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3D ADEPT MAG

3D PRINTING

CERAMIC 3D PRINTING - AUTOMOTIVE - QUALITY ASSURANCE CONTROL
SOFTWARE - MATERIALS - ADDITIVE MANUFACTURING SHAPERS - INTERVIEW

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Graphic Designer
Charles Ernest K.

Editorial team
Kety S., Yosra K., Martial Y.

Proofreaders
Jeanne Geraldine N.N.

Advertising
Laura Depret - Laura.d@3dadept.com

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All about Additive Manufacturing

Questions and feedback:
3D ADEPT SPRL (3DA)
VAT: BE0681.599.796
Belgium -Rue Borrens 51 - 1050 Brussels
Phone: +32 (0)4 86 74 58 87
Email: contact@3dadept.com
Online: www.3dadept.com

Table of Contents

Hello & Welcome

A different kind of race.

There are some dreadful conflicts happening across the world right now, but how about we focus on something that reunites for a second ? At the time we are writing this issue, there is a huge excitement about the highest class of international auto racing, a pillar of luxury with the likes of Rolex, Emirates Airline & Group as partners and Aston Martin, McLaren or Alfa Romeo Racing ORLEN as teams: Formula One.

I may be new to this world, but it's somewhat commendable to see rivalry and respect on the same track. Beyond the usual excitement of wheel to wheel racing, the controversies, it's probably the only sport in the world that puts athletes and engineers on the same pedestal. In this part of the industry, the technology and the team work that goes with it, are as important as the drivers behind the wheel of the car and that's something that definitely raises the interest of a technology-focused editorial team like ours.

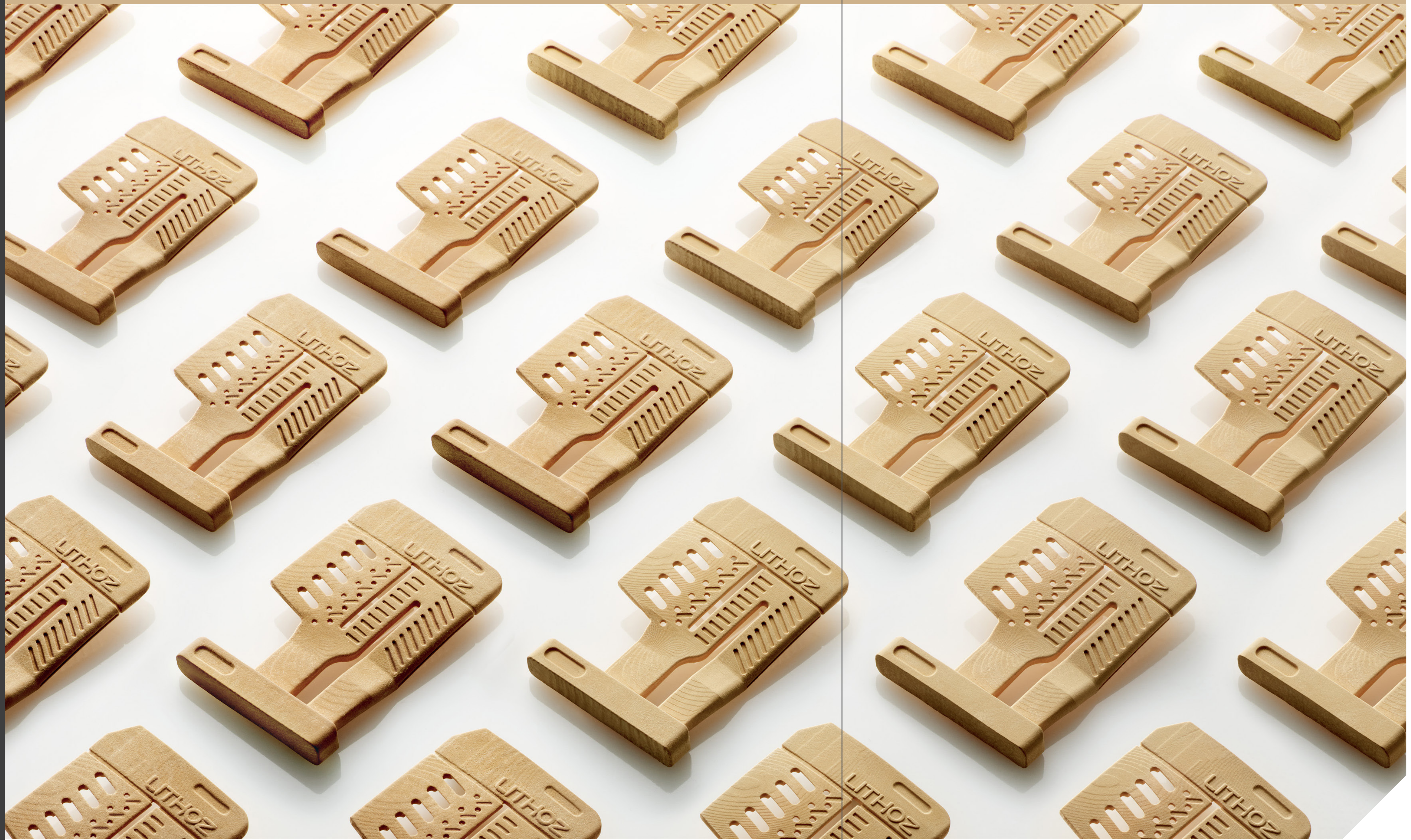
Indeed, the remarkable physical strain the vehicles are put under during a race requires the cars to be built using the most cutting edge materials and processing techniques. When we only look at additive manufacturing materials especially, from design to manufacturing, choosing the right materials ensures the highest possible standard for the finished product, but getting to this product is a road with many stops.

Ensuring the material flow with a material management system, choosing the right manufacturing process, and assessing the part's compliance with regulations through thorough quality assurance control are some of the stops on the road, and the ones we have decided to explore in this issue of 3D ADEPT Mag.

Interestingly, somewhere along this road, we realized that when they are not on a racetrack, Grand Prix manufacturers leverage their F1 expertise and race technologies to improve innovation in the production of our everyday road cars, and beyond. We have also explored their time off the racing track and how additive manufacturing technologies' providers continue to deliver dedicated and sometimes unexpected solutions – at every (single) step of the way.

Kety SINDZE
Managing Editor at 3D ADEPT Media

Editorial



THE CURRENT MANUFACTURING LANDSCAPE AND THE BUSINESS MODEL THAT DRIVES INDUSTRIAL APPLICATIONS.

2014. The excitement around ceramic 3D printing occurred when we first saw 3D printed vases and homewares but it faded progressively as the market understood it wasn't necessarily the road to success for this field of activity. In the meantime, an exhaustive list of OEMs and material producers who had understood the potential and pertinence of ceramics for industrial applications have been working in stealth mode for several years, waiting for their technology solutions to reach a certain level of maturity for industrial applications before launching them. 2022. The ceramic 3D printing market is still considered as a relatively new segment, compared with polymer and metal 3D printing. However, increasing entrants into the field, solutions to major manufacturing challenges and a 7-fold growth for the Ceramic 3D Printing Market by 2032 are some of the items that drive the conversation around this topic today.

Any segment in Additive Manufacturing always strives to address the challenges raised by the conventional manufacturing processes counterparts. The same is true for ceramic 3D printing. Hot isostatic pressing, extrusion, and injection molding have been extensively used in the ceramics industry, but their expensive costs and the long lead times make it difficult to use these technologies for prototyping and small/medium-volume part production. Just like polymer 3D printing, Ceramic 3D printing can address these issues but with a different set of manufacturing processes.

The exclusive feature below ambitions to understand and identify:

- The technological landscape in which ceramic 3D printing fits;

- What didn't work before, and what works today in terms of material & manufacturing solutions?

- The established business model in the ceramic 3D printing market and applications where there is a real potential.

1. The technological landscape of ceramic 3D printing

To provide a bit of technical background to those who are not familiar with the process, let's note that a ceramic is an inorganic non-metallic solid that can be shaped and then hardened by heating to high temperatures.

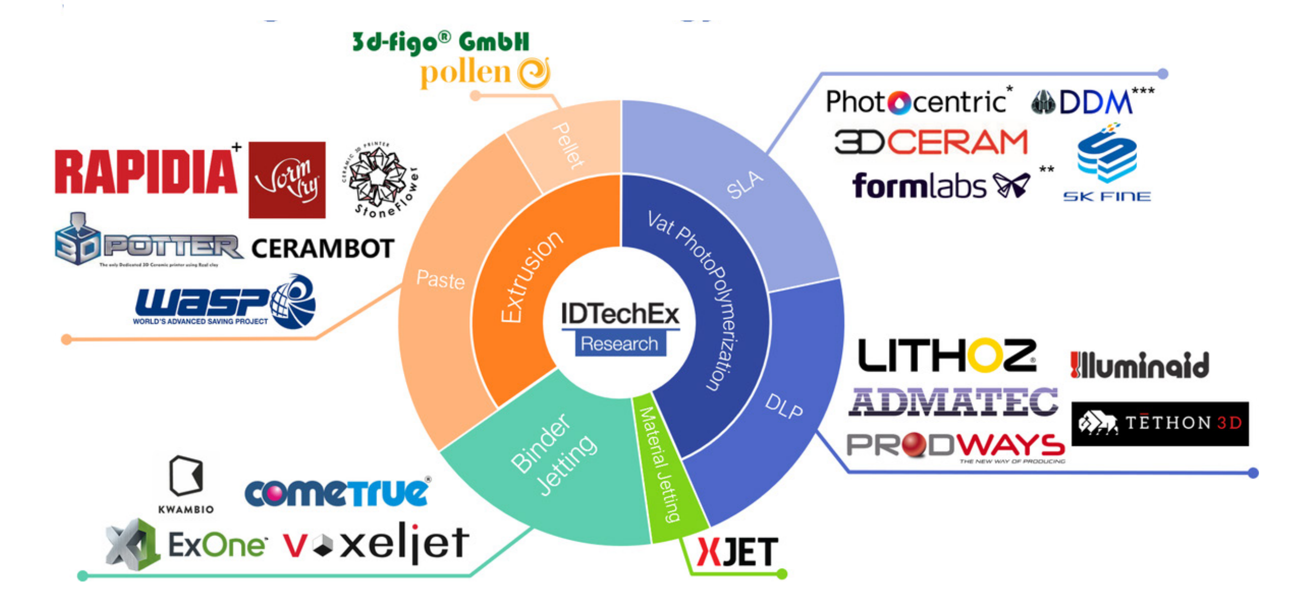
We may all be familiar with traditional ceramics that are clay-based but today, the definition of ceramics covers materials like high-performance, advanced and technical ceramics, in a nutshell, materials that can be developed from a wide range of inorganic non-metal materials. To make it easy to understand the different categories of ceramics, experts have identified two main types of ceramics: **classic ceramics** that derive from natural raw materials (clay) and **technical ceramics**.

This means that **carbon** and **silicon** can be considered ceramics, and that's interesting to note because many of the 3D printable ceramics have names that sound more like metals as they are not derived from clay. Those high-performance or technical ceramics are "materials used for engineering purposes instead of tableware". They may have the properties of high strength, high hardness, high durability and high toughness.

From the very beginning, **whether it was meant for art or industrial purpose, the use of ceramic 3D printing has been defined by materials**. And these materials have somehow defined the different technologies that can enable ceramic 3D printing applications for industry or art products.

Indeed, the current AM technologies that enable the production of (nearly) fully dense engineering ceramics are Slurry-based Selective Laser Sintering (S-SLS); Slurry-based 3D Printing (S-3DP); Binder Jetting (BJ), Fused Deposition Modeling (FDM); Direct Inkjet Printing (DIP); Stereolithography (SLA), Photopolymerization (DLP) and Robocasting (direct ink writing DIW).

Research reveals that, while the extrusion based printing process (FDM) processes primarily classic ceramics, other types of AM processes are (increasingly being) qualified to work with technical ceramics. Those industrial ceramics are available under various formulas which range for instance, from aluminum oxide (Al_2O_3), Zirconia, Silicon Nitride, Silicon Carbide, to zirconium oxide (ZrO_2) commonly called "ceramic steel".



Credit: IDTechEx

Overview of ceramics AM processes

Extrusion or FDM-based processes might be pretty easy to understand as the paste or filament that is pushed through the nozzle enables to build up the part layer-by-layer. Italian OEM **WASP** develops a **series of large 3D printers called delta**, that are worth mentioning in this area. **Pollen AM** also recently entered the ceramic market with a range of technical ceramics available **under the form of pellets**.

According to researchers of KU Leuven AM Group, Selective laser sintering (SLS) of ceramic components can be categorized as direct or indirect. In **direct SLS**, a laser beam is used as the heating source to locally heat and sinter the deposited ceramic powder layers. **Indirect SLS** involves laser melting of a sacrificial organic binder phase in the polymer-ceramic composite powder to produce 'green' parts. This requires a subsequent debinding and furnace sintering step in order to produce the final ceramic parts. Both processes are still currently most explored at the research level. Unless we are mistaken, there is no machine (yet) based on this process on the current commercial market.

Zoran Ostic, from Lithoz

Ceramic stereolithography (CSL) on the other hand, is often categorized as **Photopolymerization** ((SLA,DLP, LCD, CLIP). The process is based on the selective photo-polymerization of a photosensitive slurry (also called the 'photopolymer' that serves as 'binder' after polymerization) containing homogeneously dispersed ceramic particles to make 'green' parts, which need to be debinded and sintered. One company that stands out from the crowd in this segment is **Lithoz.**

"Our range of 3D printers are based on LCM technology, building individually-cured layers of ceramic slurry in a bottom-up manner to create high-performance complex parts without the need of a mold or other tools. Using this technique, it is possible to build far more intricate and fine features with outstanding levels of precision and accuracy unachievable using other production techniques. Our ceramic materials also offer significant advantages over other materials, such as high heat and chemical resistance and biresorbable qualities for medical applications", **Zoran Ostic**, business & application expert at Lithoz states.

In a Binder jetting process, a binding agent is selectively applied to a bed of ceramic powder one layer at a time. The challenge with this process lies in the powder bed density of the machine that should be maximized while the volume of liquid binder required should be minimized to achieve strong green parts. **ExOne**, a Desktop Metal company today, is one of the company that has developed a binder jetting process that is really scalable in the industry. Voxeljet is another one. Indeed, Binder Jetting can produce hundreds or even thousands of green parts in a single build. However, **one of the disadvantages** often highlighted by industrials is the low green part strength and low surface finish quality.

NanoParticle Jetting comes next. This process is developed and commercialized by **XJET**. It fabricates parts by jetting thousands of droplets of ceramic nanoparticles from inkjet nozzles in ultra-thin layers. With this inkjet and UV curing based approach, yielding green parts are similar to those obtained via stereolithography.

Interestingly, apart from XJET's solution that doesn't need debinding (and that has water dissolve support), almost all of these processes require debinding and sintering before obtaining the final part. However, the success or failure of these processes often depends on the material used.

The materials standpoint

"Ceramics are hard – and not just mechanically speaking! Compared with metals and polymers, ceramic materials are incredibly difficult to shape through subtractive forming methods like machining, thanks to their inherent mechanical hardness and brittleness. This is why 3D printing of ceramics is very enticing to the industry at large", **Bram Neirinck** and **Kevin Eckes**, Research Engineers at Aerosint observed.

The truth is, each printing process might come with its share of pros and cons but in general, **issues experienced are high firing contractions, low density and strength, and potential incompatibility with glazes**.

Other failures often identified, can be dropping, sticking, splitting, and flaking. While some researchers might see an opportunity to build custom-made machines, **Tethon3D's** CEO **Trent Allen** sees an opportunity to create new materials.

Trent Allen, CEO of Tethon3D

"In traditional aqueous material science, you are more limited in the materials you can process. Also, there is immense opportunity in taking materials that are difficult to process in traditional manufacturing like SiC(Wet Layup) and being able to use a non-aqueous binder to make producing parts much easier. For us at Tethon, nearly 1/3 of our business is taking powders used in traditional manufacturing at Fortune 500 companies and turning them into 3D printing resins, or powders for binder jetting. We fully expect this business to grow as additive grows in parallel", Allen explains.

That being said, while the first solution that may come to anyone's mind when it comes to overcoming challenges, might be to rethink the production process, Tethon3D highlights a more powerful and traceable alternative: a software tool. The company that sees itself more like a software company than a traditional ceramic materials producer believes that "***anyone that has built software knows a product is never truly finished****. Technology improvements within polymer material science and finding ways to improve powder processing is accelerating. With over 1,300 customers who trust our materials it can be challenging for us to make sure our global customer base knows why a material was altered, upgraded, or killed-off. Another challenge when innovating so quickly is you need to figure out how to scale from lab batches to production batches."*

Today, taking examples on UV printing & Binder Jetting which are the main processes the company has developed expertise in, Allen explains that to truly move into production and create great parts, it's essential to have consistent materials and limit the amount of shrinkage.

"Binder Jetting & UV printing complement each other. For us we generally print more precise, smaller, denser objects using UV and larger, blockier objects with thicker walls using Binder Jetting", he adds.

In the end, the key for scaling into production does not only lie in the development of new materials, but also in delivering the right final properties, while simplifying the process and ensuring safety issues. And if you've found this key, this certainly means you have figured out how to scale from lab batches to production batches.

2. The established business model in the ceramic 3D printing market and applications where there is a real potential.

It always starts with R&D and eventually prototypes. In addition to these two usages, first applications in ceramic 3D printing reveal an interest for ceramic tooling and small-batch parts across industries such as investment casting for aerospace & defense, chemical engineering, and dentistry.

Surprisingly, applications that are delivered on the market do not come from 3D printing service bureaus. As a matter of fact, we saw some leading service bureaus such as i.materialise or Shapeways cease their ceramic 3D printing services a few years go. For Lithoz, delivering successful ceramic 3D printing applications requires a close collaboration between the machine manufacturer and its customers.

That's anyway the path the team is following, as they support their customers in the discovery of new applications, thus establishing ceramic 3D printing as a reliable manufacturing technology for industrial production.

"Many of our customers service the industry by providing their specific know-how of our Lithography-based Ceramic Manufacturing (LCM) technology to players of various industries, from medical and dental to aerospace and semiconductors", **Peter Schneider**, **Business and Application development expert at Lithoz states**. *"Ceramic 3D printing, while very well suited to modern manufacturing and development in every field, is however still currently seen as a 'new' technology, much more than metal or polymer AM, and therefore companies need incentive to switch over from conventional methods. Service bureaus have by far the highest requirements for a manufacturing technology, meaning that they only offer processes with the best ROI at the lowest technical risk – there is little room for trying new technologies. In the same way, these bureaus do not have the time or resources to waste on a technology they do not already know for certain will deliver"*, he continues.

Peter Schneider from Lithoz

Moving forward, **Schneider** believes it's only a matter of time for service providers to implement industrial ceramic 3D printing into their workflow. For the expert, one incentive that will drive this change is the combination of DfAM with the desirable material properties of ceramic materials - such as high chemical resistance, high strength and hardness – Such combination can open the door to applications that were previously unachievable and break into markets where metals and polymers have already reached their limits.

This incentive refocuses the debate on applications and the ones that are not yet fully explored by technical ceramics.

Currently, there is room for growth in R&D-related sales, as there is a large number of international research institutes working on progressing ceramic 3D printing in interesting applications like energy storage and carbon capture. Industry professionals currently need to tap into the healthcare industry. First, dentistry which constitutes a great potential for this technology – closely followed by ceramic medical implants. According to Lithoz' Zoran Ostic, the potential of medical applications lies in the bioresorbability of ceramic materials.

"Bioresorbable ceramic implants, made of materials such as tricalcium phosphate or hydroxyapatite, dissolve in the body as the organic bone heals and grows. As such, ceramic implants promote bone healing and the need for a second surgery to remove the implant is completely eliminated. At the moment, however, metal implants – which often have considerable long-term side effects for the human body - are still the most common solution, meaning that the main challenge here is encouraging surgeons to shift away from a trusted solution to try a more innovative material.

In general, many applications for high-performance ceramics are under-developed by the market due to the fact that end-users of conventional technical ceramics buy from more established service providers. These manufacturers utilise traditional forming technologies and therefore have certain design limitations which the customer is accustomed to. They will design their parts based on these existing and well-known limits, despite there being huge potential improvements in part efficiency, design evolution and functionality using additive manufacturing instead. There is little motivation for the established service providers to move towards AM as they already have a successful and selling product. But we have also clearly seen that with the publication of some profitable business cases, the ceramic industry has really been

Legend: High purity alumina 3D print based a UV resin developed by Tethon 3D and Showa Denko America. This high purity alumina material is loaded 25 percent higher than other leading industry competitors. The ceramic loading is over 75 percent by volume and 90 percent by weight. Due to the higher loading, shrinkage in the x, y & z is less than 10 percent after sintering. Credit: Tethon3D

roused from that sluggishness. Therefore, the most important focus of the ceramic AM market is to educate the industry and end-users in particular about the advantages of this technology, encouraging uptake and therefore spreading the message of this game-changing technique further", the expert adds.

What's the next big question?

Until four years ago, controversial debates built up conversations around ceramic 3D printing. Today, most industry players seem to agree with one fact: the market might still be described as "nascent", but it's ready for production applications. The only thing is that technology might be ready but industry players are not. And the only reason for this is **fear**.

According to Lithoz' experts, ceramic 3D printing has in fact already mastered its most relevant hurdle – successfully upscaling materials, printers and software to empower industrial mass production whilst securing the same premium quality as offered with low volumes. The biggest obstacle now facing ceramic 3D printing is simply encouraging manufacturers and end-users to try a new technology and material over already established production techniques. Other materials, such as metal, have been used for certain applications for years and there is currently little motivation for service providers to shift away from what they trust. In the same way, other more conventional forming technologies also already enjoy great success in their fields, despite ceramic AM offering huge potential improvements in design freedom and part functionality. Consequently, this lack of incentive for trying a new technology is the biggest hurdle for ceramic 3D printing at this point.

So, the next big question might simply to know how we encourage industries to take that leap…and to this, the only response we can give (right now) is: to feel the fear and take action anyway.

Key contributors :

Lithoz specializes in the development and production of materials and additive manufacturing systems for the 3D printing of bone replacement material and high-performance ceramics. The company develops and commercializes the CeraFab System family which is specifically designed for industrial production, manufacturing large volumes of parts with identical precision over the entire surface using Lithography-based Ceramic Manufacturing technology. From a technology standpoint, *"we have already achieved the combination of complex structures and absolute accuracy in parts produced in series. The next challenge for us was to make these parts even bigger and with increased wall thicknesses – a challenge we will have solved by the end of the year using brand new technology"* Ostic and Schneider comment. From a business perspective, the next hurdle for us is taking this success to the next level: *"we are aiming to develop geographically independent, yet digitally connected, production plants all over the world to enable simultaneous mass manufacturing via digital production"*, they said.

Tethon is a US-based materials producer that develops and commercializes materials for UV, and Binder Jetting technologies. The company manufactures ceramic powders and photo curable ceramic, metal and polymer resins for 3D printing. Tethonite®, Porcelite®, Castalite®, Vitrolite®, Flexalite® and Ferrolite® are registered trademarks of Tethon 3D. According to Allen, the majority of their customers leverage their materials for their thermal properties.

External contributions:

Bram Neirinck and Kevin Eckes, Research Engineers at Aerosint

KU Leuven, Additive manufacturing of ceramics

Meyers S, et al., Direct Laser Sintering of Reaction bonded silicon carbide with low residual silicon content. Journal of the European Ceramic Society 38 (2018) 3709–3717.

3D Printing Ceramics 2022-2032: Technology and Market Outlook

Christoph Hansen

“Gaining a competitive edge”

SAUBER GROUP ON FORMULA ONE AND THEIR NEXT RACE WITH ADDITIVE MANUFACTURING

2022 rings in a new era for Formula 1: cars are designed with new regulations in mind – which means further complexities for racing teams pursuing speed and reliability. While these regulations are engaging in various ways for racing engineering teams, it remains fascinating to watch the extreme applications in which newly created parts are being applied. 3D ADEPT Media sat down with ***Christoph Hansen****, COO of* ***Sauber Technologies****, to discuss the additive production of these critical applications, and how these applications help Sauber Group build a technological expertise worthy to be explored beyond motorsports.*

A lot can be said on Sauber Group, especially when we know that the company was founded in the 1970s and that from day one, the passion for racing has always been part of its DNA. What's important to note in the context of the current Formula One season is that, after 25 years of competition in Formula One, its long-term partnership with Alfa Romeo in 2018 led the team to enter the 2021 championship under the name Alfa Romeo Racing ORLEN.

As you may know, for racing teams to perform at their best, race and engineering must go hand in hand…And for an industry that was the first vertical to leverage AM, racing cannot be achieved today without advanced technological capabilities. A strategy that Sauber Group has well understood since the Swiss motorsport company has one of the largest AM production environments in its field of activity.

“We have the complete package when it comes to additive manufacturing capabilities:, 6 large SLS 3D printers, 7 SLA machines, 4 other metal 3D printers which are fully automated and therefore very productive. On top of this, we have an R&D department for materials development and validation. The production environment also integrates special units that help us make the right decisions when AM is leveraged. These units are completed by advanced heat treatment technologies such as Hot Isostatic Pressing (HIP) which are for instance, very useful for Titanium 3D printed components, etc. We operate this entire package under the umbrella of Sauber Group”, Hansen states from the outset.

However, if the company seems to have a powerful machinery today, it should be noted they didn't start investing in AM this way. As our guest told 3D ADEPT Media, Sauber Group started leveraging AM in the 1990s, but at this time, they were sourcing parts from an external supplier. *“In 2007, we installed our first machine. It was an SLA 3D printer. And since then, we constantly increase our production capacity with other AM technologies. It's only in 2016 that we decided to upgrade this production capacity with metal 3D printing which gave a huge boost to our business”*, he adds.

Having a complete portfolio of AM & related processes is one thing, being able to make the most out of it is even better – especially in an industry where rules are ever changing.

New regulations in F1 and AM

The F1 2022 season officially started on Sunday March 20th in Jeddah Bahrain (GULF AIR BAHRAIN GRAND PRIX in the Middle East) – a chapter that Alfa Romeo F1 Team ORLEN writes with new drivers who recently joined the team: **Valtteri Bottas and Zhou Guanyu**.

Valtteri Bottas and Zhou Guanyu
Courtesy of Sauber Group

At the time we are having this conversation, **Hansen** expressed the team's relief and satisfaction after months of pressure and preparation, which led them to a very good start into the competition. Indeed, Alfa Romeo F1 Team ORLEN opened its 2022 campaign with a strong performance that delivered a double points finish, with Valtteri Bottas finishing 6th ahead of team-mate, Zhou Guanyu, in P10.

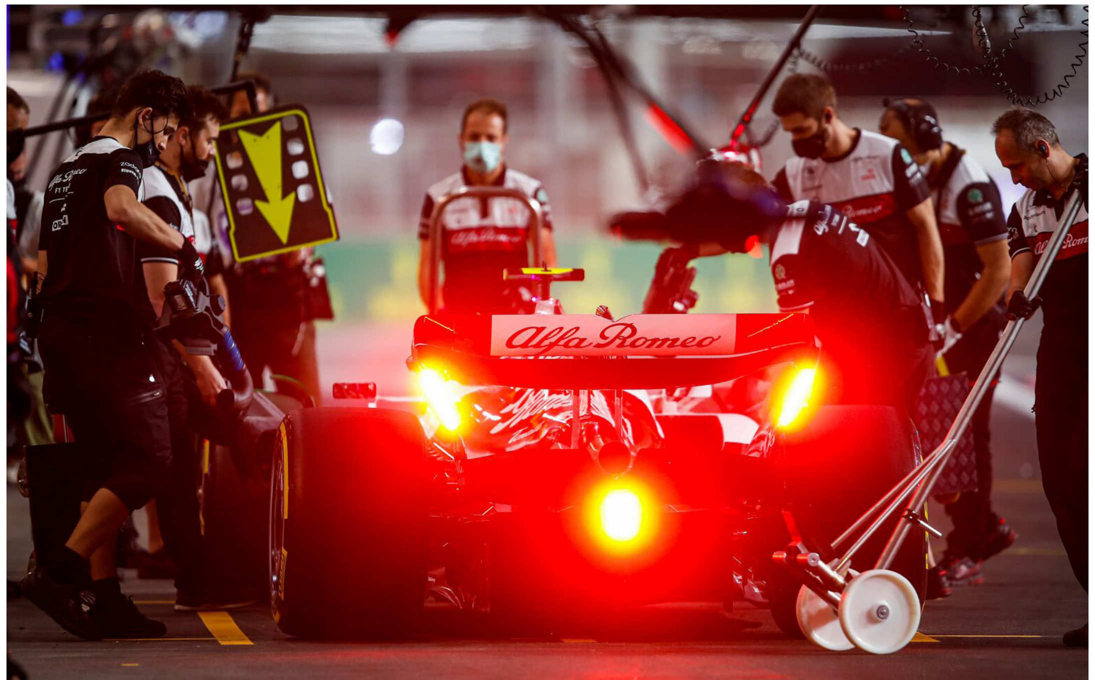
"The pressure is off now. The past weeks were tough as we needed to get the car ready. A lot of emergency parts and other development parts needed to be done for the race car itself", Sauber Technologies' COO comments.

Behind the scenes of this magical performance, it should be noted that the new regulations have raised a number of challenges for engineering teams. One of the challenges was that regulations have inflicted a new design to racing cars, which means their aerodynamic performance was completely different than usual.

From a manufacturing perspective, these changes haven't resulted in fewer aerodynamic applications for AM parts this year. However, the **Alfa Romeo F1 Team ORLEN race car C42** includes more 3D printed parts in critical applications.

The C42 is the first car the team built in this new regulations cycle. It is a radical departure from the past as it embraces the possibilities dictated by the new ground-effect floor, updated aerodynamic package and 18-inch (45cm), low profile tyres. Powered by a new Ferrari engine, this race car is designed to battle, as the new regulations will allow closer racing and competitive fighting from the front to the rear of the grid.

Speaking of Formula One in general, the main area where the use of AM is required is aero development – the wind tunnel models. The body of the wind tunnel models is essentially polymer parts and aluminium parts for the front and rear wings. This allows us to have very short iteration cycles, so we can develop the car very quickly. So the turnaround time from idea to design to production to testing is very short. In the early 1990s, when we started Formula 1, we used conventional manufactured components and it took weeks to get the expected results. With AM, the lead time has been reduced to a few days,» Hansen explains. *«AM is also very useful for making components for the race car. These components include very sophisticated structural components for the chassis but also simple non-structural electronics boxes and equipment.»*



Racing with Additive Manufacturing: the Alfa Romeo F1 Team ORLEN race car C42

Hansen said the Sauber team has additively manufactured between 300 and 400 parts for the C42. Around 150 parts out of this number have been 3D printed in metal.

The company representative did not elaborate on the exact areas where AM is used, but noted that these parts include safety-relevant structural parts where quality requires a high standard.

«For every part produced, it is of utmost importance that the quality meets the high requirements. If this is not the case, it could have serious consequences for the pilot. To ensure this, we use technologies such as CT scans, so defects can be excluded. We also use hot isostatic presses to achieve the material properties. (etc.) All this ensures our technological edge.», the expert outlines.

The chassis, which houses the driver and to which all components, assemblies and systems are attached, is usually made of a lightweight but very rigid honeycomb sandwich structure. Especially the inserts in the chassis - safety-critical class A parts – locally reinforce the composite sandwich panel. Depending on the function and load level, different materials can be used for the inserts, from carbon and aluminium to high-strength titanium for the Sauber C41 F1 racecar for instance, these **Class A safety critical parts** were produced with the Additive Industries **MetalFAB1 system** – using titanium (Ti6Al4V Gd 23) - to cope with the high fatigue and alternating loads experienced.

Furthermore, using 3D modeling and NonLinear Finite Element Analysis, Alfa Romeo also managed to iteratively reduce the weight of the 110 x 100 x 130mm inserts to just 580 grams, introducing undercut features into its design that weren't constrained by the need to leave access for tooling.

While Sauber Group did not reveal any info yet on the production process of the C42, our guess is that the critical parts underwent a similar manufacturing process for the new car.

Additive Industries is Sauber Group's metal Additive Manufacturing technology supplier since 2017. The long-standing partnership has enabled the Dutch OEM to play a pivotal role in the development and use of metal AM in the F1 car's design, seeing its use significantly increase over the years. Today, Sauber Group has already produced over 50'000 metal laser PBF printed parts all industries included.

When asked why the focus on metal laser PBF when we know that not only weight is a decisive factor in racing car components, but it can also be obtained via other AM processes like composites AM, Hansen states:

"Composites 3D printing is still a compromise compared to the traditional composites materials. Even though we can achieve lightweight parts with this manufacturing process, having parts which are made up of Titanium or Scalmalloy® does not mean that the part is heavy. On the contrary, by using these materials, we can really achieve the lightest parts. These parts are usually replacing their counterparts we used to manufacture using conventional manufacturing processes. By comparing their weight with the one of their counterparts, we realize that we achieve lighter results with AM."

Hansen's answer steers the conversation towards AM materials. For SLS technology, Sauber uses its own HiPAC, a carbon-filled polyamide 12, while standard materials are used for sterolithography.

On the metals side, in addition to titanium, there are aluminum, stainless steel, and Scalmalloy®. The latter one is a recently-approved alloy by the FIA (Fédération Internationale de l'Automobile). Developed by APWORKS in collaboration with its parent company Airbus, Scalmalloy® comes with a very high tensile strength (UTS 520 MPa) and yield strength (480 MPa). Its low density provides the metal with specific properties which are above those of other aluminium alloys.

In the manufacturing value chain, it is no secret that materials are often the key item that hinders the scalability of AM applications hence the increasing development and qualification of new materials in the industry. In this case, although Titanium and Scalmalloy® are the main materials used for producing metal laser PBF printed parts of the C42, it's interesting to note that Hansen is not in a hurry to explore new AM materials:

"I am happy with what we have right now. With the variety of materials, the complexity when it comes to achieving the required properties and quality, exploring other materials will only increase that complexity and will make it even more complex to maintain and ensure the mechanical properties. It's also for these reasons that we work with a defined and limited portfolio of AM technologies as we need to make sure we maintain the quality we have right now. Sometimes, less is more."

The next race?

Sauber Group has no intention to stop enhancing advanced manufacturing in MotorSports as its latest partnership with Camozzi Group illustrates. However, away from the track and thanks to its F1 expertise, the company has been silently building a legitimate place in the automotive 3D printing industry and beyond. It's been a while that it has been providing other demanding industries with 3D printed parts and in 2022 the company takes a clear position with the creation of Sauber Technologies, a new company that aims to bring Sauber's drive for cutting-edge innovation and Formula One mindset to business all over the world.

Sauber Technologies sees the incorporation of Sauber Engineering and Sauber Aerodynamics in a bid to strengthen services and the offer of know-how for customers across a wide range of industries. Sauber Technologies, part of the Sauber Group and based in Hinwil, Switzerland, will be fully focused on third-party business, providing a holistic service for complex engineering problems, from the idea stage to the finished products.

As Hansen said, the new company embodies the knowledge and expertise of 50 years of motorsport, matched with the latest technologies and a machine park second to none. Our staff can take care of every stage of any project, from the idea to the preliminary design, on to manufacturing and finishing of a product – in a wide range of industries.

"We have seen some of the practical applications of our expertise in recent months and we are excited about the new opportunities that await us in the future. We bring a cross-discipline approach to the table, allowing our customers to access processes and technologies in novel ways and bringing success stories from other fields into theirs. It's a unique approach in this region and we're ready to help our customers grow with our innovative mindset", he concludes.

AM NEWS

On a daily basis, our editors provide readers with AM news, reports, and analyses of the industry. To navigate through this wealth of information, we have defined a list of sections and sub-sections that could help you find what matters to you.

Do you have any current information related to 3D printing or a press release that needs to be published ?

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www.3dadept.com
+32 (0)4 86 74 58 87
Rue Borrens 51,1050 Brussels - BELGIUM

Six bionic-design pistons produced by MAHLE using 3D printing operate under the bonnet of the Porsche 911 GT2 RS. Credit: Mahle

QUALITY ASSURANCE CONTROL

Metrology and Inspection for Additive Manufacturing

Additive Manufacturing is certainly the ideal manufacturing tool to fabricate components that one could not manufacture with conventional manufacturing processes but there is one thing we tend to forget: this technology does not benefit from the century of research into the production of components that is the hallmark of precision subtractive techniques. This means that, at some point, along the manufacturing value chain, there are certain things that subtractive techniques' experts do better, and that still require a lot of improvements on the additive manufacturing side. These things are for instance ***metrology*** *and* ***inspection****.*

The first thing every engineer learns at school is that metrology is the science of measurement while inspection consists in measuring, examining, testing, or gauging one or more characteristics of a product or service and comparing the results with specified requirements to determine whether conformity is achieved for each characteristic. These two concepts have contributed to the success of several products produced via conventional manufacturing processes. While we do not doubt they can accomplish wonders with additive manufacturing technologies, the guidelines and acceptable methods that can be used in AM are still questionable.

Why is that? How important are metrology and inspection to additive manufacturing? What are the different routes a component can go through when operators are looking to perform metrology and conduct an inspection method?

The truth is, metrology and inspection are very large concepts whose advancements often create confusion in the mind of AM users.

"There are a lot of grey areas when it comes to metrology and inspection. Sometimes, these grey areas are reflected on the way each industry understands or defines each concept. Confusion can also arise when you see terms like inspection metrology, a term that does not enable to accurately differentiate the role of each concept. The fact is, both concepts are quite different, especially when we look at the quality management planning of manufacturing", **Dr. Edson Costa Santos**, Senior Application Development Manager Additive Manufacturing Process & Control at ZEISS, states from the outset.

Dr. Edson Costa Santos, Senior Application Development Manager Additive Manufacturing Process & Control at ZEISS

Interestingly, for non-experts in the field, the concept of inspection can easily be understood as it is a term that we often use on a daily basis and in different environments. *"For instance, the terms 'home inspection', 'police inspection' give you an idea of what inspection is but when we talk about metrology, a lot of people won't be able to say what this term means", Santos adds. When we look at industries, Santos said it is easy to understand the differences between metrology and inspection in the semiconductor industry while in precision engineering for instance, there is a lot of measurement definitions in inspection methods that are close to metrology ones. The easiest way to avoid confusion between both concepts is therefore to see inspection as "the first step to distinguish between an accepted or rejected component. It's simply the process of checking something, and see if it meets certain standards. Metrology on the other hand, deals with the definition of units, realization of units, standards, traceability and calibration and also the uncertainties of measurements."*

This exclusive feature therefore ambitions to capture the essence of both concepts for AM as well as draws a landscape that would enable beginners in AM to understand them. While some of the notions will not be new to advanced users, this feature aims to remind them the importance of these concepts as well as all the challenges experts in the field currently address in order to support the advancement of AM.

"If you cannot measure it, you cannot improve it", Lord Kelvin

A simple statement that highlights the pivotal role of metrology in manufacturing. This statement can also be controversial because editors at 3D ADEPT Media spend time explaining how you can improve your manufacturing process, so why would you need to invest extra miles into measuring what you manufacture ? Please, bear with us as we looked for some reasons:

- To ensure that a part is fit-for-purpose;

- To make assembly work: if you do not understand the dimensions of the components and their tolerances, it's hard – even impossible – to fit one part to another. The reason is even more important when there are several parts manufactured at different companies that need to be assembled.

- To avoid unneeded scrap material: As the ZEISS expert says, *"metrology is pivotal for quality control which allows us to attempt things such as net-shape manufacturing"* – getting it right first time as operators dream to achieve with AM.

- To enable control of a manufacturing process: imagine that you need to amend the speed of a cutting tool according to surface texture. You will have to measure the texture during the machining process.

- To give or increase customers' confidence in a product: indeed, without tolerances and quality control, there will be no confidence in the assembly processes down the line. To me, this reason alone should be enough to make you understand the ins-and-outs of metrology for AM – especially when we know that for many industries, AM remains a nascent yet very expensive technology and God knows how much a new technology may look suspicious to people.

That being said, the aforementioned reasons imply that a number of measurement techniques can be used to address the different needs to meet in the manufacturing value chain. As a matter of fact, there are several areas where metrology can be explored in additive manufacturing. They include but are not limited to on-machine and in-process measurements, metrology of surface texture, defect measurement and control, materials property measurement, process-function correlation studies, AM machine testing and validation, dimensional and geometrical product specifications and verification, Metrological traceability and uncertainty, etc.

To make it easy to understand where they should be applied, Costa Santos explains there are several ways to classify metrology tools, as identified below:

- **Contact and non-contact measurement**: *"contact-type devices must touch the part in order to perform measurement while non-contact devices can measure several points without putting pressure on the part. A non-contact measuring instrument uses for example light while contact-type measuring devices use a stylus. Non-contact measuring tools can also include optical laser or laser scanners."* Hybrid machines can use both type of measurement tools. On another note, as many automotive examples are given throughout this edition, let's note that contact systems, such as mechanical probe-based coordinate measuring machines (CMMs), are often used in the automotive industry. However, they are often considered as relatively slow and they only measure a limited number of points on an object's surface.

- One can also classify them by equipment. Such equipment includes for example micrometers, optical scanners, industrial tomography systems, microscopes, etc.

*- and **measurement volumes** which include 2D, 3D or 4D measurement techniques.*

The hidden complexities/uncertainties of inspection methods

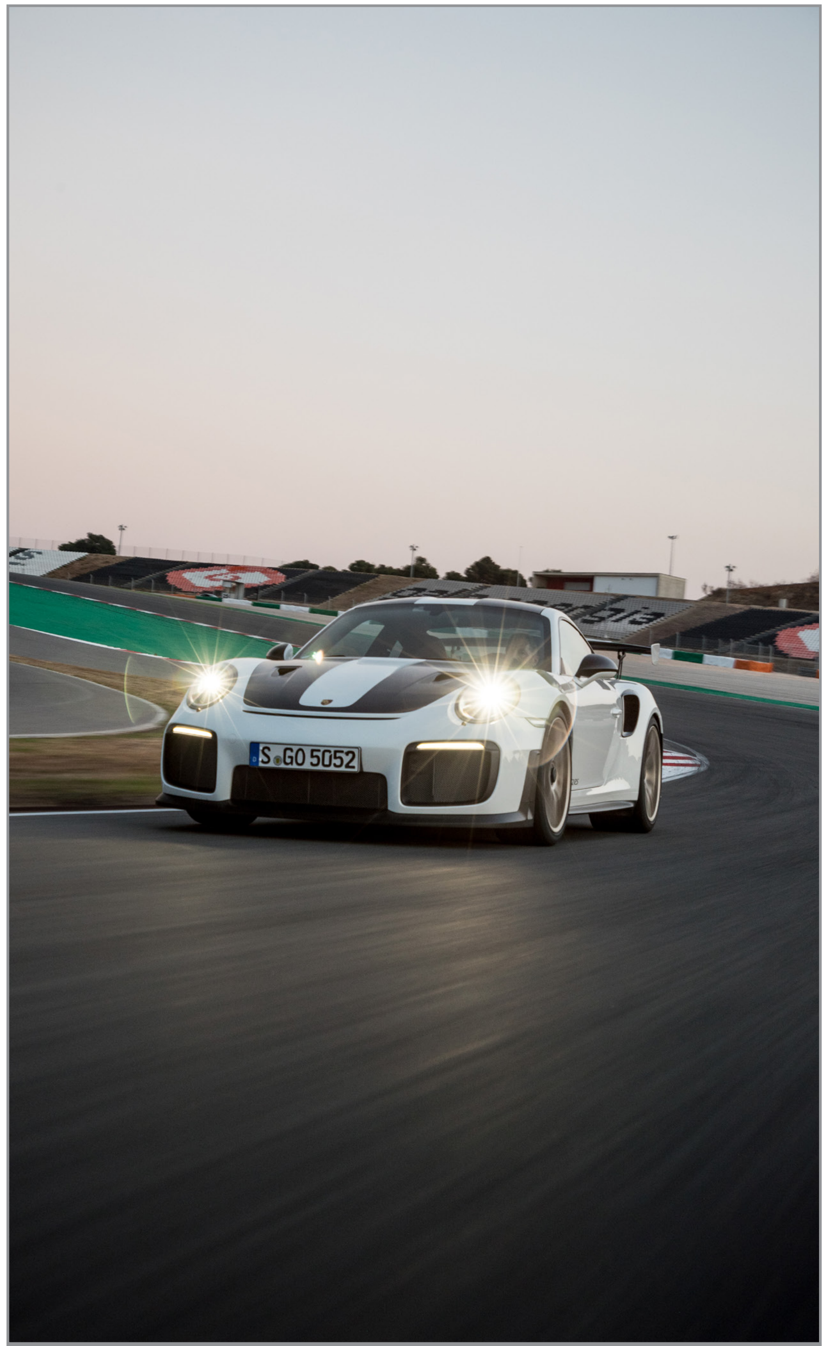
No matter what advanced manufacturing technologies industrials use, or no matter how well we focus our efforts on the manufacturing size, inspection methods make us rethink our priority which must remain **safety and quality**.

Furthermore, quality and assurance may often be mentioned as part of the post-processing stage but it is important to keep in mind that they can be used at various levels of the manufacturing value chain. *"As far as AM is concerned, we can inspect a powder, and assess if the powder meets all required characteristics before it is used for production. During production, the AM machine and process can be inspected and after production, we can inspect the 3D printed part"*, **Costa Santos** outlines.

Speaking of tools, the same mechanical and nondestructive inspections utilized in most conventional manufacturing processes can also be applied in AM. Your choice for inspection methods will therefore be determined by the type of parts you will produce. The same applies for software solutions.

"Depending on the metrology and inspection tools, you will use, you may have different software solutions for both processes just as you may have the same software solution for both processes", the expert notes. *Whether we talk about metrology or inspection, most tools can be utilized in both AM and conventional manufacturing processes. However, depending on the AM technology used, there might be a need to further adapt your tool for AM. Two examples are ZEISS in process monitoring systems to see what is happening layer by layer during the process and allows close feedback control; and the need in AM to inspect complex cooling channels non-destructively, both roughness and integrity (powder remaining). There are especially varying degrees to inspection. [At the end of the day, it comes down to choosing the option that delivers the best approach at ensuring part conformance and integrity]"*, the ZEISS representative notes.

AM processes often require **dimensional, external and internal testing**, and sometimes a **specific surface roughness**. Our guest mentions coordinate measurement machines (CMM), gages, and 3D scanners when it comes to dimensional inspections. A combination of these devices can be used in factories.



The MAHLE pistons produced by the 3D printer increase the engine performance of the Porsche 911 GT2 RS, while making it more efficient. Credit: Porsche

Other inspection methods include visual (VT), fluorescent liquid penetrant (PT), and electromagnetic (ET) for external surface testing; and on the other hand, ultrasonic (UT), radiography (RT), electromagnetic (ET), and computed tomography (CT) for internal testing.

The debate starts when experts cannot accurately attribute an inspection method to a specific AM process. Like in most cases in AM, the answer to the question "what inspection method best suits which AM process is" "sometimes" or "assuming that an additional process is performed upfront or later on". Indeed, sometimes, operators can conduct some surface preparation and smoothing or even additional thermal processing.

From a manufacturing standpoint, it should be noted that not only can the layer-by-layer principle introduce defects that traditional manufacturing processes would have not mentioned, but the 3D printed part is often produced in one unit (unlike conventional manufacturing processes that may manufacture one component in different parts before the assembly). This means that if the newly 3D printed part currently replaces 4 parts usually created via conventional processes, those parts would each have their own inspection requirements.

To these uncertainties, the Senior Innovation Manager replies: *"Quality is always aggregated to manufacturing processes. So, the level of metrology and inspection will depend on the aggregate value of your part. Is it a visual prototype? Is it a final part submitted to fatigue loads? It depends on* *how critical the part is."*

In practice, what does applying measurement and inspection techniques look like in additive manufacturing ?

Two years ago, we covered the **first experience of MAHLE with additive manufacturing**. For the production of **high-performance aluminum pistons for Porsche's 911 GT2 RS sports car**, the supplier to the automotive industry worked in collaboration with Porsche, Trumpf, and ZEISS, in a project headed by Porsche.

MAHLE's experience in thermal processes has enabled the team to design a piston which can only be produced using 3D Printing technologies. The bionic design exactly reproduces natural structures of the part.

A special aluminum alloy developed by MAHLE was added in loaded areas, which facilitated the adaptation of the piston structure to the load. The alloy was atomized into a fine powder before being printed on Trumpf's laser metal fusion technology.

However, it should be noted that the quality and performance of the materials used and of the components is ensured by means of solutions from ZEISS. From powder to finished component, ZEISS developed a comprehensive quality assurance process that could meet the highest quality standards of the automotive industry (in other terms, ensure the right component quality).

In this specific case, the team explains that the powder's particle size distribution, particle shape, chemical composition and even porosity inside the powder particles are examples of properties which can influence component quality. The fact that the powder's properties can change each time it is reused must be taken into account, and deviations need to be detected in a manner that is appropriate for the production process.

For example, if the powder's particle size distribution changes as a result of repeated use, the quality of the applied powder layer may be affected, and simultaneously the risk of pores forming as a result, or of other component defects arising, may increase dramatically.

Light microscopes, scanning electron microscopes and X-ray microscopes from **ZEISS** are used to analyze the quality of the powder before and after piston production, and the microstructure of the finished component is tested in order to identify defects or property characteristics. Through further processing of the analysis data and additional evaluation processes, it is possible to determine optimized settings for printing. Successful print results must also go through a variety of post-processing steps to ensure that the material and component properties are optimal.

During process development, for example, the component's structure can be inspected using specially equipped scanning electron microscopes or X-ray computed tomography before and after the heat treatment processes. To analyze the impact of individual production steps on the final quality of the component, an optical 3D scanner or industrial computed tomography are used in addition to a coordinate measuring machine. The ability to seamless combine these procedures is a decisive factor.

The pistons still on the print bed were scanned using a 3D scanner. Once they are removed from the bed, the individual production steps as well as the internal structures can be inspected using computed tomography while defect analysis is performed at the same time. At the end, a final measurement is performed with the coordinate measuring machine. ***The core capability of ZEISS' comprehensive quality assurance process is the linking of all data across the various analyses***.

Concluding thoughts

This exclusive feature left me with certain certainties and opens up other questions, that I hope we will discuss in other features.

The first certainty is that metrology and inspection can be different, but they work hand in hand in additive manufacturing. One thing that I am keeping in mind from my conversation with Santos is that if you do metrology, at some point, you would need to perform some inspection.

On the other hand, the technical standpoint highlights the importance of measurement and characterization of a part shape for quality control of additively manufactured parts. Most importantly, they are important when it comes to characterizing and optimizing AM processes or when new materials and part geometries are developed.

Lastly, while the application with the Porsche part reveals that ZEISS is one of the companies that has built up expertise in the development of comprehensive quality assurance processes, I am keeping some concerns regarding the current metrology and inspection methods used for AM exclusively, for example inline realtime in process monitoring systems as pointed out by Costa Santos. My expectations were probably very high when I started exploring this topic as I didn't expect to discover very few inspection methods, exclusively designed for AM (or let's say, I didn't expect so many inspection methods that can be used for both conventional manufacturing processes and AM processes). When I look across the AM value chain, I see a lot of advancements on the manufacturing processes themselves, I see dedicated post-processing steps developed especially for these manufacturing processes, and it made sense to me to expect the same for metrology and inspection processes.

Maybe I didn't dive enough (or at all) into the parameter development and optimization for specific AM processes? Maybe I should look at in-process and post-print processes that can further increase productivity and efficiency? Or identify other areas of AM where metrology can be applied?

In any case, there are definitely new inspection methodologies that need to be discussed, evaluated, and developed; and that's something we (at 3D ADEPT Media) will watch closely.

Notes for the readers

Several resources have been studied to write this exclusive feature. The main guest invited for this topic is **Edson Costa Santos**, Senior Application Development Manager Additive Manufacturing Process & Control at ZEISS. Acknowledged for its expertise in the fields of optics and optoelectronics, ZEISS develops, produces and distributes highly innovative solutions for industrial metrology and quality assurance, microscopy solutions. These solutions include coordinate measuring machines, optical and multisensor systems, microscopy systems for industrial quality assurance as well as metrology software for the automotive, aircraft, mechanical engineering, plastics and medical technology industries. Its 3D X-ray metrology solution as well as ZEISS Additive Manufacturing Solutions, an holistic integrated solution for quality inspection round off its portfolio.

ZEISS continuously collaborates with suppliers for manufacturing solutions to further improve additive manufacturing processes. Its latest expansion in the field is an investment in the start-up **MakerVerse together with Siemens Energy**.

EVONIK ON THE DEVELOPMENT OF NEW POLYMER MATERIALS AND AUTOMOTIVE 3D PRINTING APPLICATIONS

The time I have already spent in this industry makes me realize that the power of an additive manufacturing process lies in its ability to transform a material. This is in any case what is usually demonstrated in almost all the applications that are highlighted across industries. Today, with the growing popularity of 3D printing for manufacturing all sorts of items, material producers have a lot of work to do as they need to deal with new industry trends, qualification and certification. We caught with Evonik's Head of Additive Manufacturing Innovation Growth Field, Dr. Dominic Storkle, to discuss the development of materials in line with these stakes and how they interplay with automotive 3D printing applications.

The more AM is being challenged to foster industry 4.0, the more it raises debates in the way products are manufactured. In our still maturing industry, the technology increasingly holds promises for green benefits.

For example, at the production level, social, economic and environmental incentives drive the additive production with local feedstocks without the need for machining and numerous steps. At the device level, the newly fabricated object delivers new properties and optimized functionalities and at the material level, the focus is made on the use of AM with lower waste generation.

The thing is, these advantages seem to be the ideal way to go for those who manufacture end-user products, locally. At an industrial level, we are still far from an ideal world given the various elements that need to be taken into account. That's anyway what Evonik's Dr. Dominic Stoerkle draws our attention to:

"Sustainability is the core element for being successful in the future. In addition to other factors, such as efficient production or reusability of materials, sustainable feedstocks are also an important part for additive manufacturing on its way to evolve into an industrial-scale production technology. However, it is important to look at sustainable feedstocks from different angles. We select the feedstocks based on comprehensive life cycle analysis considering carbon dioxide reductions together with other important factors such as water consumption and land use. At Evonik, we follow the eCO-line approach: We are working with our value chains to substitute fossil feedstocks with renewable and circular feedstocks such as end-of-life tires and we use renewable energy for production. In this way, the overall eco-balance of our products can be significantly improved along externally certified proceedings without changing material property profiles."

If you are a regular reader of 3D ADEPT Media, you may already be familiar with the **world of "Infinite 3D Printing Applications"** that Evonik enables. The German specialty chemicals company continuously carves out a substantial place in the AM industry through its AM brand **INFINAM**® and investments made by its venture capital firm in the industry, Evonik Venture.

While some of the aforementioned incentives are being taken into account in the automotive industry for the manufacturing of metal 3D-printed parts, leveraging the resources brought by the world of plastics with AM could open up a new range of possibilities for automotive components. But that's a different subject, that I hope we will discuss in another article.

That being said, there are a wide range of 3D printed plastics used for automotive components. As a matter of fact, plastics remain the most widely used materials in automotive AM. Be it for preproduction benefits, customization or tooling, the advantages in terms of costs, time, and mechanical properties of the parts are worth exploring.

Currently, three common methods of 3D printing plastics have gained popularity across the industry: selective layer sintering (SLS)/ Laser Powder Bed Fusion (LPBF), fused deposition modelling (FDM) and resin 3D printing.

Why the focus on plastic materials for automotive applications?

It is no secret that mechanical components are often subjected to high stresses, high temperature and a corrosive environment which might ultimately lead to failure. The interest in high performance plastic materials naturally gains momentum as they can meet light weight requirements and deliver better properties in automotive applications.

According to a research on polymeric materials for automotive applications, a wide variety of plastics are used in vehicles. The basic functions of such wide use of high performance plastic materials in vehicles dictate the appearance of the automobiles, their functionality, economy and low fuel consumption. The application of polymeric materials allows more freedom in design and approximately 82 percent of an average vehicle's weight gets recycled. That is, in our opinion, an item AM should take advantage of.

Interestingly, when we look at the most-widely used AM processes mentioned above, Evonik has built up extensive expertise in the development of automotive AM materials for all these technologies.

INFINAM® TI – Ready-to-use high toughness photopolymer resins for Vat Polymerization | motor-block-motorcycle | Courtesy: Evonik

"*Our polymer materials have been used in additive manufacturing for more than 25 years; we offer both the broadest range of technologies to produce powders and a very wide range of chemistry platforms to design photopolymers*", the company's representative lays emphasis on.

The company explains that its proven polyamide 12 powders are well suited for reliable and reproducible production of a large number of plastic parts. "*With Polyamide 613, a stiff and ductile powder material with higher heat deflection temperature, we offer an alternative polymer optimized for all challenges in automotive applications – with similar good processability in Powder Bed Fusion printers as our polyamide 12. For applications that require high temperature and chemical resistance, our PEEK filament for the FDM technology is the material of choice. With respect to our photopolymer products, I want to mention the high-strength resin INFINAM® ST 6100 L which resembles glass filled nylon and INFINAM® RG 3101 L, an ABS like material. Both exhibit long-lasting thermomechanical performance and can be used above 70°C, the ST material above even 120°C, which is mandatory for automotive applications. In addition, we launched INFINAM® FL 6300 L together with the Austrian company Cubicure, a polyester-based elastomer photopolymer with unseen durability and fatigue behavior*", Storkle notes.

Speaking of applications that these materials can drive, the Head of Additive Manufacturing Innovation Growth Field explains that ***the variety of applications depends directly on the properties of the materials mentioned***. Non-visible components without safety requirements can be 3D printed from polyamide 12, as well as covers and grids for air-condition where a huge knowledge about postprocessing of the surface is already available. For more advanced applications, the polyamide 613 powders with higher heat deflection temperature are suitable. Our recently introduced elastomeric resin INFINAM® FL 6300 L is the right material for dampening applications and cable holders, whereas the high-strength resin INFINAM® ST 6100 L can be used for connectors and clips.

When we look at a bigger scale, **one of the immediate goals of automotive companies is to accelerate the electrification of electric vehicles**. It is currently estimated that 230 million electric vehicles will be sold worldwide by 2030. While the increasing promotion of electrification is partially driven by governments that tighten greenhouse gas emission regulations for carbon neutrality, it should be noted that the challenge is bigger for AM technologies' providers who need to provide dedicated solutions to enable

applications in the field.

The first step for AM companies is to understand that the pivotal component that will enable electric vehicles to stand out from the crowd is the next generation of batteries that should deliver better performance and ever shorter charging times. For material producers, the challenge lies in developing innovative materials to increase scale production at reduced times and costs, assembly speed and greater performance. Some of these materials are currently being developed by Evonik:

"*To increase the range of electric cars, higher battery efficiency is needed. The next generation cooling systems with new cooling agents are required. Both monolayer and multi-layer system solutions developed by Evonik for the pipes of the cooling system can fulfill the need for a longer battery duration and perform well with different cooling agents. Moreover, we are developing a material that will meet one of the highest requirements in e-mobility: the V0 flame retardancy of polymers without compromising the chemical and physical properties of the materials over a wide temperature range.*"

The goal here is to improve batteries with reduced weight and dimensions, that have efficient temperature control.

Other materials (all technologies included) that will play a key role in improving the efficiency and performance of a battery, include high-tech polymeric materials, polycarbonates, adhesives and thermoplastic materials.

Moving forward…

Amid the wide range of materials that can be leveraged in AM, the materials type that enables the greatest number of opportunities is polymers. The ability to transform these materials into various shapes that may fit the variety of additive manufacturing processes on the market is not only fascinating but it also requires years of expertise in polymer chemistry. Based on Stoerkle's latest comments, this is exactly what makes Evonik outstanding:

"*Thanks to our strength in innovation, years of expertise in polymer chemistry for AM and strong industry partner network, Evonik knows how to develop and manufacture materials and to scale processes for serial production. We use this expertise for the long-term development of new materials for 3D printing serial applications.*

If we consider the powders segment, new processes like the ones developed by Evolve or Nexa3D require new, tailor-made powders. For both, the STEP and the QLS technologies, we jointly develop ready-to-use materials from our existing polymer powder portfolio like polyamide 613 for higher temperature applications or our INFINAM® TPA elastomer for flexible parts to make them suitable for those very exciting processes.

Lastly, [throughout this year], you will see our photopolymers appearing on a lot of major printer platforms. Our material validation focus here is on printer systems which promise to bring down total-cost-of ownership and allow for real industrial part production.

We do encourage everyone to contact us to develop and implement further applications with additive manufacturing."

This exclusive feature has been written in collaboration with Evonik.

SOFTWARE

UNDERSTANDING "MATERIALS DATA MANAGEMENT SYSTEMS" IN AM

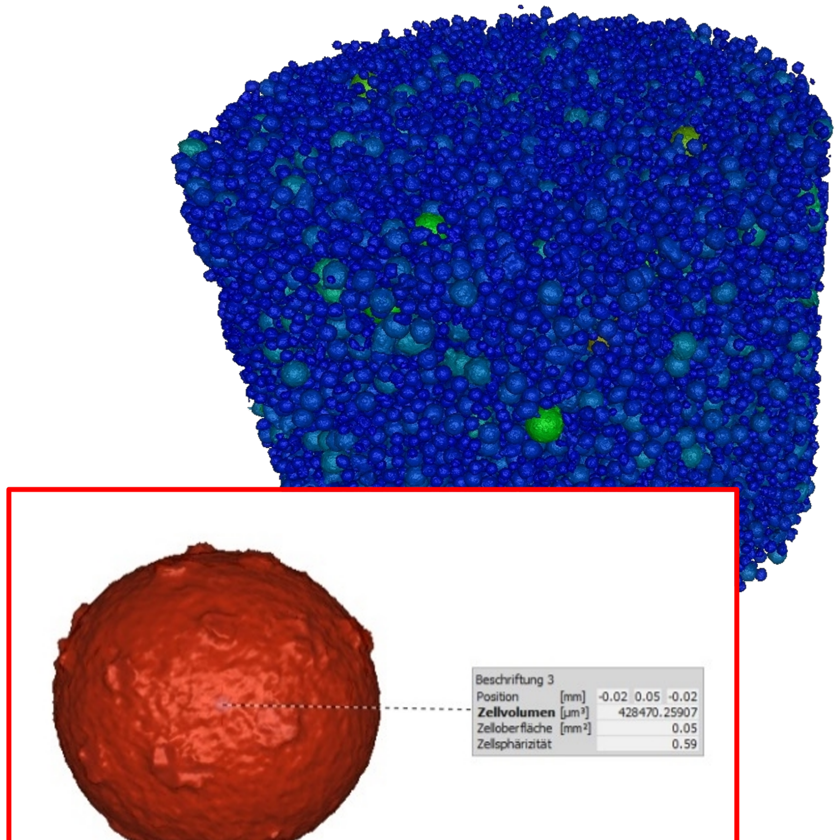
While they no longer question the potential of AM to be a great tool to meet today's industry requirements; industries do recognize that process repeatability and material availability issues remain one of the most important hurdles to overcome to achieve desired production results. Interestingly, one way to do that consists in understanding the ***"geometry-process-structure-property relationships"*** *for additively manufactured parts. In most cases, empirical approaches that seek to leverage data have proven to be effective in identifying material process-structure-property relationships.*

The relationships between process, structure, and property in materials require to go beyond the performance of a material as generally acknowledged and explore the structures and properties of components to be manufactured as well as the special variations that may intertwine during the fabrication of these components. The first step to understand these relationships is to acknowledge the importance of **materials data** which have become a critical resource for manufacturing organizations seeking to enhance products, processes and, ultimately, profitability. Most importantly, if the need for prudent handling of materials—right from their purchase till their ultimate conversion into finished product is crucial, it should be noted that ensuring that the results generated by a materials property analysis are not a wasted investment lies in an efficient use of a materials information management system.

The exclusive feature below ambitions to understand the **concept of materials information management systems (MIMS)** (aka Materials Data Management Software) in additive manufacturing, a concept that consists in but is not limited to material requirements planning, purchasing, inventory control, material supply management and quality control.

This feature will especially discuss:

- The relationship between material producers and software providers – when it comes to MIMS;
- The reasons why one can leverage a materials data management system;
- How a material information management system works and;
- The various challenges that still need to be addressed to have the ideal material information management system.



Scan powder analysis.
Credit: Hexagon

We have invited **Senvol's** President **Zach Simkin** and **Guillaume Boisot**, Head of ICME, Hexagon's Manufacturing Intelligence division to share key insights into this topic. Senvol provides data to help companies implement AM. The company's products and services enable industrials to access AM data, generate AM data and analyze data.

Hexagon is a leader in digital reality solutions, combining sensor, software and autonomous technologies. The company basically puts data to work to boost efficiency, productivity, quality and safety across industrial, manufacturing, infrastructure, public sector, and mobility applications.

In this specific field, Hexagon has the ability to combine materials data management with material modelling and artificial intelligence / machine learning and help industries to take the right decision in terms of material selection.

Senvol's President Zach Simkin AM Ventures.

The relationship between material producers and software providers

Materials data often refer to the properties and processing of materials (metals, alloys, plastics, composite materials, ceramics, etc.) that organizations use. These data may come from a wide range of resources (materials testing, quality assurance, or measurement of product performance).

Is the materials producer the one that should provide these data? For Senvol's President Zach Simkin, there are several tiers to consider:

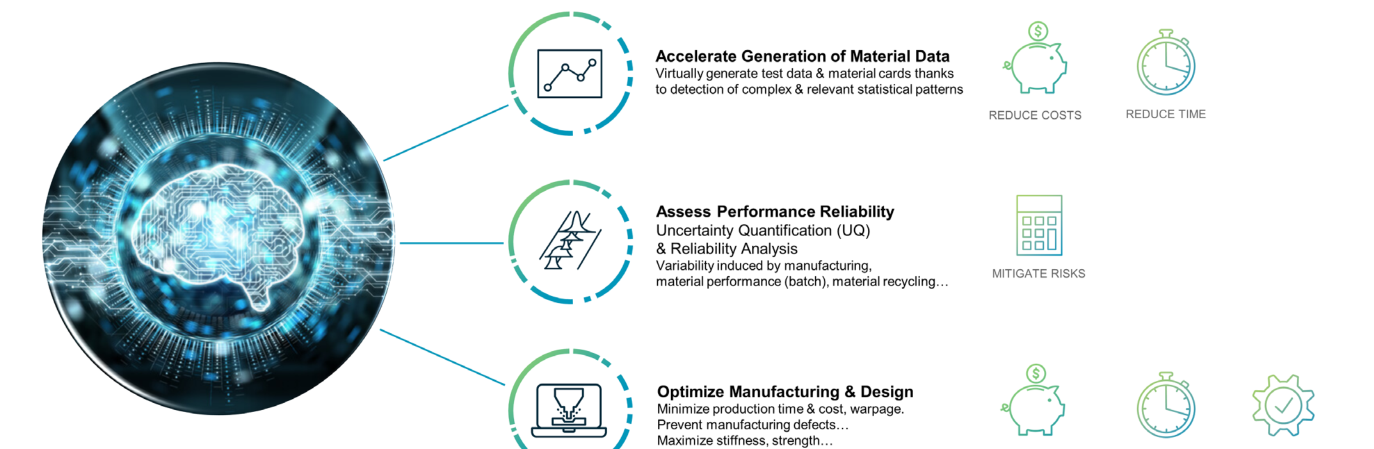
"First is to understand ***reference-level data****, which is typically (though not always) data that can be found on a spec sheet published by a material producer. At Senvol, we maintain the Senvol Database, which is a comprehensive database of industrial AM machines and materials. We work directly with material producers to catalog their materials data in an easy-to-use, searchable database. The Senvol Database is one of the most-used resources in the industry. It is available for free via our website and can also be accessed through several of our partners. Many of these partners include companies that offer AM materials data management software, such Ansys Granta, MSC Software, and Bassetti.*

Reference data is a good starting point, however it is often not sufficient. Once a material has been selected, users typically start to need ***material characterization data****, which is a more in-depth look at how a material will perform. At Senvol we offer this through our Senvol Indexes datasets. This is data that Senvol generates regarding a particular material when processed on a particular machine, and typically includes far more data than is provided on a reference data spec sheet.*

To understand how a material will perform, ***data analysis can be conducted on whatever empirical and/or simulated data*** *that a company has access to. For this we provide Senvol ML, which is data-driven machine learning software specifically for AM. The software is often used to rapidly optimize process parameters and develop materials. This software works hand-in-hand with materials data management solutions. Those solutions store the data, and our software is subsequently used to analyze the data."*

Senvol's point of view is relevant to the extent that the software company does not provide materials data management software itself but rather databases that might be stored in such software, and machine learning software that analyzes data that might be stored in such software. So, while the company alerts on reference-level data, material characterization data or data analysis, a software provider like Hexagon may receive from a traditional plastic producer a material card with parameters describing important physical characteristics that material engineers can interpret to select a good material for a part. However, this material card might not always be enough:

"Understanding how a part 3D printed from that material will perform requires much richer detailed data to predict how its behaviour, because materials are not uniform like a black metal but anisotropic – meaning factors such as the resin type and reinforcement such as glass or carbon fibres significantly affect the behaviour – after all, that's why we have composites!"



ML with AM materials data. Credit: Hexagon

"It's important to note that the material is affected by the manufacturing process used, so to predict the material performance you must also know how a 3D printer will use it – for example the direction in which fibres are aligned.

Hexagon pioneered multi-scale material modelling with its Digimat software. The accurate material model produced in Digimat can then be embedded in a Computer Aided Engineering (CAE) model so that engineers can accurately predict how a specific material grade will affect the overall performance of a product and optimise the design to make better use of the material and the additive process", **Guillaume Boisot** said.

In this case, the relationship between software developers and material producers (understand printer OEM, as most of the time they qualify materials for their machines) strongly depends on collaborations that aim to test and characterise the materials with great detail and "encode" detailed material information to create a **proprietary model**.

"This highly accurate proprietary model is validated and made available through our Materials Exchange capability. Manufacturers can request this material model directly from the material supplier through Materials Exchange, and they are granted access to this encrypted proprietary information that is ready to use in Digimat.

Many material suppliers also use these material models to support their applications engineering, enabling them to prove that a new material will be suitable for a customer without undertaking costly and lengthy physical materials test campaigns that can prohibit the adoption of new materials and additive methods that offer significant benefits for innovation and cost reduction", Hexagon's Boisot explains.

To illustrate this argument, the software expert says multi-scale material modelling and simulation enabled 3D printer OEM Stratasys to iterate designs and parameters using simulation instead of devoting time and materials to testing via printing. It also used simulation to anticipate printing problems by evaluating the impact of printing direction and location, and to explore process parameters on process quality and part fidelity. Good correlation was demonstrated when results of warpage simulation were compared to 3D scan measurements of a physically printed composite tool. As a result of material modelling, advanced simulation capabilities helped the company reduce warpage from .5 mm to less than 1 mm, or by about 20 percent.

So, what are the reasons that led to the use of a material data management system?

Using a materials data management system is not systematic to each organization. A 3D printing application that doesn't require very high quality or precision, might not require the use of a materials lifecycle management software either.

Furthermore, Simkin told 3D ADEPT Media that when

Guillaume Boisot, Head of ICME, Hexagon's Manufacturing Intelligence division

an organization is just starting out, using e.g. Excel spreadsheets only can be their first resort. Moving forward, this becomes complicated as an Excel sheet will not just be enough for the level of data being stored and accessed.

Beyond the growing number of materials an organization may have, the range of issues that affect productivity and data integrity within production environments may also drive the use of a materials data management software system.

These issues may lie in the consolidation of specialized data stored in disparate sources and varied formats, the large amount of time spent in finding property data to support analysis or simulation, the design iteration failures or the generation of data that are not used in the end. All of these challenges ultimately affect traceability, which is pivotal in demanding industries such as aerospace or medical.

According to Boisot, *"material data management has a very important role to play in managing material data, but more importantly capturing data about the process and results throughout the lifecycle.*

In large organizations, the inability to share material data and process insights prevents design teams from confidently applying modern CAE methods to parts that could be additively manufactured. Invaluable lessons can be extracted and shared from additive manufacturing trials, failed prototypes, and testing on materials and quality. Working in silos simply increases the chances of failed prototypes and often leads to wasted investments in materials, time, and money, which prolongs the time required to bring new products to market. We us the term material lifecycle management for this reason – it can't be just for materials professionals, or the benefits will be limited.

Material data management is also key to enabling the optimal use of materials in product development. Arming design engineers with the best available information involves integrating historically siloed disciplines. Material models are typically approved and validated by materials engineer then published with all relevant information (for example cost, certifications and internal classifications) so that engineers can predict the effects that materials choices and manufacturing processes will have on performance.

The industrialisation of additive manufacturing requires repeatable quality at scale. Material data management plays a crucial role in metal and advanced material printing, providing traceability of material from powder to the quality inspection of the final part. But the available design space for a product is dictated by several complexly intertwined factors, such as material and manufacturing process, budget, desired performance, and even environmental impact. Adopting and integrating the platforms that manage material data, design iterations, simulation results, tooling, and toolpaths throughout the product-development cycle is essential. Managing this data and applying statistical analyses and AI and machine learning will play an important role in improving and optimising these processes over time".

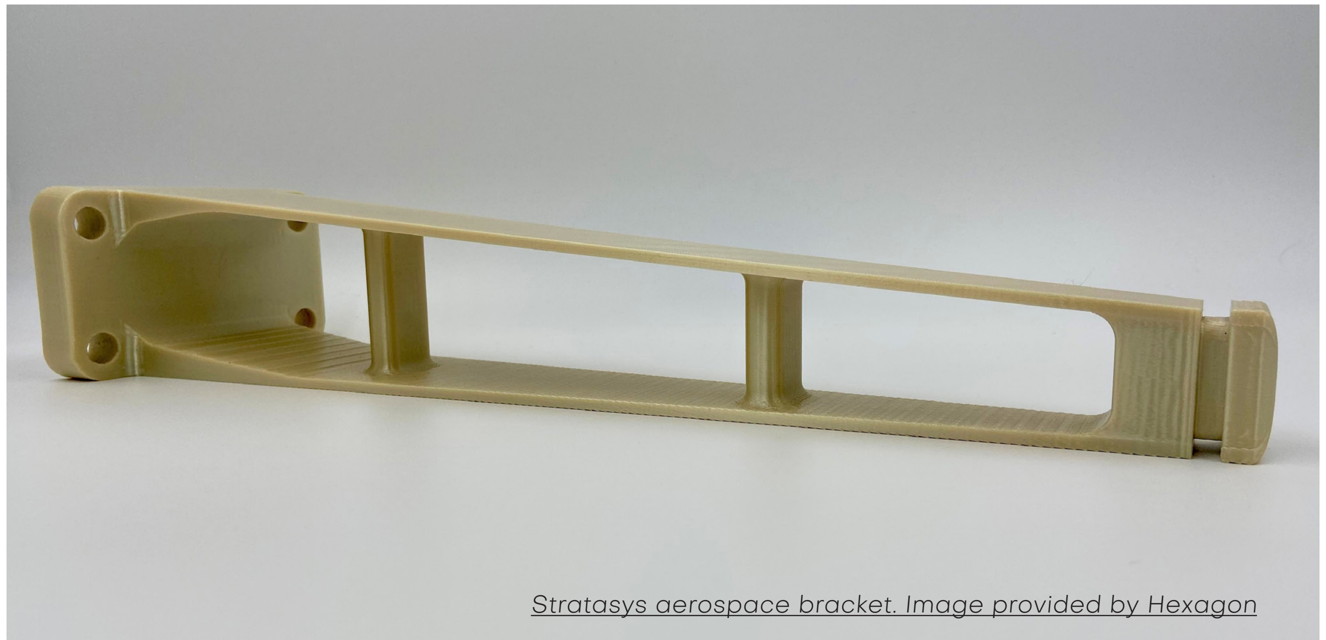
How does a material data management software solution work?

Given the fact that each software solution has its own modus operandi, one cannot legitimately explain how a material data management solution works. Whether we talk about identifying the right material for an application or developing a new material, it often comes down to the purpose the organization ambitions to achieve.

"Material data management systems enable organizations to seamlessly store all of their materials data in one central repository. This helps with everything from material screening, qualification to material development and characterization", Senvol's President notes.

For example, by using Hexagon's MaterialCenter, Formula 1 team McLaren Racing allows its engineering team to make optimal design decisions for their vehicles quickly and efficiently, with full knowledge of the performance and cost implications at every step. It captures data from material testing and the many tools and processes the team employs to ensure full traceability throughout each component's lifecycle.

Traceability is even more important when we know that basically, every 3D printed part sent into production requires some form of serialization in order to reconstruct provenance hence the necessity to save the right machine's parameters, and every data linked to its production. In this context, the material lifecycle management concept becomes of paramount importance for additive manufacturing teams.



Stratasys aerospace bracket. Image provided by Hexagon

Existing challenges & concluding thoughts

It's been a few years that we continuously witness how the focus on process management enables industrials to monitor the full data lifecycle of high-quality data. A few years ago, when the Material Data Management Consortium (MDMC) – a collaboration of leading aerospace, defense, and energy enterprises – started tackling this topic, they laid emphasis on the importance of allowing the right engineers/stakeholders to deploy effectively the results generated by a material property analysis. The stages ***"capture, analyze, deploy, and maintain"*** ambition to define each of the steps in this process.

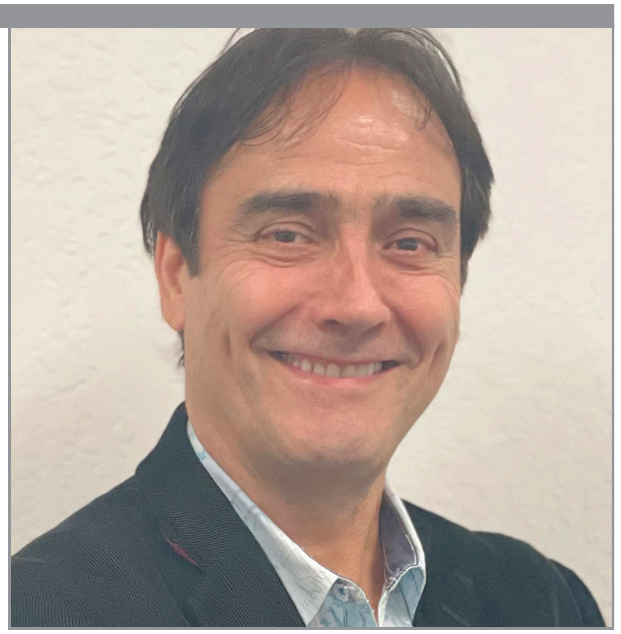
Today, despite the advancements of the various technological capabilities of the market, despite the fact that we should recognize that web-based tools that 100% focus on materials are already a big change forward to manage valuable – and expensive to produce – data, **openness** remains absolutely vital, because, as Hexagon said, *"no single vendor has everything you will need to build the technology stack that will deliver against your specific needs for quality, volume, material, etc." "You need a platform that can connect in a meaningful way with the best available technologies and help you to use materials to the very best of their potential for a sustainable, compliant, high quality and hopefully innovative final product.*

Open means integrating in a deep and meaningful way with material modelling tools, design engineering tools, test and metrology software and tools such as PLM that can help manage some of these processes", the expert adds.

Moreover, while the potential for material digitization and digital transformation to accelerate product development, especially once combined with additive methods – is no longer a debate, the road is still long to go when we look at the slow pace at which **standards** related to this topic are being addressed.

"One organization might use and organize the tool differently from another organization, and that can lead to interoperability issues. There are organizations, such as NIST, that are actively working on standards for data in AM, and I believe that these efforts will help mature the industry overall", Zach Simkin concludes.

Robert Bagheri - CEO of Sakuù Corporation



Interview of the Month : Sakuù Corporation

A conversation with Sakuù on SSBs & 3D printing: something more than just batteries

Founded in 2016, and headquartered in Santa Clara, California, **KeraCel** was initially known in the 3D printing industry as an organisation that uses the technology to manufacture multi-material ceramic batteries or 3D printed solid-state batteries. The company's journey has taken a fascinating twist when it decided to rebrand as **Sakuù Corporation**, a rebranding that reflects alignment with advanced additive manufacturing platform as it became clear for industries since then that the company is not just a user of 3D printing technologies, but a developer of its own technology. In a nutshell, this rebranding was meaningful for both the company's future and what it wanted to convey to industries.

From the outset, **Robert Bagheri**, CEO told 3D ADEPT Media: *"Our rebrand to Sakuù, meaning "bloom" in Japanese and "platform" in Arabic, signals a new stage for us as an AM company for all active devices, not just batteries. We've kept the name KeraCel™ for our solid-state battery, but we were keen to now position ourselves as an enabler for manufacturers to tackle more complex fully functional devices at high-volume with our agile AM platform."*

The company's new vision was followed by other exciting announcements which include for instance, the three patents related to its technology and the development of the first generation of solid-state batteries (SSBs).

In the middle of these advancements, we feel it was the right time to catch up with **Bagheri** to understand the world of SSBs and its constraints, the company's 3D printing technology applications and how far they can go to meet industries' requirements.

The focus on solid state-batteries

The manufacture of solid state-batteries (SSBs) has found a wide utilization in pacemakers, RFID and wearable devices. Often compared to lithium-ion batteries which integrate a heavy liquid or polymer gel electrolyte, SSBs require the use of a solid electrolyte that can come in the form of glass, ceramics, or other materials like solid polymer. Unlike lithium-ion batteries, SSBs are often said to provide better safety efficiency, high energy density, and a wide variety of operating temperatures.

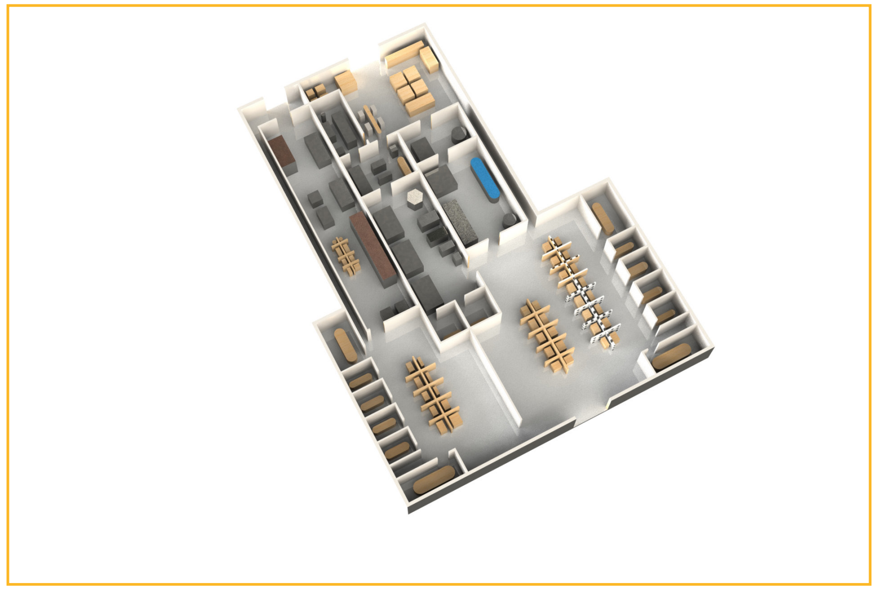
Indeed, with a solid-state electrolyte, batteries can withstand more discharge and charge cycles than lithium-ion batteries. This is made possible because they don't have to suffer electrode corrosion caused by chemicals in the liquid electrolyte or the build-up of solid layers in the electrolyte that deteriorates battery life. In addition, SSBs could be re-charged up to seven times more, having therefore, a potential lifespan of ten years as opposed to the couple of years a lithium-ion battery is expected to effectively last for.

As industries like the automotive are encouraging applications of sustainable energy sources – which means getting energy from somewhere other than an internal combustion engine –, recent developments saw interesting advancements in hybrids and electric vehicles. The good news here is that batteries can take the place of fossil fuels. However, there is still a long road to go, as SSBs are not yet being used in mass-market cars.

Despite their potential for e-mobility, **Bagheri** said, *"their complex manufacture, especially in the high-volume needed to keep up with demand, means they're not yet at the stage to be implemented in EVs. Today's low energy density SSBs are also characterised by thick, brittle ceramic layers and poor interface."*

"SSBs are praised so highly because of how they overcome safety risks that are prevalent in lithium-ion batteries. The fact that they do not use flammable materials enables the implementation of ultra-fast charging technology, without the danger of battery fires. The sooner we can get SSBs implemented into EVs, the sooner common consumer worries surrounding EVs, like range, can be eliminated", he adds.

The truth is, from a manufacturing standpoint, SSBs face constraints related to energy and power density, durability, material costs, sensitivity and stability.



According to experts in the field, they are also traditionally expensive to develop and rely on manufacturing processes thought to be difficult to scale, requiring expensive vacuum deposition equipment. All of which can be improved with additive manufacturing technologies.

Sakuù's CEO explains that their team has worked around these barriers by bringing AM into the game. With their platform, they can produce rapidly and in volume production, SSBs that compared to lithium-ion batteries offer some crucial advantages.

"It can deliver twice the energy capacity as we're packing 1,200 watts per litre in the same volume size. Or if we keep the same energy density, the cost will be halved because the size is halved. And on that important issue of cost, since our platform uses easy to obtain materials, such as ceramic, it's a lot less expensive for the manufacturer. Locally sourcing materials also reduces reliance on overseas imports which can, as we've seen during the pandemic, be unstable. Our AM platform will ensure every single layer is tested, so that nothing is wasted, thereby significantly reducing costs that would come with faulty applications", he lays emphasis on.

Although we wanted him to give away some of the firm's secrets regarding this platform – and we know he couldn't do so for the sake of IP –, the CEO explained that **their AM process is both multi-material and multi-process.** This means, it perfectly meets the requirements to produce a solid electrolyte using ceramics or other complex devices using metals. They have also developed their propriety support material called **PoraLyte™**.

"Using a combination of powder bed and jetted material deposition, the platform prints the device in a single layer without the need to assemble externally", our interviewee points out.

In a recent press communication about this 3D printer, we also learned that the platform is modular, which means that modules can be added, depending on the application. So, if a customer wants an option for photopolymerization, he could probably have it – in addition to other previously mentioned modules.

Sustainability and climate change concerns taken into account within the company and in targeted industries

We couldn't help but raise Bagheri's attention on the fact that they claim to develop a 100% recyclable technology.

To this, he reminded us that they are dealing with only half the level of materials to begin with, and everything they are creating is done in powder form, so it is all recyclable. *"This powder-to-powder process means that once a KeraCel™ battery is at end of its life, we can reclaim almost all of the materials. Unlike the case with lithium-ion options, there is no requirement to extract graphite and the absence of polymer means no incineration or burial in landfill. All in all, this ensures a recycling process of ceramics and metals that is both cheaper and easier compared to conventional methods"*, he outlines.

Moreover, as EVs are at the forefront of the debate to address climate change concerns, Bagheri believes that one should recognize that *"they're not a solve-all, but undeniably will reduce emissions significantly."*

While we may expect a greater uptake among consumers, in parallel with an increased discouragement by governments for fuelled cars, industries should be aware of a few changes that need to be made.

"First, the range of EVs needs to increase – range anxiety is very much a pain-point that remains an issue for many consumers. This is something that e-mobility manufacturers need to look at, especially when you consider that not everyone lives in towns or cities, and so do not have easy access to charging stations. Secondly, the cost of EVS is also an issue; they're too expensive for many consumers to own, let alone upkeep, which coupled with the range problem makes for an important combination that wields a lot of weight insofar as influencing the buying decision.

Thanks to the way in which Sakuù is addressing these crucial issues, I do think our own technology will support an acceleration to greater uptake by making EVs more accessible" Bagheri argues.

However, although the current focus is made on EVs, let's recall that Sakuù's 3D printing platform can enable applications beyond the energy/automotive industries. Other applications include active components like sensors and electric motors for aerospace and automotive; power banks and heatsinks for consumer electronics; PH, temperature and pressure sensors within IoT; and pathogen detectors and microfluidic devices for medical machines, to name a few.

"Microreactors in healthcare for example, are currently quite expensive to make, while Sakuù's platform has the potential to do it for just a few dollars", the spokesperson said.

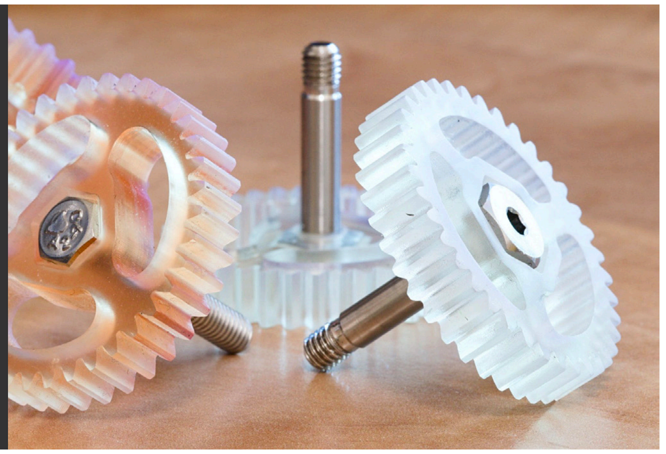
Moving forward…

Well, almost all has been said. Sakuù is making the right steps, slowly but surely. Its 3D printing technology is not yet ready to produce a full car battery, but that's something the company will certainly achieve in the future, and at a mass manufacturing level.

For now, the Sakuù Alpha Platform is set to be released later this year, with Beta platforms being targeted for installation and testing with the company's customers this year.

"We are already working on the higher performance of our platform's next generation, which is set for release late this year. The possibility with this technology is huge for a variety of industries beyond energy, so what we're most excited to see is how others use our unique technology and how it could transform manufacturing as we know it", Bagheri concludes.

Opinions



What more can we expect from Additive Manufacturing materials?

Wood, pellets, resins, powders, filaments… industries can almost 3D print any form of material and the fascinating processes that enable to transform these materials into finished products are also the ones that make the use of appropriate materials so complex. As AM advances, it creates new trends and new complexities that material producers continuously need to unravel. In this series, 3D ADEPT Media asked material producers various questions on different topics that create debate across AM materials users.

3D printing Resins

While the title is not official, it's simpler to describe the group of machines that work with resin materials as resin 3D printing. There are different types of resin 3D printing processes, each of them having their share of pros and cons. From a manufacturing standpoint, let's remind that resin 3D printing processes often rely on the principle of photopolymerization; they operate according to a code (or the 3D printer creates a code straight from an uploaded digital model); the material – stored in a VAT - can be UV or daylight resin.

SLA, DLP and LCD are often the most mentioned processes when talking about resin 3D printing, yet other processes are being developed and commercialized – processes such as inkjet 3D printing, Digital Light Synthesis TM or even the recently launched Viscous Lithography Manufacturing (VLM)TM technology. Interestingly, no matter what resin 3D printing process is, the stake is still the same at the materials level: what does it take to use them in series or industrial production?

First of all, let's recognize that extraordinary advances in "single-cure", "dual-cure" resin technology or UV chemistries (which have expanded from various shades of the same rigid, brittle materials to a wider spectrum of properties including rigid, tough resins, and elastomers) have allowed space for innovation. The problem that hinders series or industrial production the most is likely to be the constant comparison with injection molded thermoplastics and what they enable in terms of production. The truth is SLA, DLP or any other types of resin 3D printing technology can achieve different purposes when it comes to manufacturing – not to mention that they are being improved at their own pace and across different features, but this comparison is probably the first argument that prevent industrial users to appreciate their capabilities.

That being said, despite the advancements that are currently being made at the materials level, some resin 3D printing processes themselves are not ready to reach a new stage in manufacturing yet. 3D inkjet printing for instance (a low-temperature, low-pressure process that involves the deposition of liquid materials or solid suspensions), is natively multi-material but it has often been hindered by non-end-use applications.

Interestingly, the current developments in resin materials show a **focus on both low and high viscosity resins.**

Surprisingly, viscosity is usually mentioned as one of the most important rheological parameters that enables to determine optimal processing conditions for FDM and Pellet AM. Just like density, viscosity helps to give information about the material itself. "As a rule of thumb "the higher the viscosity of 3D resins the higher achievable mechanical properties and safety", Nika Borges, Sales & Marketing Manager for materials producer 3Dresyns says, speaking of resin 3D printing.

In practice, two schools of thought are currently emerging when it comes to viscosity: the small group of people that see the advantages of low viscosity resins for SLA 3D printing and the other one that sees a range of opportunities in high viscosity resins.

The role of resin viscosity has been largely explored for stereolithography, where a very low viscosity material is preferred. For Borges, the problem with low viscosity 3D resins, is that they "exhibit inferior mechanical properties, such as poor toughness and mechanical strength. They contain low viscosity monomers, [which can lead to] high toxicity (…)." The materials producer explains that "despite having lower viscosity", its monomer free and monomer-based 3D resins stand out from the crowd as they "exhibit unique high performance and safety."

High viscosity resins on the other hand, obviously deliver higher overall mechanical properties and safety.

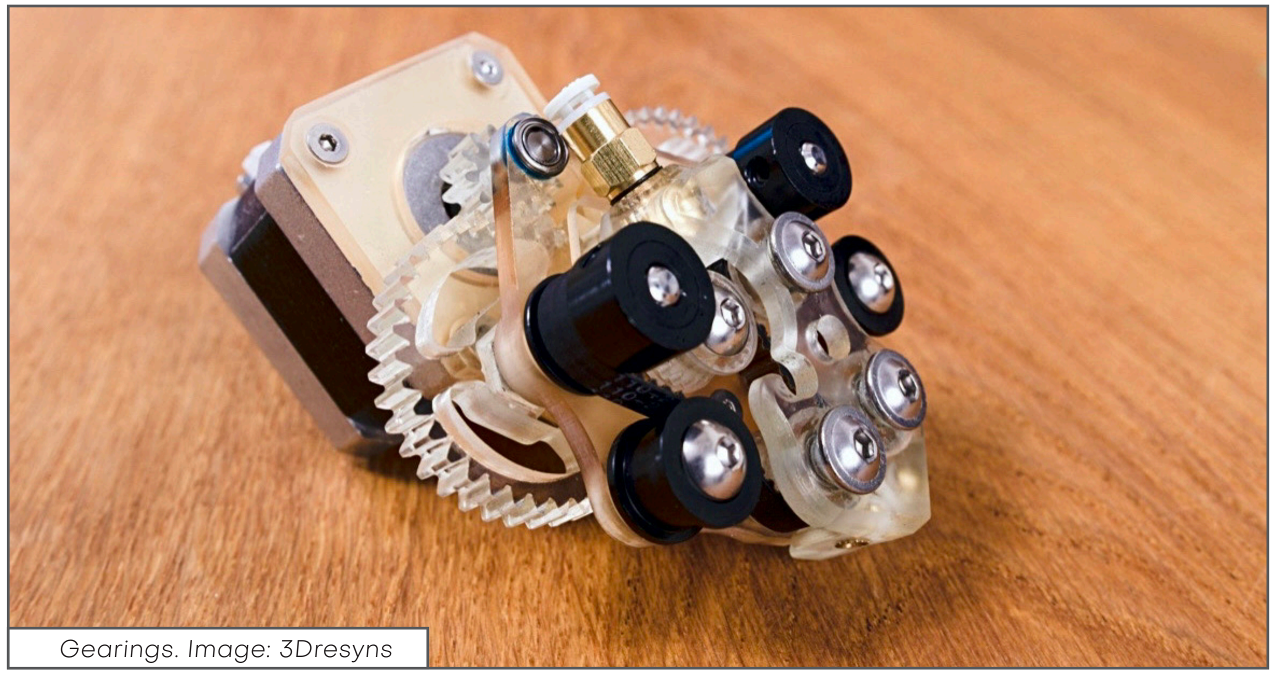
"A higher viscosity means a thicker resin. This has an effect on the reflux of the polymer and on the movements of the platform. If you know the volume of your 3D model and the density of the material you selected, you can easily calculate the weight of your 3D printed model", resin materials producer Liqcreate said.

While high viscosity resins contribute in "making ultra-high performance safe materials", Borges notes that at the production level, "they can be printed in most commercial printers at 25-50°C after installing a heater."

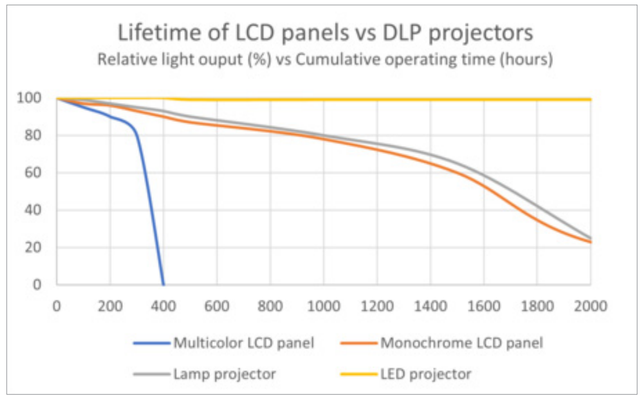
Whether we talk about low or high viscosity, we'll keep in mind that the viscosity of the resin does not depend on accuracy. High viscosity resin does not mean that it is easy to accumulate in the voids of the prints, low viscosity resin does not mean that it is not easy to accumulate either.

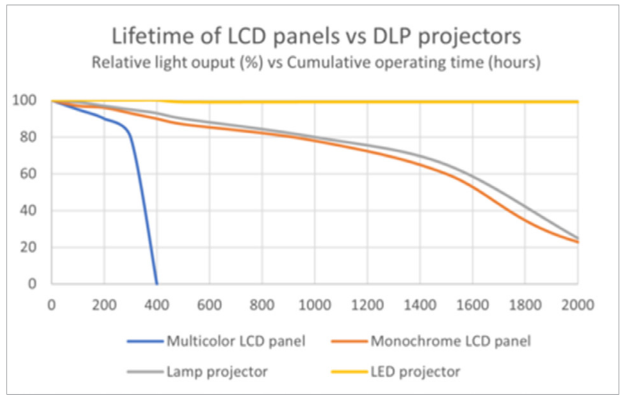
No matter what type of materials are used, 3Dresyns currently urges 3D printer manufacturers to develop affordable and reliable bigger printers based on MLCD and DLP technology. At the end of the day, the variability related to each 3D printer can greatly influence the result of the finished product. Taking the example of light power, Borges explains:

"Depending on the chosen 3D printer technology, its design, configuration, light wavelength, power, its distribution across the vat and the cumulative operating time, the real light power available across the vat for printing may vary significantly, and consequently as well the printing settings for similar printers and even from unit to unit of the same model due to small production differences among units. The following graphs show the typical light output decays vs cumulative operating time of standard multicolor RGB LCD panels, monochrome LCD panels, digital lamp projectors and LED projectors, all typically used in SLA, DLP & LCD 3D printers.



Gearings. Image: 3Dresyns





Unfortunately, light power varies and decays vs cumulative operating time. Even different units of the same model, new as supplied, often have 10-15% light power differences, which affect the overall printing results. Additionally, as shown on the graph above, light power decays versus the cumulative operating time of the printer. Light power variability upon usage and lack of light power control over time need to be addressed to promote the 3D industrial revolution. Right now, unfortunately, only few printer manufacturers have addressed these basic problems.

Lack of light power control, monitorization and prevention of its decay are some of the main reasons for frustration, printing problems, variability, or failure. Professional printing requires printers with constant specifications to promote the shift from traditional manufacturing into additive manufacturing."

Today, the issues of **costs** and **applications** continue to enliven discussions across resin 3D printing users.

As far as applications are concerned, advanced users hope to see further developments with photo-curable composite or nanocomposite resins.

It's currently a Holy Grail to scale adoption of photopolymer-based resins because a great number of photopolymer components' price depend on their use in the coatings and ink jet industry where they were primarily used. While large volume part production may enable to reduce raw material costs, technologies and service providers could further educate the user on the ability of a technology to create a product whose value is worth a new price.

Composites.

Composites are fascinating materials. For those who are not familiar with composites yet, please note that a composite refers to a thermoset or thermoplastic polymer matrix material reinforced with continuous or discontinuous fibers. Interestingly, those fibers could be carbon fiber, glass fiber, or natural fibers such as jute, flax, aramid or basalt fiber.

As we said in an exclusive feature dedicated to composites 3D printing, when Additive Manufacturing came to composites fabrication, we did not expect this combination to work and lead to the development of some niche, yet interesting applications for the industry.

If these materials have won their place in various applications made possible through additive manufacturing, the best part of it is that, there is a wide range of AM techniques that can actually process them: laminated object manufacturing, powder-bed fusion, VAT photopolymerization and material extrusion (this one including 5 different sub-segments) – each of them featuring its share of pros and cons:

Techniques	Advantages	Disadvantages	Fiber alignment
Laminated object manufacturing	· Low cost · Parts with high strength can be produced · No requirement of support structrues	· Higher wastage of material · It is relatively difficult to build parts with complex cavities	· Random fiber orientation · Uniform direction of the fiber
Powder-bed fusion	· Support structures can be removed easily · Composites with higher reinforcement of loading can be achieved · Fine resolution · Powders that remains unused can be reutilized	· Rough surface finish · Slow printing · Not possible to fabricate composites with long fibers · Expensive · High porosity in the final parts	· Random fiber orientation
VAT photopolymerization	· Fibers can be aligned randomly · Finer resolution	· Formation of bubbles takes place · Limited materials can only be used. · Sedimentation of fiber in resin · Increased resin viscosity with the addition of fibers · The issue with the penetration of UV rays	· Random fiber orientation · Along the direction of electric-field · Along the direction of magnetic-field · Along the direction of laying · In accordance with the fiber pattern of the mat
Material extrusion	· Easy to fabricate · Economical · Multi-material capability · Print-heads can be easily modified	· Degradation of the nozzle · Obious layer-by-layer effect · At higher reinforcement loading, nozzle gets clogged.	· Along the direction of printing

Table: Advantages and disadvantages of additive manufacturing techniques for composite materials.
Credit: An Insight into Additive Manufacturing of Fiber Reinforced Polymer Composite

Advancing composites AM mainly depends on the partnerships between manufacturers and adopters. According to Regina Pynn, expert at Hexcel, *"end users drive the technical requirements, and that's what flows up through the supply chain to inform what machine and material producers focus on. The tailoring of material properties you can achieve in composites and the differences that build orientation can drive in composite materials, make that link a real driver for innovation."*

That being said, it's interesting to remember that composites AM opens up new possibilities for lightweighting, when experts are looking to transitioning from metal to polymer. "Lightweighting has been a driver in traditional composites adoption and that trend continues in additive", Hexcel recalls. Indeed, while strength and stiffness are often mentioned as desired properties delivered when leveraging composites (and especially continuous fiber) with AM, they are not as powerful as the advantage of lightweighting.

"When we're replacing metallic components with HexPEKK-100, which is an SLS fabricated CF PEKK material, the weight savings for our aerospace customers is as important as the cost savings we bring to the program. Composites also lend themselves to customization of materials properties. Conductivity, flexibility, impact resistance: all these areas affect where a material can be controlled and adjusted in a composites material system", the expert outlines.

Despite these benefits, composite AM still presents some grey areas when it comes to the opportunities that carbon and glass fiber reinforced polymers (CFRP and GFRP) can enable. Indeed, CFRP (which stands for carbon-fiber reinforced plastic) is lightweight and has low density. It is also extremely conductive and highly expensive which is often considered as a key limitation in several applications.

The glass-fiber reinforced plastic on the other hand (GFRP), has a medium weight and medium density. It is insulative and less expensive.

To open more room for opportunities, Hexcel prefers to focus on new properties composites enable when combined with AM – that one cannot achieve with conventional manufacturing processes.

"At this phase of adoption most customers are trading AM versus traditional manufacturing methods. Composite AM has a great advantage when it comes to this competition. Against traditionally metallic components composites can bring properties like EM signal shielding, which we have in our HexPEKK-EM offering, that previously were a show stopped for non-metallic replacement."

Furthermore, another grey area is the current process around material allowable generation along with machine and part qualification. This process is not specific to composites as it is also what slows down the adoption of AM in general. The truth is, for a great number of AM users – especially those coming from a demanding industry, it's a real bottleneck to predict all materials allowables for a specific part. Due to the lack of accurate data, engineers and material experts should redesign the ideal material

Regina Pynn from Hexcel

each time or take over the development of AM process simulation to predict as-built material characteristic.

"For many of our aerospace composite customers it's the current process around material allowable generation along with machine and part qualification, so for Hexcel that has led to us focusing on fleet homogeneity and material allowable work to give the technical community the information they need to design the material without starting at the beginning for each new part. Long term that means leaning more on in-process or post-process verification, like NDI or quality sampling, and less on locking down every specific build detail for every specific piece. You can move a lot faster with adoption if everyone agrees on what good hardware looks like at the end and you're giving the manufacturing team the ability to change and optimize the process to get there. That feeds greater efficiency, which gives the adopters a broader business case for where this technology makes sense", Hexcel notes.

Filaments.

3D printing starts with filaments, advances thanks to filaments (and other materials obviously) and is currently in the middle of a revolution thanks to opportunities for more sustainable and local production created by filaments. However, a number of questions continue to raise debate across industries, questions regarding sustainability of materials, certification and metal 3D printing.

As far as sustainability is concerned, let's remember that 3D printing has always claimed to be sustainable due to its reduced wastage in manufacturing compared to other forms of manufacturing like machining. However, the most popular materials have always been carbon-based polymers, which are inherently not sustainable since they are derived from non-renewable resources. When it comes to filaments precisely, some material producers have started highlighting the "green benefits" of their materials.

In reality, they are quite "unclear about how sustainable [their materials] are, e.g. percentage of recycled material, the provenience of the recycled portion, etc. To increase the adoption of sustainable materials in production, customers have to trust that the material is sustainable with good engineering properties and, above all that, it will be reproducible", Thiago Medeiros Araujo, LUVOCOM 3F Global Product Manager shares.

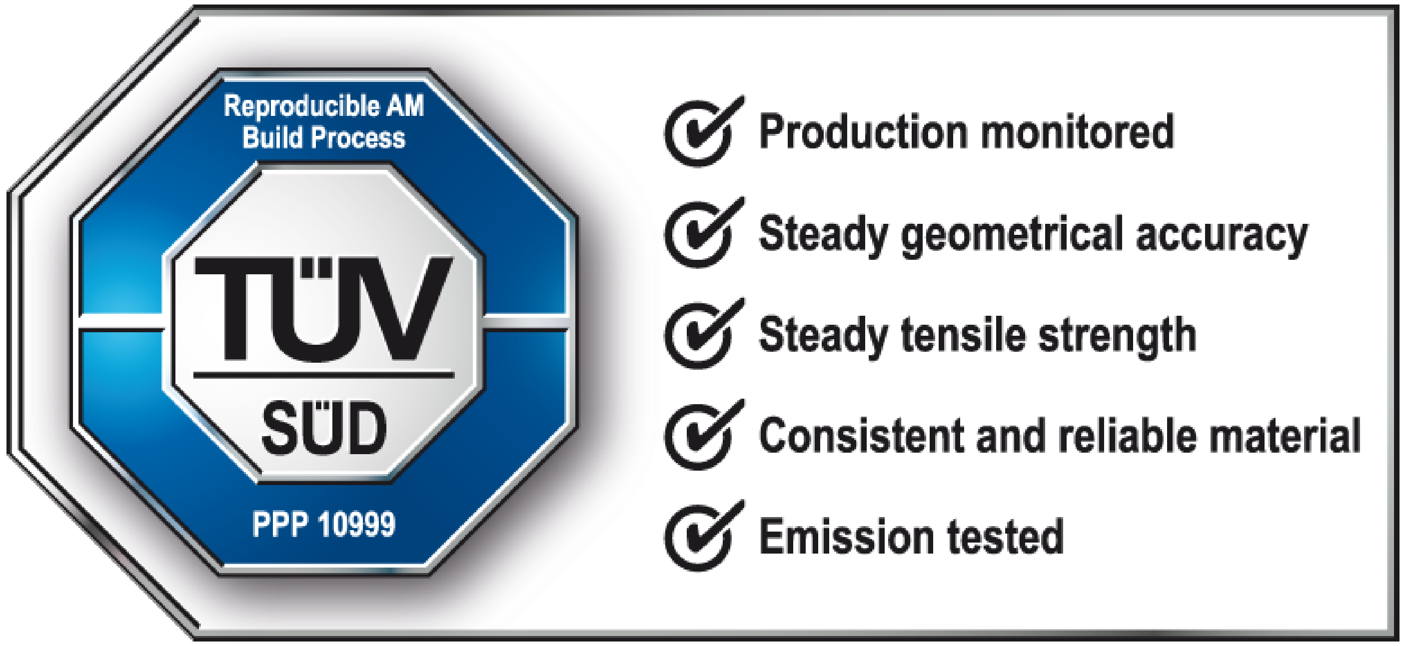
Characteristics like recyclability and reusability were a trend that came into full force in 2021 as a different approach to sustainability in 3D Printing but mentioning them alone is no longer enough today.

Thiago Medeiros Araujo

Certification.

The question regarding certification has often been asked by domestic users who needed to ensure that their materials meet an indoor air quality safety standard. In an industrial setting, this characteristic tends to reassure engineers on the quality of the material used for their projects.

While certification provides the material a certain legitimacy, Medeiros Araujo draws attention on the fact that it does not necessarily mean that this material delivers "industrial capabilities":



"Certifying a material per se in 3D printing is not something that adds value, as in most cases, its properties are directly related to the way the material was printed. However, having an independently certified build process has an enormous impact on the adoption of the material as it gives the customer enough confidence and trust to use the material straight away. So, it saves the user not only costs for having the material assessed but it also reduces the time for adoption".

Metal 3D printing.

Metal-polymer filament extrusion is currently gaining momentum as professionals are continuously looking for affordable metal 3D printing solution.

From a commercial standpoint, this business segment increasingly grows, giving the opportunity to industrial FDM 3D printer manufacturers such as 3DGence to develop machines capable of processing metal 3D printing filaments or to material producers like Nanovia or BASF to develop metallic filaments.

"However, we have to bear in mind that it is not only about producing the metallic filament but providing the customer with the whole structure for further processing of the parts, e.g. de-binding and sintering", Lehvoss' expert alerts.

Indeed, at the manufacturing level, metal 3D printing filaments and other materials that contain additives often need to be sintered to increase part density, helping users achieve the full set of high-performance mechanical properties.

Moving forward, one of the main challenges of the industry remains to achieve a "first time right" solution, no matter what material is used. And to do this, it's important to recall that it's a stage that can be reached through collaborations between various stakeholders. As Medeiros Araujo said, "each partnership demands a lot of commitment and effort from both sides to make it a flawless experience on the additive manufacturing journey of the customers."

Notes to the readers

The feature above has highlighted various insights from material producers on topics that currently raise debate across industries. The main opinions shared on this topic are coming from 3Dresyns, Hexcel, and Lehvoss Group. Their representative shares insights into resins, composites and filaments.

3Dresyns is a Spain-based materials producer that provides a comprehensive range of 3D resins, made to order and ready to print in the majority of open mode and closed mode commercial SLA, DLP & LCD printers. The company's new 3D printing resins are based on bioplastics, are bio-based and environmentally friendly. They compete in performance with the best engineering plastics, such as TPU, Nylon, PEEK, POM, PP, HDPE, LDPE, PC, etc. They can be used in a wide range of applications including orthodontic, dental, biomedical, engineering, jewelry, etc., for modelling or prototyping purpose.

Hexcel has made composites technology its core business. The company develops carbon fiber reinforcements and aerospace materials. With the acquisition of the Aerospace & Defense (A&D) business of Oxford Performance Materials (OPM), which specialized in PEKK additive manufacturing materials and supplied 3D printed parts for the Boeing Starliner aircraft, Hexcel has positioned itself as a key player in the AM industry. The company currently commercializes its PEKK 3D printing composite under the **HexAM brand**. To date, the company focuses on supporting the multiple commercial and defense programs where HexPEKK-100 parts are being used.

"As the build rates ramp back up for these programs it gives us more opportunities to demonstrate that HexPEKK-100 is a production scale material and technology. Also on the horizon is the publication of our NCAMP allowables database in the next few months. This will allow all potential end users to have a set of FAA compliant data to base their designs around without each end user having to invest in a proprietary allowables dataset. We've already had new aviation and space customers reach out excited to use that data to design with HexPEKK-100 in their systems", its representative said.

The Lehvoss Group operates under the management of its parent company Lehmann&Voss&Co., and it comprises several chemical companies that develop and commercialize special materials for a variety of industrial clients. The company currently focuses on creating new processes (ThermoMELT) or making process certification possible (Tüv Süd AM Build process certification). Its AM team ambitions to make the technology become another tool on the toolbox of each engineer to a point where decentralized production is enabled and local to local production will be possible, bringing a much more sustainable way to produce things.

Start-up AREA

6 YEARS LATER, VALCUN REVEALS THE NAME, TYPE OF AM PROCESS THEY DEVELOP, ITS CAPABILITIES AND POTENTIAL

"He didn't have an answer to this basic question." **Jan De Pauw**, CTO & Co-founder of ValCUN took 40 minutes of his Friday shift to share their company's journey – and at some point, the way the company started is a fresh reminder that the only stupid question is the one that is never asked.

In 2014, when **Jonas Galle**, ValCUN's other cofounder was designing a rocket engine for aerospace, he immediately thought of AM as a production method. While he understood the capabilities of metal 3D printing (LPBF) for this process, he quickly realized its expensive cost. The willingness to reduce costs for such production led Galle to consider FDM 3D printing as an option. The only thing is that FDM could not process aluminum or other metals. ***Why can FDM not process aluminum or other metals?***

This question led to several other ones, an investigation that ambitions to explore how one can reduce the cost of a metal part with AM and in 2016 to [ValCUN](). Yet, it's been 6 years and the Belgian startup remains intriguing, continuously raising interest from those outside its bubble. Sometimes, "less is more", **Christoph Hansen**, COO from Sauber Technologies recalled in this edition of 3D ADEPT Mag *(AM Shapers Segment – page 17)*.

ValCUN's will to operate in stealth mode is legitimate when we know that the less you say, the more you keep a competitive advantage over others; most importantly, when we know that hardware-tech companies do not benefit from the same "generosity" of investors to raise funds in Belgium as elsewhere. Here is the thing, this strategy can be a double-edged sword, because if you do not firmly define yourself, you let others define you.

That's the reason why, in this Q&A series, **De Pauw** reveals some of the key capabilities of their technology – at least the key strengths that will make you knock on their door for a possible partnership.


Jan De Pauw, CTO & Co-founder of ValCUN

3DA: What type of AM process does ValCUN develop? And how does it work?

We operate in the metal AM segment and we focus on aluminum. Not only is it a hard material that can be processed by various types of metal AM technologies (powder-bed fusion, binder jetting, etc.), but it's also a very interesting material in terms of properties and applications.

We name our technology **molten metal deposition (MMD)**. It's an analogy to FDM but with molten metals. It's easy to think that our technology is similar to Markforged's desktop AM system but it's not. The main difference is that in our case, all filaments are direct aluminum alloys wire while with other OEMs like Desktop Metal and Markforged are a mixture of metal and polymer. Furthermore, their process requires three steps to get to the final process (printing – debinding and sintering) while everything is performed in one step in our case. That's the basic difference between the most known *"metal FDM"* technologies and our technology.

So far, we believe we are the only OEM that develops a continuous extrusion-based method for metal 3D printed parts that processes molten metals. Few people did try this and stop their R&D activities as it is hard to get stable and reliable extrusion rates. We are aware of this and that is a reason why it took us so much time for us to come with a solution. But as long as the physics make sense, perseverance always wins.

3DA: Materials are often highlighted as a key challenge to achieve repeatable and industrial production parts. Do you face the same challenge with your technology?

The short answer is NO. :)

The long one requires to compare the process with other processes. For the LPBF process for instance, experts change the alloys, the ones that are mostly frequently used today in the industry (AA6061 – AA7075). Everybody likes them in the industry except one has difficulties printing with LPBF. By changing the alloys, industrials get suspicious and are not willing to explore applications with them. That's the reason why, aluminum AM is not widespread yet.

With our technology, you can take any aluminum alloy and process it. The main reasons are the nature of the physics in our process that are significantly different from powder based technologies. This means that, all aluminum alloys that have been used during the last decade on conventional manufacturing processes, can now be made available in AM. This is a game-changer for the industry.

3DA: Let's focus on automotive. ValCUN could be a supplier for the electric vehicles' market. What challenges can your technology address in this specific vertical?

We are focusing on heat exchangers. Electricity or power electronics tends to be seen as one of the main challenges in the production of electric vehicles but it is not. It is the heat that is generated by electricity and the drain of this heat that is the technological limitation in such production. [AM has already proven to be an excellent tool]() to address this limitation. In our case, we can print very large overhangs and bridging, similar to FDM. The fact that we only focus on aluminum printing plays to our strengths. First of all, aluminum delivers properties that are ideal for heat exchangers. Furthermore, since metal powders are used with SLM, it can be tricky to produce heat exchangers with internal channels as it might not be 100% free of metal powder or due to half adhered particles. That's the reason why operators would rather choose to explore WAAM, binder jetting , MMD or any other AM process that does not use powders for this application.

3DA: Are there any examples of applications that you can mention in this vertical?

Our technology can also be a good production candidate for heat exchangers in ICT centers. Another category that is raising our interest is near-net-shape production. With such manufacturing, we can easily achieve the desired production results with post-processing. In the long-run, we would focus on everything from hundred to thousand parts.

3DA: ValCUN has secured [1.5 million euros in fund raising](). What happened since this fund raising?

We expanded our team, from 3 FTEs to 5 FTEs. We expanded our machines. We acquire a new patent and we developed a new extruder.

3DA: What are the next urgent steps the company ambitions to achieve?

This is the period of pilot projects for our technology. We are willing to demonstrate the capabilities of our technology and we absolutely need to do so – as you may know any new technology is suspicious, so industries need to know and feel what they can perform with MMD. At the moment, projects that fit with our roadmap are those related with aluminum parts, thin-wall structures… We therefore welcome any company that is interested in exploring some applications to reach out to us.

In the long-run, we will secure another funding round and hopefully will announce it in Q1 next year.

GUEST COLUMN

SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING: WHERE ARE WE?

Gabriele Favaro   Gabriele Favaro

SAM project stands for Sector Skills Strategy in Additive Manufacturing and it aims to tackle the current European need for developing an effective system to identify and anticipate the right skills for the Additive Manufacturing (AM) sector demands in response to the increasing labour market needs, thus, contributing to the smart, sustainable and inclusive growth of the AM sector.

2022 is the final year of the project and many results from the planned and performed activities are starting to become noticeable. In this brief article, you will be able to discover the most relevant milestones reached recently.

Last year's actions have been focused on implementing the International Additive Manufacturing Qualification System (IAMQS), expanding the network of Associated Training Bodies (ATBs) able to assign certifications, improving the quality of trainings through pilot courses and related impact assessment and finally the gathering of the first results and preliminary findings on skills needs and future skills trends.

IAMQS

The IAMQS is the core of the SAM project. The International AM Qualification System is composed by a set of qualifications for different proficiency levels in the field of AM technologies, grounded in industry requirements and validated by experts.

The System uses a modular structure composed by competence units for learning outcomes to describe the expected knowledge and skills acquired by trainees after the successful completion of the training courses. Within the system, a single syllabus for each level is defined, supported by a harmonised system for assessment and quality assurance, resulting in the same qualification being awarded independently from the country.

The AM Qualification System covers Metal AM Qualifications for Operators, Technicians, Designers, Supervisors, Inspectors, Coordinators and Engineers, as well as one Polymer AM Qualification for Designers. The system ensures that the transfer of knowledge process is developed in a harmonized way, by every authorized organization worldwide.

This Qualification System provides a way to recognize technological knowledge for AM Personnel and it is supported by innovative training guidelines that cover front-end emerging technologies in AM at the industrial level, offering individual learning pathways opportunities.

The IAMQS addresses the specific industry needs and involves trainers from industry and case studies based on real industrial issues. It is recognized as a best practice of international qualification system by CEDEFOP.

System Outreach

The last period's focus has been on the creation of a national network of Associated Training Bodies (ATBs) which are selected after a specific process conducted by the Authorised Nominated Bodies (ANBs). This has been done at national and regional level by engaging with organizations that can support the implementation of the IAMQS.

As part of the development of the IAMQS, Associated Training Bodies (ATBs) have been identified to perform training and release certifications for AM. During the last months, SAM project has increased the number of ATBs, reaching 15 affiliated training centres belonging to the network of training centres with geographical representation in Portugal, Spain, France, Italy, Germany, UK, Ireland, and Turkey.

Adding to this, CESOL is already engaging with other potential AM ATBs in order to increase the project results roll-out. AITIIP has been developing collaborations with the Digital Industrial Hub in Aragon (managed by Aragon Technology Institute).

For instance, in Portugal, ISQ is currently engaging with different organisations, training providers and industry, to support the implementation of the IAMQS in Portugal. Currently, ISQ has authorized two ATBs, ISQ Academy and FA, that are already performing some training courses. In Ireland, IMR have begun the process of becoming an ATB and expect to be a fully realised ATB by 2022. In France, AFS association is acting as ANB for France and, jointly with France Additive association, is acting to select the future ATBs.

Impact of Training

The participants involved in the 1st stage of SAM piloting activities have been interviewed to assess the impact and satisfaction about the training programme. These activities included the piloting of the methodology for creating professional profiles and skills through the implementation of revised training guidelines for the IAMQS. In total, 13 CUs were implemented virtually and 4 on-site, as in-person training and face-to-face meetings. The implementation of the 1st Stage Real Case Scenarios counted more than 500 participants (about 22% female) in the lectures, from which 408 students completed the assessment.

According to the results of the conducted surveys, we can affirm that the impact of training has been satisfactory. Namely, AM courses were attractive for a variety of attendants coming from different backgrounds and having several professional profiles (Engineering, Machine Operations, Design, Management, Research) and have been appreciated by both workers and unemployed people. Moreover, most of the participants confirmed that the training had a positive impact regarding the applicability and transfer of knowledge/skills into their professional activity.

Skills needs results

Implementing Additive Manufacturing requires preparing the coming workers and reskilling the current workforce to successfully adopt these technologies. In this sense, it is important to better anticipate the current and future AM skills needs at manufacturing workplaces in Europe.

One of the most important goals in resolving the issues faced by competent professionals in the field of AM is to prepare European, National, and Regional Training Organizations in terms of equipment and experienced personnel. Strengthening collaboration between industry and education is the strategy to be pursued in order to accomplish the desired impact, which is to eliminate skills gaps and ensure alignment of training programs and industry demands.

SAM consortium has recently developed its Report on the Analysis and Validation of Needs aimed at identifying skills gaps and demands of the AM sector for the current state of play and the short-term scenario (3 years). The analysis has been realised through the engagement and inputs coming from key target groups, namely Companies, AM Workers, and Training Organisations.

The validated data will be used afterwards as reference to support the European AM Skills Strategy and to revise existing training courses as well as to develop new ones.

The analysis of needs consists of determining the outcomes of the surveys, comparing different target groups, namely for workforce's current needs and employers' future needs (1 year and 3 years scenario).

The core of the assessment about the workforce regarded the interviewees' expertise on different process types, materials, how they have acquired their AM knowledge and skills (self-study, online courses, external training, etc.), what are the expected relevant technical/digital skills and much more. On the other hand, the scope of the employers' response was to investigate the most wanted professional profiles (NDT technicians, metrology engineer, resource efficiency engineers, etc.) as well as the most requested tasks and skills.

Concluding, a really interesting result we received from the 2021 training survey, that was also confirmed in the preliminary findings of the 2022 surveys, regards an augmentation of the use of the online training methods and tools. This is a fact that was provoked by the COVID19 pandemic situation all over the world because, as we see, all the organization are adapted to the new conditions of distance learning, using new technologies and tools with the aim of providing comprehensive and flexible training.

It has to be pointed out that the general results remain the same as last year's results and in line with our 2020 findings. This reflects that the main ideas and ways of working of the training organizations remain unchanged.

Gabriele Favaro', Policy and Project Officer at CECIMO – Responsible of Communication and Dissemination for SAM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