies of the time – UV lasers, optics, and photopolymers – into a clever mechatronic system to create the first additive process. Many other techniques followed and were initially mainly used to produce prototypes for some industries like automotive but didn’t attract much public attention.

The “niche” AM technology businesses with their high margins and patent protection created significant barriers to entry to the market for a long time, but that started changing when an open-source version of the expired fused deposition modelling (FDM) patent was published by the British engineer, Adrian Bowyer. The project, called RepRap, was welcomed by the maker community and led to the creation of many startups, attracting a lot of attention and resulting in some over-expectations. A kind of 3D printing hype peaked around 2013 as the market wasn’t ready to support so many manufacturers. However, the interest and motivation around these technologies continued and has led to much riper technologies and many applications.

While the AM market, currently estimated at US$15.2 billion (Wohlers Report 2022), is still minor compared to traditional manufacturing, it has been growing in two-digit percentages year after year for the last 20 years. It therefore bears all the indicators of a very disruptive technology.

Q. What are some of the most interesting application areas at present?

A. There are applications for Additive Manufacturing at all levels of research, development and production across a variety of industries – from food and biomedicine, to dental, automotive and aerospace. The most exciting areas of development can currently be found in the industrial and medical industries and involve the use of a variety of materials – polymers, metals, ceramics and compounds. This opens up new opportunities for the traditional metal or polymer industries i.e. through the creation/addition of fibre-reinforced polymers or ceramic elements. As a result, we are now seeing an increased blurring of borders between traditional material silos.

Q. What are the most important advantages and benefits of AM?

A. Additive processes offer the ability to produce extraordinarily complex, intertwined, or inner structures that are impossible to mill or mould. In this space, AM is already being used, for instance, to create lightweight structures to achieve up to 60% less weight with greater durability (as an example of this, see GE Aviation using AM to produce lightweight parts for Boeing and Airbus). Even if the production cost might be a bit more expensive at first, the fuel savings or greater efficiency offset these costs.

Another huge advantage of AM, considered as a form of digital production, is its ability to produce individualized parts to achieve high customization. In a fully automated process based on digital 3D models it is irrelevant whether 100 identical parts or 100 distinct parts are produced.

Q. Can you give us some examples of how AM is disrupting various sectors?

A. There are some very disruptive AM business models in the industrial and medical sectors, and there are also many promising experimental and research applications. One area where we are seeing massive adoption of AM to generate complex and highly customized parts is in the medical sector – for instance in the dental implants, prosthetics, and prostheses industries.

Courtesy of Lithoz

One prominent example is Invisalign, a form of transparent braces for teeth. This fully customized product has some specific advantages for patients, while benefitting economically from a highly digitized production chain. Such digitally supported individualized medical treatment offer the potential to reduce prices for consumers and medical insurers/public health providers.

A comparable disruptive application in the medical sphere can be found in the area of hearing aids: by taking a 3D scan of the inner ear, a unique inner ear shell can be automatically generated and printed for a perfect fit.

So, wherever business models are able to combine automation and individualization an attractive business case can arise. In addition, it is expected that as the technology becomes more widespread, economies of scale will come into effect and machine and material costs will fall.

Q. What are some of the bottlenecks affecting the adoption of AM by industry?

A. One of the major bottlenecks around the adoption of AM, in my opinion, is that many engineers are currently still trained on traditional manufacturing technologies that have more limitations.

As AM offers more freedom of design, a kind of additive thinking approach is required to completely rethink products that have been optimized for other manufacturing principles. This requires a change in the education and training of engineers.

Q. What is the connection between simulation and AM?

A. Many think that simulation should be a competitor to AM, yet it isn't; it is facilitative and supportive. The need to create prototypes before the physical realization of new products is greater than ever. Prototypes are used even more than before because of more complex products, more product variations, shorter product life cycles, and the rule of ten: mistakes early in product development multiply the costs of stepping back in the process to correct them by a factor of ten. As a result, developers invest significant effort in planning before mass producing a part. Simulation software and additive manufacturing both play an important role here.

Courtesy of Lithoz

An example is the use of AM to generate inner layer temperature structures for injection moulds to perfectly control temperature for higher efficiency and better quality. With AM, the mould can simply be printed directly with perfectly organized inner layer temperature pipes but simulation software is required to first calculate the optimal temperatures to be maintained, and the consequent optimal structures and positions of these inner layer pipes. Combining simulation and AM therefore enhances the availability of this tool and can increases production speed. These benefits would not be possible without using this combination of simulation and AM.

Another prominent example of this winning combination is the ability to generate a product with a grid bone structure. Previously, it was laborious and manually intensive to translate a full block of metal into such a structure; today, the ideal or optimized structure can be calculated with simulation software and then printed directly using AM.

This brings us back to the issue of skills: there is a lack of expertise in the market regarding the use of simulation tools and AM, and the skills are highly sought after. Trained AM engineers are lacking, and the skills are diffusing too slowly within the education system because there is still too large a focus on traditional manufacturing techniques and not enough on AM techniques. This will change in time, but it is not changing far or fast enough yet.

Q. Are there any other challenges to be aware of?

A. Generally, in industry, trying to print a part that has been optimized for traditional manufacturing is the wrong approach. Instead, the parts need to be ideated from scratch, starting with the customer value in mind to enable additional customer value and, in the best case, to simultaneously reduce the production effort (i.e. by consolidating the production of the various parts).

We are dealing with a bias of expertise in the market: engineering experts who know too much about traditional techniques are often not able to see new opportunities. There is also a high learning curve involved: studying this new production paradigm requires time and some trial-and-error experience, but engineers in traditional manufacturing sectors often do not have enough time for this due to the demands of their workdays.

In the short-term, I think that companies should just get started to better understand the opportunities of AM. Rather than immediately investing in a costly additive manufacturing solution, they can start training their employees in additive thinking using a low-cost machine, and they can make greater use of specialized service providers. There is lots of knowledge stored in AM service providers that can be leveraged without a company needing to make a big investment immediately.

Comparable with cloud computing, there is an extensive network of AM service providers around the world where industrial grade machines can be accessed.

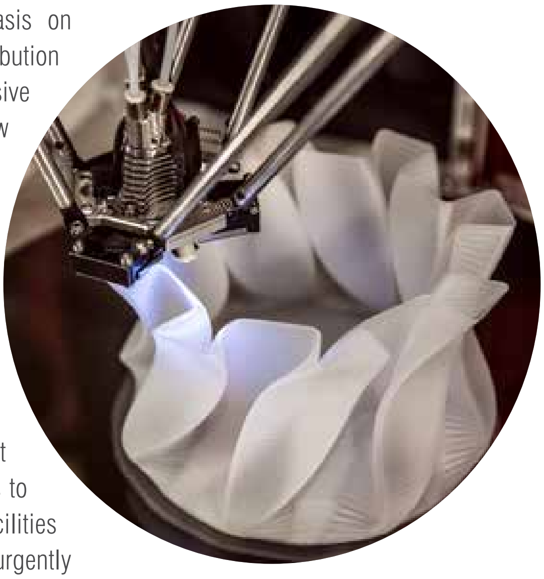
Q. Where is more investment needed?
A. This depends on the stakeholder perspective. There is already a very lively start-up scene and lots of research in the different areas of science.

In my opinion and as mentioned before, investment into training and education is one of the most critical areas. Furthermore, it is important to get policy makers to recognize the important of AM for a country's industry.

For instance, if we take Austria, a highly developed and industrialized market with many SME producers that are responsible for a majority of jobs, it is very important to them to master new production technologies to remain competitive internationally and to ensure that digital manufacturing and its added value does not migrate abroad, as was the case with the majority of the internet industry. This is especially important in the digital age where new technologies are already replacing many jobs.

Q. What do you see in the future?
A. Europe still has the opportunity to be a major player in the AM industry because many patents and developments are already happening in Europe. Unfortunately, the continent doesn't have the same venture funding systems as the USA, nor the public initiatives of China and the Middle East.

We are also seeing more emphasis on AM post-pandemic as global distribution chains are affected by successive crises. The AM product market grew even in 2020 and 2021 and has not been impacted like other industries. I believe that the reason for this can be found in its digital and local characteristics – it provides the ability to produce flexibly and independently on site.



This is one of its big benefits: it allows governments and businesses to have multifunctional production facilities onsite that can continue to produce urgently needed parts, i.e. to keep their critical infrastructure running.

We are already seeing such applications in the military sector. Since in a war situation you cannot know what will break down, and the logistics chain is often extremely complicated or even at risk, the US military is equipping its aircraft carriers with AM machines to enable it to produce whatever replacement parts are necessary wherever the carriers are and in whatever circumstances.

Q. What about the issues of sustainability?
A. Onsite AM production also offers sustainability advantages. AM uses energy, of course, but a massive part of CO_2 emissions internationally comes from the global transport of semi-assembled parts.

Moving to onsite production requires less transportation and enables you to only produce what you need as you need it. However, AM is still currently quite centralized, so the full benefits of these savings on transportation are not yet being fully realized. But we are seeing some fast-moving consumer goods (FMCG) players who are starting to leverage some of these benefits, for instance when it comes to the availability of replacement parts after the end of life of products. If a company had to stock all these obsolete parts just in case, it would generate a lot of waste, not to mention the warehousing costs. Using AM, they can produce the specific replacement parts as necessary and thereby prolong the lifetime of their products.

Another aspect regarding the sustainability of AM is that its many processes only require the amount of material that goes into producing the product, unlike subtractive techniques that still generate a lot of waste. Then, as mentioned earlier, positive sustainability effects already arise from the applications themselves.

For example, the reduction of fuel/energy consumption through light-weight parts for aerospace or e-mobility applications. This has a positive effect for industry in terms of costs and also for the environment. So, used correctly, AM has major potential to be a green technology.

About Johannes Gartner

Dr. Johannes Gartner is VP of Additive Manufacturing Austria, co-founder of 3Druck.com, the leading German-language online magazine for additive manufacturing, and of 3Printr.com, and he is a technology management researcher with a doctorate from Johannes Kepler University in Austria.

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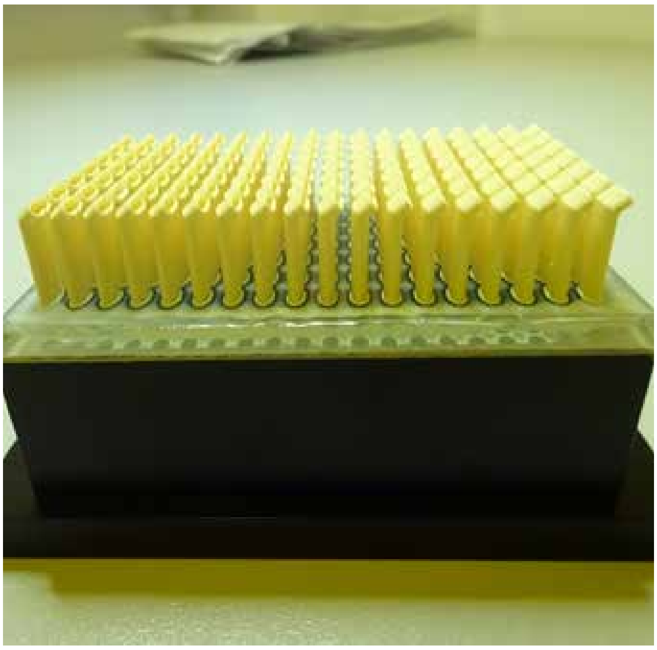
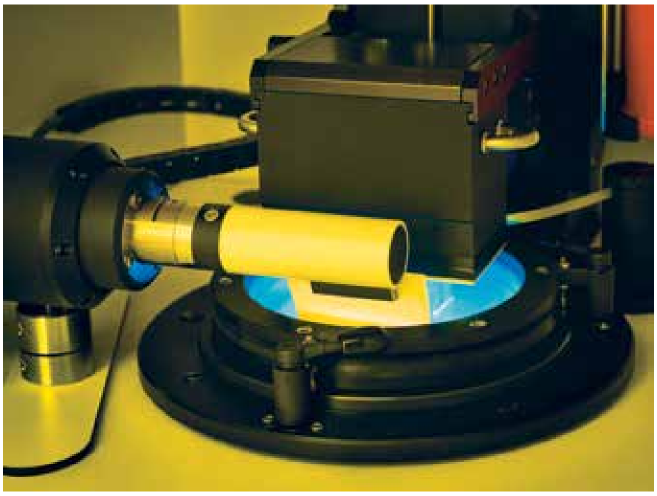
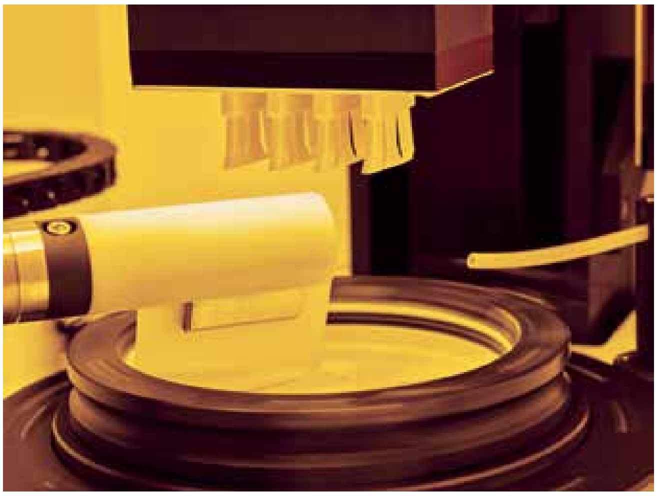
Lithography-based ceramic manufacturing: the industry standard for mass production with ceramic 3D printing

by Norbert Gall
Lithoz

As the market-leading producer of innovative lithography-based ceramic manufacturing (LCM) technology, Lithoz has enabled a wide range of previously unimaginable applications in the industrial field, medicine and beyond. Steinbach, who are considered pioneers in the use of additive manufacturing (AM) for the mass production of high-performance technical ceramics, are just one example of a company who has used powerful Lithoz technology to drive their innovation further. This case study describes their journey to the successful and profitable manufacture of a new type of ceramic tube with complex geometries. Steinbach achieved an annual production rate of 12,000 units with comparable reject rates to conventional manufacturing technologies, and thus established itself as a leading ceramic AM service provider.







In the summer of 2017, Detmold, Germany-based Steinbach was requested by a renowned manufacturer of medical devices to produce a ceramic tube to be used as a guide element in a newly developed surgical instrument. After testing the first component printed with the Lithoz CeraFab 3D printer, the customer appointed Steinbach to develop and mass produce the part using the Lithoz LCM process. These complex tubes cannot be produced using traditional manufacturing processes and had to satisfy some very challenging requirements to meet the customer's business objectives.

The project had a specific target for the manufacturing costs and a tight deadline of six months to begin production. The obviously pioneering aspect was to use the established LCM ceramic 3D printing technology at an industrial scale.

Steinbach's specific objectives were to ensure the scalability of the production process and maintain consistently high part quality throughout.

Key features of the part and the requirements of the mass production project

At the beginning of the project, the biggest challenges Steinbach faced were to meet some of the dimensional parameters defined in the production order. Producing a completely new tube geometry with a sharp bend and inner contours, minimal wall thicknesses of 200μm, and perfectly smooth surfaces with roughness values of Ramax $=$ 0.4, required all the innovative value of this new LCM solution. It was economically impossible to achieve the required narrow tolerance of $+20\mu$m in the outer geometry at a reproducibility of 12,000 pieces per year using traditional production techniques.

To meet the customer's economic expectations, Steinbach had to reliably transfer the superior material properties of the first parts produced with LCM technology into mass production. Implementation took place in three phases, focusing on the key criteria of productivity, process stability, quality assurance and economic efficiency.

Phase 1 – Identifying a suitable part design for LCM technology

Using consistent Design for Additive Manufacturing (DFAM) of the complex geometry, Steinbach collaborated closely with the customer to ensure the full functionality of the tubes throughout the mass production of thousands of components.

The functionality of the developed prototypes was thoroughly evaluated under close-to-series printing conditions to ensure that the component quality was ready for mass production from the first part. The product was validated at the customer's premises, with the printed part geometry obtaining the customer's approval.

Phase 2 – Scaling the process up for industrial mass production

Subsequently, Steinbach's technical ceramics team focused on detailed process optimization to ensure the reproducibility of the part properties without any loss of quality during mass production. To achieve this, all the available potential of the LCM technology had to be fully explored and exploited. Software upgrades to

ensure pixel-precise component alignment were conducted in close cooperation with Lithoz. Systematic control measures were implemented to ensure consistent configuration of the manufacturing process.

After achieving solid production results, further measures were then implemented step by step to increase productivity – for example, by optimizing the part cleaning sequence and developing more efficient loading of the furnace to achieve better thermal processing.

About Lithoz

Lithoz is the world and technology leader for high-performance ceramic materials and 3D printers. Founded in 2011, the company is committed to breaking the boundaries of ceramic production and supporting customers in expanding the manufacturing opportunities for the ceramic industry.

The company's export share is almost 100%, it has more than 125 employees, and has had a subsidiary in the USA since 2017. Lithoz has also been ISO 9001-2015 certified since 2016.

Project at a glance:	
Task	Production of high-performance ceramic tubes in batches of 12,000 per year.
Material	LithaLox (aluminium oxide)
Solution	Additive manufacturing-compatible design and implementation on a Lithoz CeraFab system.
Benefits	Economical mass production of ceramic tubes with geometries impossible to produce using traditional manufacturing processes.

The data obtained during the process optimization served as an analytical basis for quality assurance and as a statistical basis for decision-making in future projects. The customer's process audit concluded the final milestone of the second phase.

Phase 3 – Ramping up to mass production with economic optimization

Six months after receiving the order, Steinbach delivered the first mass produced batch of components on schedule. By July 2019, the full production volume of 12,000 tubes per year was achieved in line with growing customer demand.

Each new adaptation was subject to customer approval of the resulting sample. By continuously increasing the efficiency of the process, as well as tailoring additional developments to the material, Steinbach's team repeatedly reduced manufacturing costs and minimized scrap to reach the specified target range.

Successful completion of the project

In achieving economical production of 3D-printed ceramic components (as described above), Steinbach has taken a decisive step from business theory into business practice. By consistently optimizing the entire manufacturing process, the company successfully implemented mass production with LCM technology and reached the expected return on investment (ROI) across the entire value chain.

Through this project, Steinbach's team acquired full competence across the entire production process – from part design, through post-processing, to the finished sintered component. Other customers have also benefited from the proven knowledge gained, combined with Steinbach's efficient quality management and high-performance delivery. The success of this foundational project took Steinbach to a leading position in the AM mass production of high-performance technical ceramics for industrial and medical applications.

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Fig. 1. Liquid media flowing through a channel structure dissolving internal support structures (Picture courtesy of RENA Technologies Austria).

The power of liquid media for finishing 3D-printed metal parts

by Wolfgang Hansal
RENA Technologies Austria

Additive Manufacturing (AM) with all the freedom it offers in part design requires new methods for post-processing printed metal parts. The design freedom is also used to create specific textures and lettering on the surfaces and to realize complex internal channel systems throughout the part. Mechanical post treatment routines in particular, as well as classical electropolishing, are not capable of finishing such internal structures. For this, post-processing methods are needed that distinguish the part from unwanted structures such as powder residues and supports. Modern electrochemical methods based on liquid media can help to overcome such limitations and enable appropriate post-processing, especially for internal channels and chambers.

Powder residues and laser marks are characteristic of the surfaces of additively manufactured metal parts. In addition, support structures and adhering powder residues must be removed in a first step. Without the removal of such undesirable features, the parts cannot be used technically at all, since classical mechanical or "dry" methods are not able to penetrate deep into internal part features.

Printer manufacturers are looking for ways to realize completely support-free printing. This again comes with some geometry limitations. Some larger internal compartments and some channel structures still require supports. Does this mean that such geometries cannot be used in industrial production? Would this significantly limit the core feature of design freedom in 3D-printing? As Albert Einstein once said: problems can never be solved with the same thinking that caused them.

Design freedom is a core feature of additive manufacturing. It sets the process apart from other production methods and gives it its raison d'être as a new manufacturing technology. Enabling new multifunctionality and currently impossible design features (think of flow-optimized impeller geometries that cannot be produced by casting) gives metal AM its own place among competing manufacturing processes, even at significantly higher production costs. The possibilities are endless and are just beginning to be explored by scientists and engineers around the world.

Fig. 2. Cross-sections of a manifold used in automotive applications. The printed part (left) includes internal support structures that cannot be removed mechanically. In the finished part the support structures have been completely removed and the surface levelled. (Hirtisation® treatment, picture courtesy of RENA Technologies Austria)

Maintaining full design freedom does not mean avoiding support structures, but reliably eliminating them via finishing. The most complex parts require supports, and even if most of these can be avoided, their avoidance may be accompanied by an increase in printing costs. In industrial production runs, the price is crucial; any increase can make the run unprofitable. The solution to this problem lies in changing of the finishing method.

Internal chambers and channels can be easily reached by liquid media, even if they cannot be reached by mechanical means. When the power of active fluids is combined with the application of modern (dynamic) electrochemistry, the part can be surface treated wherever the fluid can reach the surface. The chemical-electrochemical approach dissolves the support structures as well as powder residues, and levels the surface. Fig. 1 demonstrates the treatment of internal channels including support structures by liquid media. By pumping the electrolyte through a channel system, this effect can be enhanced and/or accelerated. This does not require a high-pressure regime. but a slow, continuous flow. A prominent example of such post-processing based on dynamic electrochemical and chemical principles is Hirtisation®, which enables industrial post processing of complex component geometries – inside and out.

As with any post-processing, consideration should be given to this aspect early on within the file generation process. Post processing will not miraculously eliminate all problems, nor will it compensate for printing errors. It is only after post processing that a part achieves its final dimensions and not, as most users believe, after printing. Meeting the specifications of mass production requires guaranteeing certain final dimensions of the part when it reaches the (end) user. Machining or electrolytic dissolution reduces the part size a little.

Each finishing operation has its own characteristic method of material removal. This must be calculated when creating the print files. In addition, carefully coordinated process chains will increase overall production efficiency and thus lead to lower production costs. Closing the interface between printing and finishing can reduce the amount of post-processing required by up to 30%.
Measures that can be taken to increase overall production efficiency include ensuring proper flow through internal channels and aligning support structures in the media flow direction.

A good example of the above assertions is a study of a manifold used in automotive applications. This part has a complex internal geometry with widening channels and a larger central compartment. It requires internal support structures for the printing process, and its design does not allow for classical, mechanical post-processing. For demonstration purposes, a part was cut in half before post-processing was applied. The internal channel structures and the support structures are clearly visible. Another part was cut in half after applying the chemical-electrochemical treatment of Hirtisation®. All supports were able to be removed and the (internal) surface of the part was levelled and shiny. Fig. 2 shows the results compared to the untreated parts. The treated part is ready for use.

In conclusion there is no need to apply special tricks of the trade to achieve support-free printing of metals. There are industrially feasible finishing techniques that can completely remove internal support structures and powder residues and level the internal (channel) surfaces. Even curved, widening, or narrowing channel structures can be treated. However, as with any post-processing in an industrial environment, matching printing method to the final surface treatment is crucial for efficient and reliable part production. This allows the industrial production of complex parts to be automated and meets the requirements of mass automotive production, for example.

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About RENA Technologies Austria

RENA Technologies is the global technological leader for wet processing equipment. We provide the most valuable, innovative wet-chemical solutions for our clients to reach the next level of state-of-the-art. We manufacture the highest quality flexible and high-throughput equipment in the Semiconductor, MedTech, Glass, Additive Manufacturing and Renewable Energy sectors. RENA is the German acronym for Reinraum-Equipment, Nasschemie, and Automatisierung (cleanroom equipment, wet chemical, and automation) – the company's four core competencies.
Together with customers from every sector of the semiconductor, medtech, renewable energies, glass or additive manufacturing sectors, RENA Technologies develops pioneering solutions for the production of premium-quality machinery for wet chemical surface treatment applications.

RENA is an expert partner for your production solution.

Soft Shaping of Hard Metals

by Michael Kitzmantel, Kunal Mandal, Christian Pfeifer, Christopher Wallis, Erich Neubauer
RHP Technology

The desire for 3D printed shapes is growing strongly in the cemented carbide (WC-Co and other hard metals) space, as in other sectors. These composites of ceramic phase tungsten carbide (WC) and a metallic binder (Co in our case) have excellent physical properties and are used in many applications requiring wear resistance and tribological properties.

There are three main applications for 3D printed cemented carbides according to their specific properties in the field of composites ranging from nano-grained microstructures to coarse carbides using nickel or cobalt or other metal binders.

Application Areas

Cutting tools and inserts

Cutting applications require high hardness, extreme toughness, and specific, customized microstructures. The increasing performance and durability of products in this area also requires full density, i.e. no or only low porosity in the bulk material. From an additive manufacturing perspective, this could be called the highest class of perfection.

Protection and wear elements

Wear resistance is a key property for such applications, but hardness while important does not have to be at the highest values. The same is true for toughness. On the other hand, high geometric complexity and

Fig. 1. WC-Co parts printed from granules by the indirect 3D technology material extrusion additive manufacturing.

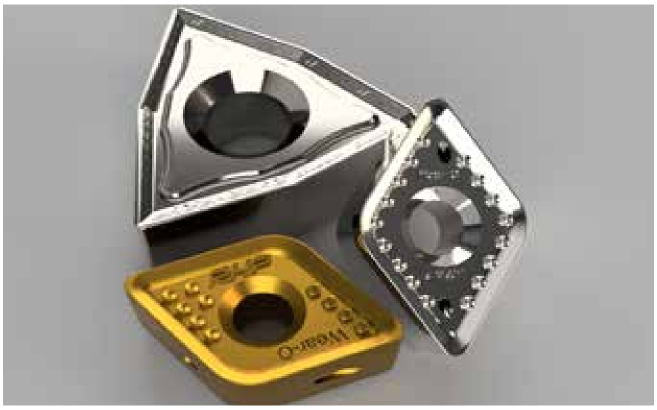

Fig. 2. Geometries of cutting tools that can be realized with 3D shaping technologies.

Fig. 3. 3D printed and sintered miniature cathedrals.

high precision are essential. Examples of this class of applications are nozzles for filament printers, waterjet cutting tubes, or sliding elements in moving joints.

Jewellery and watch making

The main tribological requirements in this area are scratch resistance, followed by medium hardness, and defect size (porosity) below optical visibility. The parts must also withstand daily use and look beautiful. When we talk about 3D printing, this industry demands individualized features, spectacular surface topologies and novel haptic experiences.

It is in these application fields that additive manufacturing can play its most valuable cards – and particularly for very hard materials that are difficult to machine, AM technology offers unbeatable advantages.

Injection moulding vs. additive manufacturing

For small metal parts, ceramic parts and also cemented carbides, injection moulding technology holds a great advantage in producing the same part in high volumes. With its high level of automation, large production batches compensate for the high price of essential moulding tools and show high commercial competitiveness. This is not easily achieved by additive manufacturing.

However, both these technology classes produce so called ‘green’ parts that need to be sintered (heated to remove polymers and grow them into solid metal, ceramic, or metal-ceramic parts). When demand grows for new developments, small series, or deviating geometries, injection moulding requires significant investment, and this is where additive manufacturing comes in. AM offers rapid prototyping realization by maintaining this indirect manufacturing process (including the sintering step) rendering design changes easily feasible without increasing the cost of each iteration. A great benefit for industry!
In the following case study we show two technologies for processing cemented carbides by 3D printing: MEAM (material extrusion additive manufacturing, using granules or filaments) for parts with simpler geometries or very low-cost applications, and metal lithography for parts requiring high precision and surface quality.

Fig. 4. Geometries of cutting tools that can be realized by 3D shaping of MEAM.

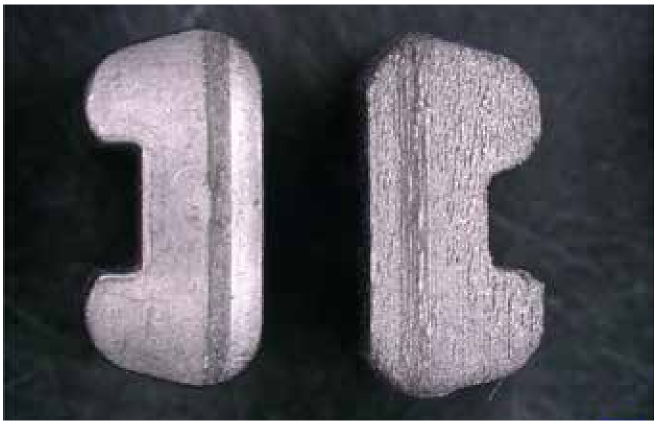

Fig. 5. Injection-moulded sintered hard metal part (left); MEAM 3D-printed and sintered hard metal part (right).

MEAM technology already sustains comparison with injection moulded parts, even if the surface quality is not comparable to that of typical injection moulding. Fig. 5 shows a microscopic image of a part manufactured by these two technologies.

Material extrusion AM (MEAM)

This is an amazing technology that uses filaments, granules or pellets as its feedstock. In our case study, the printer is filled with WC-Co particles at a loading of 50% by volume. Several printers on the market that typically process polymer filaments or granules can be used for this process of 3D shaping of compounds. However, when it comes to geometrical complexity, this technology has the potential to create hollow structures and internal supports without a connection to the outside. This is possible because no residual powder removal or material extraction is required – the interior can be manufactured hollow and remains so throughout the process chain. The metallographic microstructure of MEAM-produced cemented carbides shows typical sintered structures for this class of materials, and hardness and toughness are also confirmed

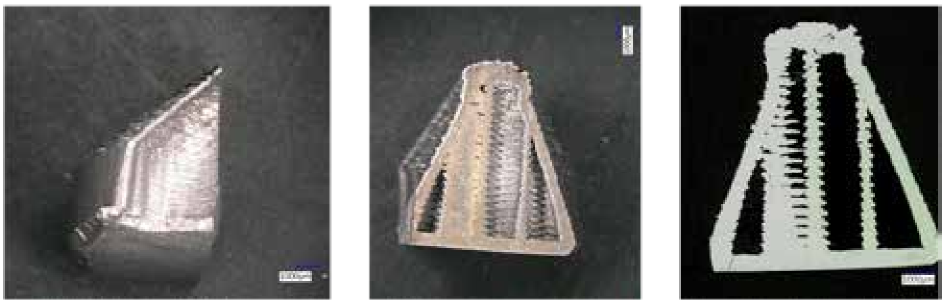

Fig. 6. Cross sections of cut sintered MEAM parts with hollow structures internally.

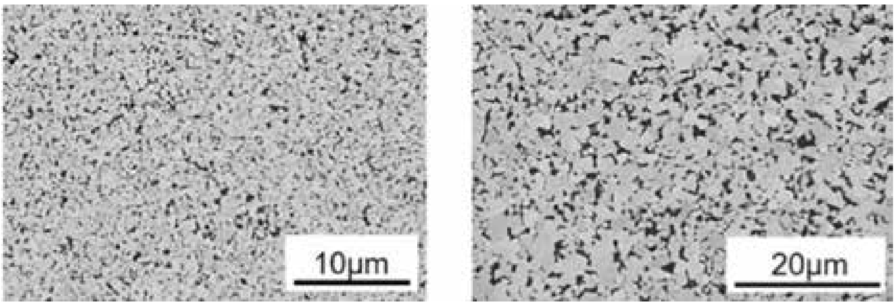

Fig. 7. MEAM microstructure of fine-grained (left) and coarse-grained (right) cemented carbides.

to be comparable. The main disadvantage is the occasional appearance of pores or cavities, which can result from incomplete path planning in the 3D printing process.

Metal lithography

Compared to many other additive manufacturing technologies, stereolithography offers several major advantages for manufactured products: in addition to high geometric accuracy, excellent surface quality and aesthetics are also achievable. The technology under investigation is a VAT polymerization 3D printing technique in which the photosensitive binder that is part of the starting material solidifies when exposed to UV light. It supports a wide range of materials, and many systems allow for quick and easy replacement of these source materials. The AM system in use at RHP-Technology features a highly viscous feedstock that eliminates the need for any support structures during printing – an unbeatable advantage for the production of complex and filigreed structures.

According to the above studies of our 3D printing system, and considering the advantages, this article illustrates that we were able to develop a carbide feedstock for lithographic 3D printing and continue successful parameter development for the printing process. As a result, complex parts for industrial applications were produced. In particular, an M6 bolt and nut made of WC-Co composite material were designed, 3D printed, and sintered. To obtain this final product, the production process consisted of feedstock preparation, 3D printing, post-processing and cleaning, two distinct types of thermal debinding to remove the binder, and sintering. A microstructural analysis was then performed. The first major challenge was to precisely mix the WC-Co powder with a photosensitive binder to develop the right amount of viscous feedstock to meet WC-Co printing requirements. The second was to find the printing parameters considering the light absorption of the carbide and the refractive index value. Carbide is certainly one of the most challenging materials to print. Finally, it was difficult to identify the sintering parameters to obtain a product with high relative density in which the Co distribution was uniform and homogeneous.

In our laboratory for photosensitive products (shown in Fig. 9) feedstock development takes place in a UV light-free atmosphere. Tungsten carbide (WC) with 10-20wt% of cobalt (Co) powder was homogenously mixed with photosensitive binder. Since the binder is UV-

Fig. 8. HM part comparison of manufacturing routes.

Fig. 9. RHP-Technology's cleanroom laboratory.

About RHP Technology

Powder technology in Seibersdorf since 1996.

In October 2010, RHP-Technology was founded as a spin-off of the AIT (Austrian Institute of Technology). Since then, the company has transformed from a 4-person research group in the field of hot pressing to a world-renowned company for innovative powder technologies and intelligent material developments. Today, RHP is headquartered in Seibersdorf in Austria, with a second location at TFZ Wiener Neustadt, the national Austrian centre for innovative materials, space-related products, and advanced manufacturing. RHP is active in more than 100 customer and research projects, with its international team of 50 scientists and engineers strongly committed to innovation and going beyond the state of the art.

Fig. 10. Lithography-printed WC-Co M6 bolts and nuts.

Fig. 11. Sintered WC-Co M6 bolt and nut.

sensitive, it must be protected at all times – during storage, handling, and processing. The WC-Co has high light absorption properties, which means that it becomes difficult to cure the binder for sharp and filigree structures during print exposure time, which affects the overall print quality. To overcome this, the binder had to be modified and the WC powder size selected accordingly. The final WC-Co powder content was about 50% by volume. Fig. 10 shows the M6 bolts and nuts fabricated using the lithography printing set up in our light-sensitive laboratory.

To achieve a high-density part, the green bodies were treated with several thermal steps in a hydrogen atmosphere, where the binder content is eliminated from the previously 'green' parts. In addition, a high-temperature sintering step was performed in a pressurized argon atmosphere (50bar) to obtain the final hard metal products with reduced porosity. To obtain general information on product density, we performed metallography and cross-sectional analysis of the M6 nut shown in Figs. 10 and 11. A hardness test measurement was also conducted to evaluate the WC-Co properties such as strength and wear resistance.

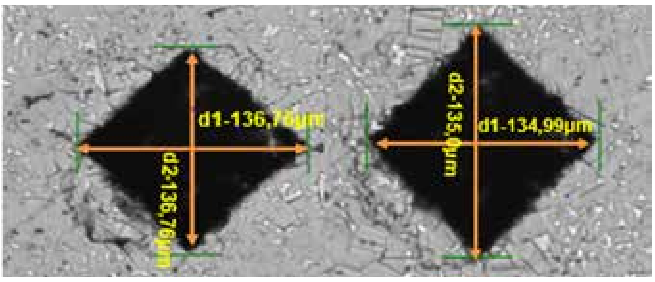

Fig. 14. Measuring points 4 and 5: 991HV10 and 1018HV10.

Fig. 13 shows the metallographic examination of the sintered samples after a process sequence of sectioning, mounting, grinding, polishing, and optical microscopy, specifically the WC and Co phases, with the black arrow indicating the Co phase (white area) and the red arrow indicating the WC phase (grey area). Resulting hardness values on the cross sections were measured between 896 (HV10) and 1018 (HV10).

Fig. 14 shows the fourth and fifth measuring points for Vickers hardness. Here we have determined 991 (HV10) and 1018 (HV10) for both measuring points. From all five measurement points we evaluated 972.40 ± 46.50 (HV10). In summary, we demonstrated the development of WC-Co structures using both metal extrusion additive manufacturing (MEAM) and metal lithography techniques. The latter is a unique approach in the field of indirect additive manufacturing for extremely fine detail and high geometric resolution.

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Fig. 12. The nut was cut in the area marked in red for the cross-section.

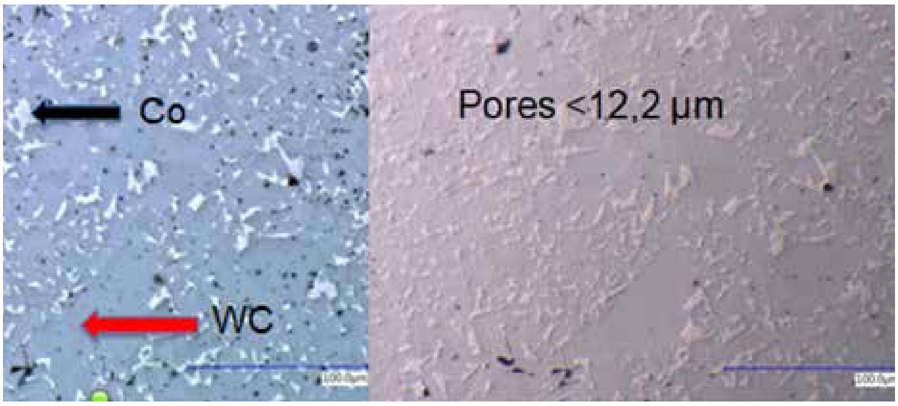

Fig. 13. Optical microscopy captured images in two different light settings for phase and pore analysis.

Think big: XXL 3D printed titanium structures for space

by Johannes Niedermayer
SBI

The industry's demand for unlimited geometry design is growing. Top wishes include optimizing the functionality and resource requirements and reducing the weight of final products. Additive manufacturing, also known as 3D printing, is one of the hottest game changers for these issues and has already conquered shop floors and R&D labs. There are a handful of technologies on the market focused on directed energy deposition (DED) to produce large-scale metal parts. One of these, Plasma Metal Deposition (PMD), stands out for its great economic potential and superior material properties.

Plasma Metal Deposition (PMD)

SBI develops and manufactures plasma power sources and automation systems for welding tasks at its site in Ziersdorf, Austria. As a result, it began producing AM systems a few years ago. PMD (plasma metal deposition), the technology it offers, is a directed energy deposition process that uses a plasma arc as the heat source and materials in the form of wire, powder, or a combination of both. The PMD technology was developed in collaboration with RHP-Technology from Seibersdorf, Austria to give potential users of the process maximum flexibility in terms of raw material selection and application. Fig. 1 shows the diagram of the PMD process.

The constricted plasma arc forms a melt pool to which wire feedstock or coaxial powder is added laterally. The combination of both materials makes the process more flexible. Firstly, wire is widely and generally available in many materials. Secondly, the use of powders provides access to an ever wider range of materials – even hard metals or carbides that cannot be processed in wire form can be used. Thirdly, the combination of both materials makes it possible to print a bulk geometry with wire and give specific properties (e.g. corrosion and abrasion resistance) to the surface by printing the final layer with

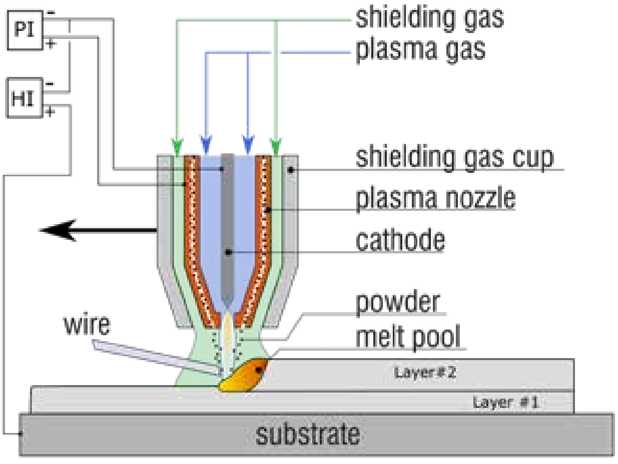

Fig. 1. Diagram of PMD technology.

Fig. 2. Printed bearing bracket made of Ti64 with partial machining.

powder. In general materials such as steels, aluminium, nickel-based alloys, and titanium can be processed with deposition rates up to 8kg/h. After printing, the part has an almost net-shaped geometry and in most cases postprocessing by milling, turning, etc. is required.

M3DP, an industrial DED system

At SBI, the PMD process is integrated into the M3DP and M3DP-SL turnkey machine series. The metal 3D printer and its smaller brother, the SL (Scientific Line), make up SBI's portfolio of turnkey systems for additive manufacturing. Both systems work with G-code programming, which can be done either manually or with the CAPRICORN toolpath planning software. While manual G-Code programming is sufficient for simple mock-up walls for research studies, more complex structures require CAM-assisted toolpath planning and this is where CAPRICORN comes into play. With highly flexible strategy settings, the 3D model can be modified and prepared for planning (known as slicing in material extrusion 3D printing).

A subsequent simulation of the toolpath within the virtual machine model of the M3DP (or -SL) allows the user to check the toolpath, but also features safety functions such as collision detection.

Fig. 3. M3DP-SL system configuration.

When using titanium, the working chamber of both systems can be filled with argon gas to achieve oxygen concentrations of 50ppm and less. Within this protective atmosphere, the liquid and hot titanium is protected from harmful oxygen, moisture, and nitrogen which would influence the material properties towards higher tensile strength, but also higher brittleness, which is an undesirable property for most applications.

When it comes to printable part size, the M3DP offers a maximum working area of 2.0×0.6×0.6m, while the M3DP-SL can process parts up to 0.4×0.4×0.4m, both at a maximum deposition rate of 4kg/h for titanium and 8kg/h for steels.

The Athena X-ray eye

The PMD process was initially trialled within the framework of the international R&D feasibility study ATHENA, initiated by ESA (European Space Agency). There, the process was used by RHP-Technology to print a total of six titanium demonstrators for an X-ray telescope. PMD demonstrated its potential to save materials ten times more effectively than conventional manufacturing i.e. milling. Whereas milling from a solid ingot would produce a total of 8.6t of titanium chips, PMD technology only produces 800kg.

Fig. 4. Machined demonstrator of a sensor bench made with PMD technology. Photo: RHP-Technology, © Ing. Robert Syrovatka

Together with RHP's R&D partners, Aerospace and Advanced Composites (AAC) and Forschungs- und Technologietransfer Gesellschaft (FOTEC) (both Austrian), the material properties of the demonstrators were intensively evaluated and analysed.

At its final size the sensor bench will be equipped with 750 mirror modules to form a high-performance X-Ray telescope for exploring the hottest and most energy intensive celestial bodies.

Analysis and qualification of the 3D printed components

The additively manufactured segments were fully analysed for material properties and defects. Selected segments were subjected to non-destructive tests such as CT (computed tomography) scans to find any deviations, bonding problems, blowholes or similar. Critical defects could not be identified in the structure.

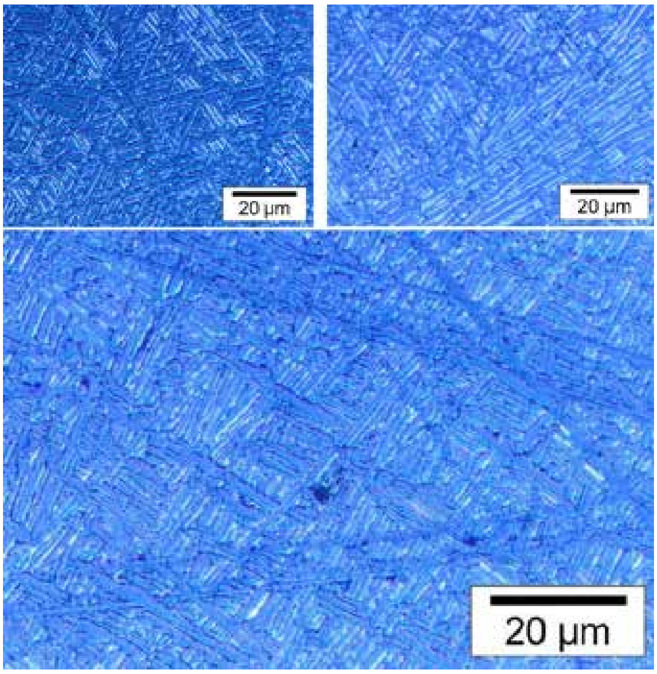

Fig. 5. Microstructure images based on sections from different areas of the additively manufactured component segments (in x, y, and z directions).

The program provided for the production of the segments via PMD powder and PMD wire and their comparison, so that comparative values are also available for both branches of this technology. Challenging locations such as nodes or welding gussets in the web guide were also examined in detail. At these points, the energy input or material deposition can differ significantly from wall or weave structures due to the process control. Also, with PMD components, one repeatedly sees the heat-affected zones of subsequent welding layers, which must be homogenized accordingly before a component can yield its maximum properties in use.

Standard	Material	Origin	Mechanical properties		
			UTS MPa	YS MPa	A%
ASTM B348	Grade 5	Billet	895-1000	828-910	10-18
ASTM B637	Grade 5-C	Casted	895	825	5
RHP	Ti-6Al-4V	PMD	895-930	825-865	10-13

Table: Evaluated mechanical properties of additively manufactured segments compared to characteristic values from ASTM standards.

Of course, thermal management requires special attention throughout the build process, especially with titanium materials where thermal conductivity is low. Therefore, appropriate time for heat dissipation must be planned for in the process control.

In addition to the plasma welding technology, the M3DP systems are equipped with a variety of sensors and cameras that enable continuous process control, monitoring, and regulation of the AM building process. Thus, material developments, prototypes, and series components can be produced on this system. Subsequent milling processes or heat treatments are undertaken via industry-standard equipment downstream so that the AM machine is not unnecessarily occupied with non-AM capacities.

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