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AM & CASTING: HOW IS AM DISRUPTING METAL CASTING?

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3D ADEPT MEDIA
All about Additive Manufacturing

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Table of Contents

Editorial 04

Dossier 07

AM & CASTING: HOW IS AM DISRUPTING METAL CASTING?

Post-processing 15

HEAT TREATMENT FOR ADDITIVE MANUFACTURED PARTS: A DIRTY LITTLE SECRET THAT IS YET TO BE UNDERSTOOD

Interview of the Month 21

CONFLUX TECHNOLOGY: REINVENTING HIGH-PERFORMANCE HEAT EXCHANGERS WITH ADDITIVE MANUFACTURING FIRST, THEN APPLYING THIS EXPERTISE TO OTHER AREAS.

Materials | Guest Column 25

METAL POWDERS FOR AM APPLICATIONS IN AEROSPACE

Software 33

4 SOFTWARE STRATEGIES THAT CAN BE EXPLORED TO ENABLE LIGHTWEIGHTING WITH ADDITIVE MANUFACTURING

AM Shapers | Applications 37

CONSUMER GOODS INDUSTRY: 3D PRINTING IS AT THE HEART OF THEIR BUSINESS

Opinions | Hands-on Experience 41

AM 101: TIPS FROM THREE INDUSTRY EXPERTS TO REDUCE COSTS AND LEAD TIME IN 3D PRINTING

Hello & Welcome

Both for Advanced Users & Beginners. Always.

As Additive Manufacturing keeps moving forward, so do we. We move forward with the vertical industries that explore and exploit it daily, periodically or on an ad hoc basis. In doing so, it is easy to get carried away by the wave of advanced users, those who are sometimes looking for unlikely solutions to ever more complex problems. It is the adrenalin linked to the desire to demystify the unknown – and when it subsides, we remember that next to them there are new users. Those people who are starting their adventure, exploring AM processes and who do not know what tune to dance to. They also come from all over the world, from different industries and backgrounds. They are looking for advice, tips and tricks, and receive them easily when they meet other users like themselves.

In this issue of 3D ADEPT Mag, we give voice to these two user profiles. Through our various articles, we go back to the basics of 3D printing, but we also tackle more complex and technical subjects. The funny thing is, I think they fit in well with summer. So, if you feel like talking about lightweighting, heat (as in heat treatment and heat exchangers), powders, metal casting in AM or typical summer applications, you certainly are in the right place. Welcome !

Kety SINDZE
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Editorial

ADDITIVE MANUFACTURING (AM) & CASTING : HOW IS AM DISRUPTING METAL CASTING ?

If one only looks at the manufactured part, at first glance, it could be easy to say that casting technology has nothing to envy to metal 3D printing as both technologies can deliver parts with internal holes and similar surface roughness. Here is the thing, surface roughness and internal holes are not enough to tilt the balance in favour of one technology or another. Mechanical properties, productivity and costs are other items that could help determine if both technologies can be seen as "enemies" or "friends".

Have you ever realized that almost every object that surrounds us integrates some casting parts? The gate of a house, a wrench, an aircraft, an office building, a truck, etc. Each of these objects integrates some metal cast parts. With such a high number of applications covered by casting technology, and given the well-known advantages of additive manufacturing, logic would have it then that combining AM and casting would automatically lead to a number of more performant applications in a wide range of industries, but things are not always that easy in manufacturing.

It makes sense to explore how these technologies can advance hand in hand when we know that the foundry industry represents a big percentage of the manufacturing industry.

Casting technology is one of the oldest production technologies in the world – as a matter of fact, the process of casting was used in Egypt by 2800 BC. For those who are not familiar with this process, it could be interesting for you to keep this description in mind: typically used to create hollow and intricate shapes, **casting refers to a liquid material being poured into the cavity of a specifically designed mold** (the cavity referring to the shape of the product to fabricate). Once the liquid material cools, it solidifies into a part called a **casting**.

As manufacturers are increasingly looking for solutions that could deliver the most favorable ***price-time-quality conditions***, how can we not imagine that additive manufacturing, one of the recent manufacturing technologies, can have its part to play in a fabrication process that involves casting?

This dossier ambitions to explore the different roads where AM & Casting can be seen as complementary processes, as opposed to the ones where they can be seen as competitive processes. To do so, this exclusive feature will discuss:

- The various casting processes that exist while laying emphasis on the ones that are a great match for AM;

- The software & materials standpoints for hybrid manufacturing approaches that involve AM & Casting;

- The various expectations in terms of productivity and costs that may arouse.

Types of casting processes

There are usually three different processes that immediately spring to mind when talking about casting: **Die casting, Investment casting**, and **Sand casting**. In reality, research shows that one can have up to 13 different types of casting processes. In addition to the three processes mentioned above, the other casting methods include: Shell mold casting, Plaster mold casting, Ceramic mold casting, Vacuum casting, Permanent mold casting, Slush casting, Pressure casting, Centrifugal casting, Continuous casting and Squeeze casting.

Interestingly, *"the main casting processes that are being combined with AM are* ***sand*** *and* ***investment casting.*** *Both casting processes can be addressed with Binder Jetting. Either to print sand molds and cores directly and without the need for tools, or by printing PMMA plastic to create models for investment casting applications. By combining sand or investment casting with AM the costs and delivery time, especially for prototypes and small volumes or large single components can be reduced by up to 75 % due to the needlessness of tools*", **Christian Traeger**, Director for Sales & Marketing at voxeljet states from the outset.

A sand casting method requires the production of castings in a sand mold, steel, iron and most non-ferrous alloy castings. It involves several stages in order to achieve a high-quality finish. However, a few of its advantages and disadvantages can be summarized as follows:

Advantages	Disadvantages
Cheap production costs, especially in low-volume runs.	The process yields a lower degree of accuracy compared to other methods due to shrinking.
Possibility to manufacture large parts.	It can be difficult to sand cast parts with predetermined size and weight specifications.
Ability to cast both ferrous and non-ferrous materials.	Potential poor surface finishes may occur.

The well-known investment casting method on the other hand, starts in the wax room and finishes with testing where castings are carefully fettled, blasted and heat treated. Traditionally, this process requires creating a mold into which a molten alloy can be poured: a wax pattern is coated with a refractory ceramic material; as the refractory material gets hardened, its internal geometry takes the shape of the wax pattern; during the third stage, the wax is melted out and the molten metal is poured into the mold cavity. This molten metal thereafter solidifies and the outer ceramic material is broken down to take the casting out.

As summarized above with the sand casting process, here are a few advantages and disadvantages of this process:

Advantages	Disadvantages
Can achieve the casting of highly complex, extremely accurate parts with good surface finish right out of the mold;	Ideal for parts with small sizes.
Can cast very thin (~0.015 in) sections with incredibly low tolerances (~0.003 in)	Parts with cores or holes smaller than 1.6 mm or holes deeper than 1.5 times the diameter of the part are difficult to investment cast.
Possibility to automate the process, therefore to produce a large amount of parts;	May involve expensive equipment and resources
Various types of parts can be manufactured using a wide range of materials: stainless steels, magnetic irons, brass and more.	
Thorough testing carried out throughout the process.	

Some of these advantages and limitations have been shared by Suraj Kathale from HCL Technologies.

While attention is often made on sand casting and investment casting when talking about AM & casting, it should be noted that AM can also be a response to die cast tooling in certain industries like automotive.

In a die casting process, the high-pressure metal liquid is pressed into a precision metal mold cavity at high speed and the metal liquid is cooled and solidified under pressure to form a casting.

Unlike other processes, this method involves the following advantages and disadvantages:

Advantages	Disadvantages
High production efficiency and die casting molds can be used several times.	Long lead times
Reduced requirements when it comes to post-casting machinery	Large parts cannot be cast
Ideal for mass production	

Applications of AM in die casting can demonstrate how 3D printed conformal cooling channels close to the surface of these tools create a thermally balanced die, and how the benefits cascade into decreased cycle time, lower scrap rates and lower labor costs.

What AM process can be integrated to casting ?

Sometimes, exploring routes where AM and casting are complementary, comes down to finding a faster (and somewhat affordable) way to create the mold before completing the manufacturing process. As you know, in this case, AM is often used to create the sand molds and cores that are thereafter used to fabricate parts by casting.

That being said, **binder jetting** remains the most widely used process with casting – sand casting especially. In this process, a printhead deposits a liquid binding agent onto a thin layer of powder particles — foundry sand, ceramics, metal or composites –. In this case for example, sand is usually the 3D printable material, the binder is foundry-grade resin while the component manufactured is a sand mold or mold core. This form of AM is often referred to as **sand 3D printing**, and on the current market, only a few manufacturers have built solid expertise in this area. They include for instance voxeljet, ExOne and ETEC (formerly known as EnvisionTEC).

As far as investment casting is concerned, applications reveal that another technology that is a great fit for casting workflows is **SLA (Stereolithography)**. The technology can enable the production of metal parts at a lower cost, with greater design freedom, and in less time than traditional methods. One of the objectives in investment casting is to use as little material as possible, while maintaining shape and accuracy. This objective can easily be met with SLA, where a UV laser cures and solidifies thin layers of resin in order to deliver internal structures, thin walls, surface finish and ideal resolution. The manufacturing steps that lead to the final product may often vary from one manufacturer to another, but ultimately, when using SLA patterns, it's easy to modify the original design of the pattern mold and examine the results in just a few days.

Due to the fact that investment casting foundries cannot often produce prototype castings until the injection mold is completed, FDM 3D printing is often used as an another option for producing investment casting patterns that are a lot more efficient and cost-effective.

That being said, other items that are worth considering are the materials and software standpoints as well as the mechanical properties of the parts achieved.

The software standpoint

Very little credit is often given to the design software, yet it can play a crucial part in ensuring the success of the part. Every single manufacturing process starts with a design, and as always, operators will look to deliver the maximum performance of the part by making the most of the manufacturing process.

Needless to say that Sand Casting (3D printed Mold) and Investment Casting (3D printed pattern) have different manufacturing constraints, therefore imply many differences at the design level. As seen with some traditional AM processes, **Martin Solina**, Vice President, Inspire Manufacturing Solutions, Altair recommends foundries to ask themselves some basic questions before going to production: "*"Can I cast this shape?" This is key to have sound parts without defects and to minimize rejections. What will be the production cost? How does it compare with a traditional method? What are the benefits?"*

Nevertheless, at the very beginning of the design stage, when AM and casting are explored in a hybrid manufacturing approach, one of the concerns that may arouse might be the right way to achieve the **optimal geometry** of the part. For **Martin Solina**, *"this shouldn't be a concern as this is a great advantage that can be obtained using a hybrid process." "Hybrid casting has benefits from both worlds: additive manufacturing gives flexibility to design lightweight and optimal designs, while casting provides proven manufacturing method with good material properties. [This means that] by using 3D printing and casting, we are maximizing the design freedom while increasing performance and reducing weight of the parts"*, he explains.

Martin Solina, Vice President, Inspire Manufacturing Solutions at Altair

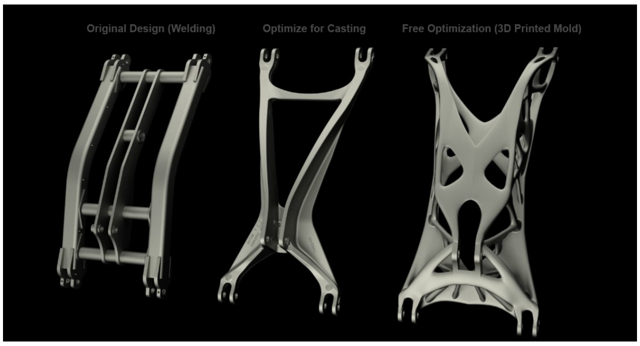
Furthermore, if in a solely traditional casting process, it's possible to have a software tool that enables the investigation of the cast parameters and eliminates the possible failures of the casting process during the design phase, it makes sense to expect such dual function in this hybrid manufacturing approach. To make the business case for AM & Casting compelling, **design software should allow users to do more than simply provide CAD tools.**

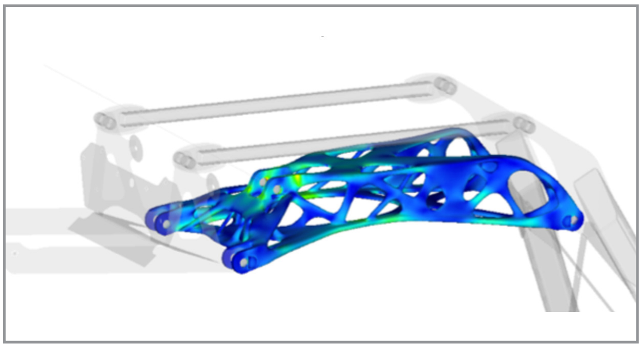
For Altair's representative, this means that design engineers should – for example - be able to optimize the *"performance of the part while defining manufacturing rules to ensure the manufacturability of the part for the particular manufacturing process. Design software must provide the freedom to the user to redefine the part and provide quick answers to questions regarding performance under different load cases, manufacturability, defect prediction or validation of the manufacturing process. Based on this, the role of a design software today has changed from a basic CAD tool to a simulation-driven design tool that provides feedback and information to improve and optimize the design of the part and processes integrating topology optimization and different type of analysis and simulation tools like structural, thermal or fluid analysis. Manufacturing simulation and many other tools help designers make decisions based on information, like:*

*- **Create and Modify Designs with Ease:** Create, modify and defeature solid models quickly, use PolyNURBS to create free-form smooth geometry and study multiple assembly configurations.*

*- **Optimize for Manufacturability:** Arrive at the ideal design direction extremely early in the process: topology optimization is based on physics and observes manufacturing process constraints.*

*- **Simulate at the Speed of Design:** Experience an interactive engineering design environment for rapid design exploration and product creation, without the need to invest in new computer hardware."*





Legend: Rocker arm Diet! The way to lighter agricultural machines through topology optimization and Manufacturing simulation – Altair, Amazone and Voxeljet have not only made a rocker arm unit lighter and durable but also with fewer stiffness variations. The rocker arm started as a 245kg welded part, with 16,5 m welded seams, which took very long to produce and was expensive. They ended up casting the part with 8% less weight, lower production costs and higher flexibility for customers in add-on modules. Images shared by Altair.

At a practical level, one should not forget that "designing" is very much dependent on the "human element", which means that two engineers designing the same part will not always obtain the exact same "rendering" not to mention that, the complexity of the part – if not well handled, may lead to defects, low part performance, excessive weight, excessive time to market and even expensive operations of redesign and having to revisit process conditions.

"To meet today's requirements of performance, weight reduction and especially costs, it is necessary to take advantage of new processes and design components for these processes require the combination of new software features, including:

• ***Parametric Geometry:*** *provides the ability to perform geometry modifications and changes based on analysis and simulation.*

• ***Structural and Motion or dynamic analysis*** *to understand the working conditions of the analyzed part.*

• ***Topology Optimization*** *to improve the part performance and reduce weight based on the working conditions.*

• ***Manufacturing simulation to predict the Mold filling and thermal analysis*** *for different types of casting process such as investment casting or gravity sand casting considering the different types of AM molds too.*

And most importantly, all these features should be linked to one another in a seamless way to be transparent for the user", Martin Solina lays emphasis on.

The materials standpoint

One of the main concerns often raised by materials is the one of **mechanical properties.** Do we have satisfying results when assessing the tensile strength, hardness, surface roughness, and microstructure of the part?

In a traditional sand casting process for instance, three materials/binding systems are often utilized and it's easy to think that they can be directly transferred to AM production methods.

"When looking at sand casting the answer is a classic: it depends", **Christian Traeger** brings a nuance. *"Most of the materials used have been used in metal casting for centuries: sand and furanic resin. Other binder types, such as phenolic or inorganic binders are also capable with AM. Depending on the binder used, the system setup need to be adapted as well. Furanic direct binding requires the sand to be mixed with a promoter that reacts with the binder and glues the sand particles together. Both phenolic and inorganic binder work with unmixed sand. By irradiating the building platforms with temperature, the resins react and glue the sand particles together. Since unprinted sand is unmixed, it makes it a lot easier to recycle and reuse. In investment casting we see a great acceptance and growing market interest in the PMMA material set. The rapid production and flawless integration into existing process chains are the main benefits. The only way to optimize this material set further, is to further increase the surface quality."*

Moreover, research reveals that the production of casts by binder jetting requires several basic materials properties for the individual process steps. The particle material must be free flowing to fill the model form. The binder must have very low viscosity for metering and for the resulting molding material flow characteristics. Both properties are also a basis for processing of materials in machines within the binder jetting process. Therefore, the materials can be used in 3D printers without major modifications in their physical or chemical properties.

We then asked voxeljet's **Christian Traeger** if parts produced with AM and a casting method possess the same mechanical properties as parts produced via casting as the only production method. He said they do.

"Reason for that is that, the casting process itself remains the exact same as it was before. By using typical foundry materials such as silica and special sands and complementary furanic, phenolic or inorganic binders, we only change the way molds, models and cores are built. Within the foundry, 3D printed parts can be integrated into existing process chains. Since the mechanical properties of castings depend mainly on the properties of the alloy used, additive manufacturing has no influence on these. Of course, there are some details that need to be kept in mind when designing to mold or the model such as cleaning of the printed parts. Also, the surface quality depends on the material used and can show differences compared to the materials used in conventional manufacturing, but when all these details are accounted for, and the metal is casted, the parts show the exact same mechanical properties as conventional manufactured cast parts."


Christian Traeger

What about productivity and costs?

Calculation is in general easy when you compare production time with AM with production time of the same part achieved via a conventional manufacturing process: AM usually wins no matter what happens. What's interesting here is to discover the steps that are removed in an AM process, but still required in a casting process.

Let's say for instance that the production time is calculated as from when the parts' producer receives the 3D CAD geometry from a customer. The casting process of a part with an average complexity might require two additional core boxes for pattern equipment. The operators would need 3 days to redesign a 3D model with all necessary draft angles and prepare the 3D pattern geometries. Two additional weeks will be necessary to move from 3D geometries to a ready pattern: this includes CNC machining for negatives, CNC machining for core boxes and copying epoxy models and making the gating system. Not to mention that extra time is necessary for the main production and forming.

AM as you may know does not need all these steps. For the same part, the operator will need a couple of hours to prepare a program to start producing the part. Most time is dedicated to the printing process here which might take up to 3 days – depending on the speed of the machine. Thereafter, the operator can spend a couple of hours on the various post-processing steps that need to be conducted.

Nevertheless, one advantage that remains worth mentioning is that in a casting process, in one mold there is more than one part, which means that in one casting process it is possible to produce 10 parts. This number is likely to vary – and may not always be reached – with a 3D printer. While casting remains an attractive process for series production, AM is a great fit for very complex parts and for productions where time is a limiting factor.

"AM works with digital CAD data and does not require any form of tooling. Conventional tooling can take up to 12 weeks to be produced and only then the casting process for this specific part can begin. Binder Jetting can create molds and models within hours or days, reducing the time needed to create e.g. a prototype by up to 75%. Binder Jetting is a quite easily scalable process technology, meaning that build volumes and productivity can be increased, making the technology not only suitable for prototype production but also for small to medium large batch sizes", **Christian Traeger** comments.

However, when asked if the combination of AM & casting is the most cost-effective way to produce parts – when looking at other metal AM processes, he said:

"This depends on the material and the required batch

Image : voxeljet. Impeller, sand casting

size. For prototypes and small series, AM supported casting process is much more cost-effective than e.g., Direct Metal Laser Sintering. Reason for that are the printing materials as well as the casting alloys. 1 kg of aluminum costs around 6,50 EUR when casting. Special Steel alloys can cost up to 38 EUR. The same materials but for AM technologies can cost something between 78-133 EUR per kilogram.

When it comes to batch sizes, binder jetting molds, cores and models is cost effective for prototypes and small to medium batch sizes. Binder Jetting is on one of the most productive AM technologies around and can also be scaled quite easily in order to meet larger batch size needs. Also, it offers build volumes beyond the capabilities of any existing metal printers. While metal binder jetting is of course a technology on the rise, the build volumes still lack the volume that sand printers offer. To say Binder Jetting supported metal casting is the most cost-effective way to produce metal parts is a strong statement and a little far-fetched. In certain scenarios, as described above, the cost effectiveness of Binder Jetting is very hard to beat, but those scenarios have to be identified and carefully evaluated to find the best fit and solution."

Concluding thoughts

The casting industry may not be known for its speed, but the economics and opportunities are just too good to be left apart. This industry is responsible for parts that fuel everyday life, the economy and many other industries, yet when we look at manufacturing, the sector remains one of the biggest losers with production declines of around 30% due to crisis and other ongoing transformation across industries. Price and production time make AM an appealing and competitive production candidate to address part of this problem, especially when we look at the production of small parts and for small quantity (up to 5 parts).

Furthermore, as mentioned by voxeljet, despite the high cost of AM equipment, one notes that machine manufacturers continue to invest time and resources to develop a portfolio that can easily enable industries to scale their production for larger batch size needs. Lastly, beyond these investments, it's crucial to keep in mind that when looking at this hybrid manufacturing approach that involves AM & Casting, sometimes, the right design software and utilization of this software can make a whole difference, not only in casting the *"un-castable"*, but also in delivering the ideal benefits in terms of time, costs and performance.

Resources

Several resources and contributions have been leveraged to produce this exclusive content. Two companies have also been invited to share their thoughts as subject matter experts on the topic:

Voxeljet, an industrial 3D printing company known for developing powerful 3D printing systems for large components or large runs of small components. As far as AM and casting are concerned, the company focuses on sand and investment casting. “With our technology we directly print the mold from CAD data. Leaving tools obsolete and reducing costs and delivery times drastically. So, we basically print a negative mold to create a positive part. Another AM suitable casting process is investment casting. Here, instead of creating a mold, we print a positive PMMA model. In the investment casting process, these models get covered in a ceramic slurry to build a shell. While burning the ceramic, the model melts and the hollow shell remains to be poured in. Traditionally, these models are produced from wax. But wax tends to break the ceramic shell when it’s not carefully burned out. PMMA however, has a negative thermal expansion factor, meaning that the material doesn’t expand when it comes into contact with heat. This lowers the risk for shell breaking during burning considerably which in return reduces reject rates as well as the time to build the shell and the overall investment casting process. With further surface post processing the surface quality of 3D printed PMMA parts can also be improved, e.g., via wax infiltration”, the company told 3D ADEPT Media.

Altair Engineering, multinational information technology company that provides software and cloud solutions for simulation, IoT, high performance computing (HPC), data analytics, and artificial intelligence (AI) has been invited to take part in this feature. The Altair Inspire platform accelerates simulation-driven design. Applied early in the product development lifecycle, Inspire accelerates the creation, optimization, and study of innovative, structurally efficient parts and assemblies through collaboration. Altair Inspire’s award winning user experience for geometry creation and modification can be learned in just a few hours, and delivers dependable Altair solver power, including:

· Structural analysis with the speed and accuracy of Altair SimSolid – as independently validated by NAFEMS – provides the ability to analyze large assemblies and complex parts.

· Dynamic motion simulation, including loads extraction, using the reliable multi-body systems analysis of Altair MotionSolve.

· The industry standard for structural efficiency, topology optimization by Altair OptiStruct, for the generative design of practical, viable, and manufacturable geometry.

“Our platform offers a unique set of simulation tools to evaluate product feasibility, optimize the manufacturing process, and run virtual try-outs for many traditional, subtractive, and additive manufacturing processes. Users can validate designs early in the manufacturing process with the simplicity and affordability of the simulation software, as well as use optimization technology with specific manufacturing constraints to design better, more efficient products”, the company said.

A. Vevers, A. Kromanis, E. Gerins and J. Ozolins, Research, Additive Manufacturing and Casting Technology Comparison: Mechanical Properties, Productivity and Cost Benchmark.

HEAT TREATMENT FOR ADDITIVE MANUFACTURED PARTS : A DIRTY LITTLE SECRET THAT IS YET TO BE UNDERSTOOD

In a previous dossier dedicated to the use of furnaces in additive manufacturing, we found out that the reasons that may help catalogue the type of furnaces manufacturers will use, are often dependent on the process the part will undergo: sintering (and often debinding) on the one hand, and heat treatment on the other hand. Here is the thing, heat treatment is a bottleneck that is quite underestimated… yet a thorough understanding and handling of this process can help manufacturers to avoid a wide range of unexpected challenges.

When looking at the various post-processing steps that can be carried out in an additive manufacturing process, it's easy to understand why powder removal is given top priority. Everything surrounding this process is relatively "new", whereas for heat treatment, operators easily see some similarities between the steps they need to take, to heat treat their 3D printed parts and the steps to follow when the part has been manufactured via a traditional route. That's probably where the trap is. They only see "similarities".

This article aims to highlight the main differences between heat treatment performed for AM and heat treatment performed for conventional manufacturing processes. A specific emphasis will be laid on typical heat treatment steps & considerations to take into account for L-PBF, EB-PBF and Binder jetting.

Heat Treatment: AM vs Traditional manufacturing processes.

As a reminder, heat treatment consists in heating material to a specific temperature and then cooling it to enhance its mechanical properties. In theory, the process involves three different stages**: heating, soaking, and cooling. In practice, the grades and cycles are different, and sometimes, there might be slight variations that occur depending on the metal AM process utilized. Interestingly, these cycles are often referred to as heat treat processes or techniques. Four of them** stand out (from the crowd): annealing, normalizing, quenching, and tempering.

"The differences between heat treat cycles are based upon and driven by chemistry [understand, chemistry of the material processed]. Chemistry dictates what heat treatment step you need to take to achieve your desired properties. That's the reason why, for instance, different alloys will require different heat treat cycles. Even within the same alloy, you might have different levels of heat treatment as well. In this case again, your chemistry will dictate what's going to happen if you heat the part in a certain way" Anthony Mott, Global Additive Manufacturing Leader at Wabtec, told 3D ADEPT Media.

Acknowledged for the fabrication of products for locomotives, freight cars and passenger transit vehicles, Wabtec made a real splash in the AM industry last year, when it became the anchor tenant of Neighborhood 91, an additive manufacturing supply chain hub located on the 195-acre airport campus. Mott and his team are on a mission to integrate AM within the company. To do so, they work with other engineers across the company to understand the applications and explore where it makes sense to apply AM.

Image via WIN Group

Reasons to perform a heat treatment process therefore vary from one application to another and the goal to achieve. In one case, the objective might be to soften the metal while in another one, the objective might be to increase hardness or develop certain mechanical properties to the metal or alloy used.

When one tries to compare heat treatment performed for AM & heat treatment performed for traditional manufacturing processes, there *"is limited to no differences between these two types of manufacturing processes. If you are using the same exact chemistry on the traditional side for instance, the material is the same and it's what really dictates your heat treatment profile. With AM, the only change is that you may have a more narrowed temperature profile. For example, you might run a high-performance nickel alloy processed by traditional processes from 1750 to 1950 while with additive, you'll run it from 1850 to 1875° – That's why I talk about a much narrower window on the same profile. The reasons why you may have some deviations in temperature is because with AM, we have a melt pool that melts your material and then rapidly cools. You have much smaller microstructures, much smaller green structures vs a cast part that has very large melted cool areas. That's why you need narrow process profiles. This will help you ensure to get consistent properties out of this thermochemical treatment"*, Mott told 3D ADEPT Media.

Anthony Mott, Global Additive Manufacturing Leader at Wabtec.

Mott's statement highlights three essential considerations to take into account when performing heat treatment: temperature, materials and microstructure challenges.

Heat treatment by nature is about control, control of the heating temperatures, control of the cooling rates, and the quenching types that are used to land on the desired properties.

In the same vein, it's normal to witness some slight differences in the reaction of materials that are processed via traditional processes versus when processed with AM. "It's difficult to 3D print pieces using materials containing high amounts of carbon, such as many steels. Carbon leads to issues in the microscopic resolidification that occurs in the AM process. It can affect expansion, contraction, shrinkage, and localized stresses, causing parts 3D printed with high carbon material to have cracking issues once completed. While carbon greatly complicates 3D printing, it is essential in many heat treatment processes", an expert at Paulo notes. – Paulo is an organization that has dedicated its core business to address thermal processing challenges.

Besides materials, one thing that is often difficult to avoid in heat treatment is distortion in 3D printed parts. That deflection of the component from the shape created by the AM process can be caused by a variety of loads placed on or inside the part by the AM process or the surrounding environment. For some experts, the more complex the part is, the more it might deliver tight tolerances that one does not always have with conventional manufacturing processes such as machining, and the greater the chances are to face some distortion. On this specific point, experts have various opinions to mitigate the risks of distortion :

For the team at Paulo, *"the risks of distortion can be mitigated by precise adjustments to the part's initial design to yield a geometry in the treated piece that will fit in the application."* For others, one can heat treat the parts together with the build platform **to avoid major distortion**. Another interesting idea comes from metal additive manufacturing service provider and CNC machine shop **Wagner Machine** that 3D scans practically every one of its 3D printed parts after it returns from heat treating. The idea of the engineering team at Wagner is to grab every possible information that can help them understand the effect of heat treat on 3D printed parts, in order to better predict heat-treating-induced distortion.

To illustrate this point, the company shared the image of a microturbine generator housing they created using aluminum alloy F357 on an LPBF 3D printer. The part is about 23 cm in diameter by 23 cm tall (9 inches x 9 inches) and it is made with large open spaces inside its form through which fuel flows to cool the part. After careful analysis, the team admitted that these unsupported openings increased the margin for potential distortion.

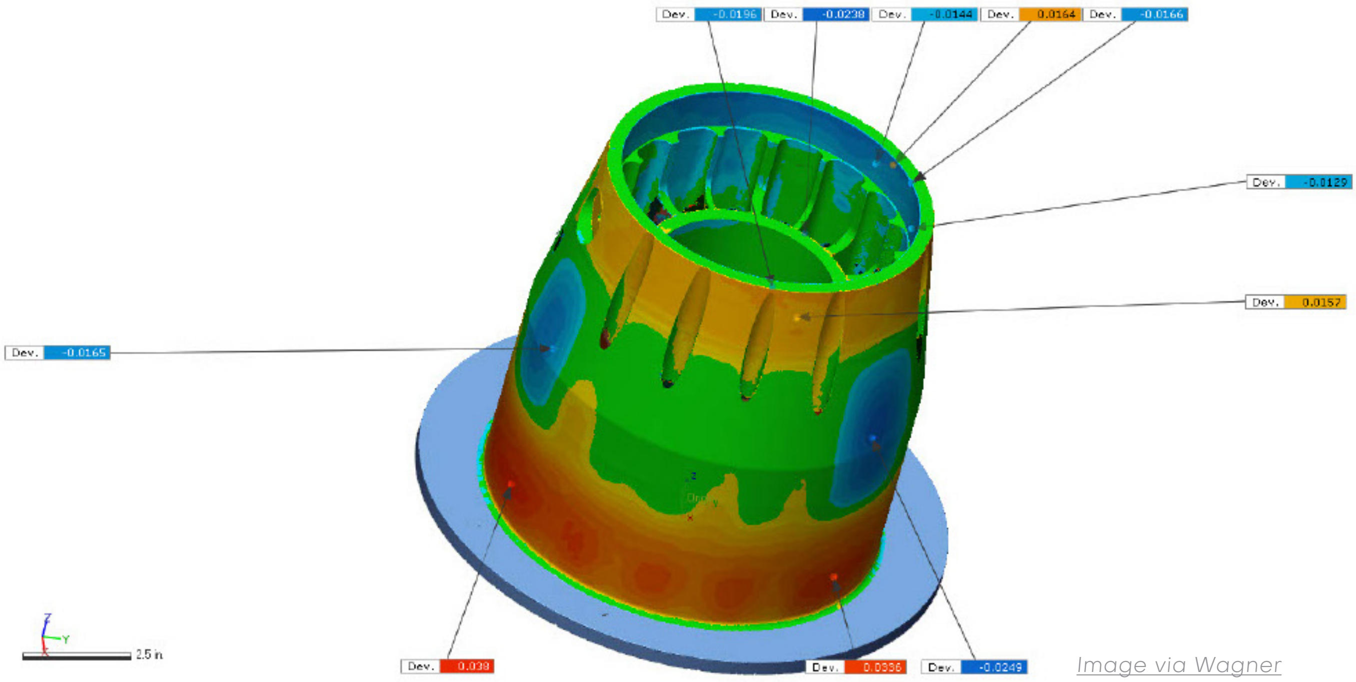


Image via Wagner

However, while most of the time, the main goal of heat treatment is to stabilize the metallic microstructure and balance material properties, one tends to realize that these microstructure challenges may vary from one metal 3D printing process to another.

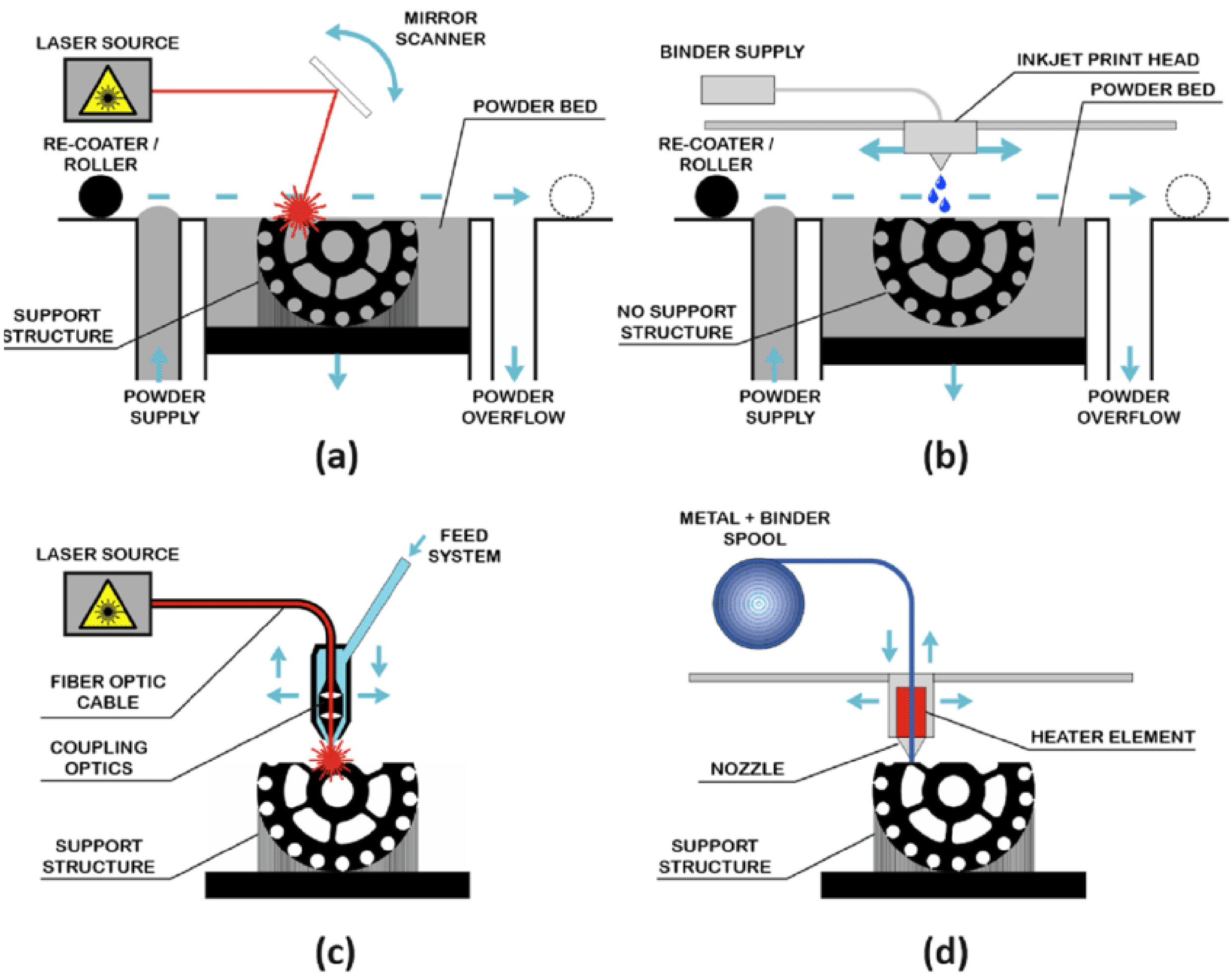
Considerations to take into account for L-PBF, EB-PBF and Binder jetting

Amid the range of metal AM processes that are commercialized on the market, there is a great chance that you have already heard or deal with laser powder-bed fusion (L-PBF), electron beam powder-bed fusion (EB-PBF) and binder jetting. When your part is manufactured using one of these processes, it is almost always advisable to apply a heat treatment at the post-processing stage. However, applications of this process may come with some differences. **Wabtec's Global Additive Manufacturing Leader** highlights the most important ones:

"There are some changes that do happen across the three AM processes. For example, in L-PBF, the build temperature is anywhere from 50°C to 200°C. This creates very high stresses in the part, which leads to the use of a stress-relief thermos treatment followed by a full heat treatment. For binder jetting, you need to remove the binder on the part, that's why you will need to conduct a debinding stage before a sintering process. Only after this, you could potentially jump in the same heat treatment that you would use in L-PBF. For Electron Beam Melting, the temperature you will deal with, could range from 600 to 1000°C. In this process, when you are printing, even though you are putting a lot of stress on your part, you are running a stress profile, so you won't necessarily need a stress-relief treatment here".

By taking the example of laser powder bed fusion (LPBF), the expert at Paulo lays emphasis on a phenomenon called **microsegregation**, which is the result of the solidification and resolidification of each layer during the printing process.

"In this condition, the AM process itself creates a series of microscopic melt pools (essentially weld pools) throughout the part's interior structure. Although this can be advantageous by keeping the part's microstructure very fine, those microscopic melt pools throughout can present segregation issues within the material, with particles separating into distinct zones and affecting the part's overall structure. This phenomenon can actually work in your favor, since homogenization of the microstructure can happen more rapidly in some AM parts, which reduces hold times during heat treatment."



1. Common metal AM methods: (a) laser powder bed fusion (L -PBF), (b) binder jetting (BJ), (c) directed energy deposition (DED), (d) fuse deposition modelling (FDM).

The table below summarizes what characterizes heat treatment for each of these metal AM processes:

Metal AM processes	Laser powder-bed fusion (L-PBF)	Electron beam powder-bed fusion (EB-PBF)	Binder jetting (BJ)
Description	This process uses a laser to sinter or fuse atomized powder particles together. Like most additive processes, it is performed one layer at a time until the part is completed.	In this powder bed fusion method, an electron beam is used to melt and fuse material powder together.	In Binder Jetting, a binder is selectively deposited onto a powder bed, bonding these areas together to form a solid part one layer at a time.
Type(s) of heat treat process you are likely to perform:	With the rapid melting and cooling of each layer, residual stresses are created in the fabricated components. This means that a stress-relief cycle will need to be performed to minimize distortion. Depending on the alloy used, and the density to achieve, a HIP (Hot Isostatic Press) treatment might be conducted.	In this process, the stress relief treatments are not necessary given the hot powder bed process of the technology. Depending on the alloy used, and the density to achieve, a HIP (Hot Isostatic Press) treatment might be conducted.	Sintering is required in this process in order to achieve the desired density of the part. (Prior to this stage, there is a debinding stage that needs to be performed).

With all these considerations, how do you verify if a heat-treat cycle was run successfully?

Anthony Mott shares three tips that can help operators verify if they have successfully performed their heat treat cycles:

- Thermocouples can be attached to the thickest areas in order to ensure that the process is conducted under the desired temperature.

- Operators can also use a "sacrificial coupon" that they will print with the part. You print a cylinder with a hole, and you put a thermocouple rate inside that hole. It will act as a representation of what your part will go through when temperature variation will occur.

- And the last one that's most typically done is to print test coupons for tensile or density, break them or analyze them to ensure that you are achieving the desired properties in the right area of your part.

What now?

Despite the advancements and precautions one can take during the manufacturing process, it is sometimes challenging to address the mechanical properties variability that occurs when the manufactured part is subjected to different heat treatments and process parameters. The truth is, even if the manufacturing technologies used are performant, the result of each fabrication is greatly influenced by the application and the product reliability. We may not be at the end of the "what ifs" that govern the heat treat cycles and processes when they are combined with AM, but by sharing their holistic experiences, users can learn from the road of success or failures of each other.

Notes to the readers:

Here are a few explanations on the main terms used in this article.

Heat treatment involves **three different stages**:** heating, soaking, and cooling.

During the heating stage, the foremost aim is to make sure that the metal heats uniformly. The purpose of the soaking stage is to keep the metal at the appropriate temperature until the desired internal structure takes shape. In the cooling stage, you'll want to cool metal back to room temperature, but there are different ways to do this depending on the type of metal.

(Descriptions shared by Kloeckner Metals).

Four heat treatment processes have been mentioned in the article**: annealing, normalizing, quenching, and tempering.

Annealing is a heat treatment process used to modify the microstructure of a metal to improve its ductility while reducing internal stress and overall hardness.

Hardening heat treatments are used to enhance the hardness of the metal's surface through heating and rapid cooling. The material is heated in a hardening furnace to a temperature that transforms its internal structure without melting it.

Quenching refers specifically to heat treatments that rely on rapid cooling of the metal to achieve the desired physical or mechanical properties. Heated materials are often cooled in oil, but can also be quenched using air, water, and brine, depending on the material and desired qualities.

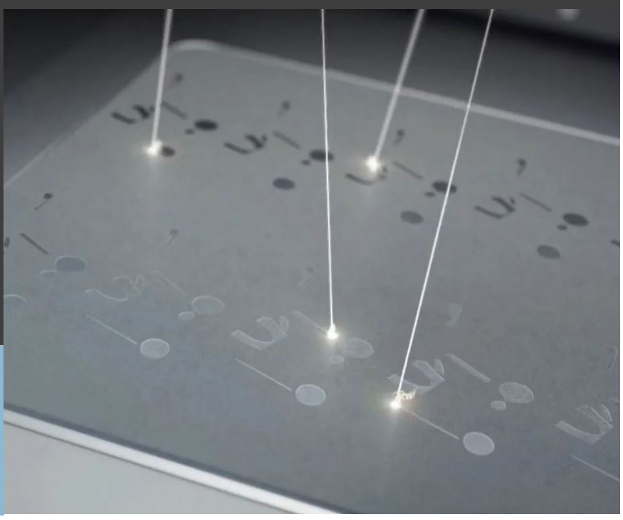
Tempering is a low temperature heat treatment process normally performed after a hardening process in order to reach a desired hardness/toughness ratio.

*(Descriptions shared by **S.M. Engineering & Heat Treating**).*

CONFLUX TECHNOLOGY: REINVENTING HIGH-PERFORMANCE HEAT EXCHANGERS WITH ADDITIVE MANUFACTURING FIRST, THEN APPLYING THIS EXPERTISE TO OTHER AREAS.

Michael Fuller

I knew, from day one, that Conflux Technology was the kind of company I would closely watch in this industry. Founded in 2017, it came out of nowhere last year by closing a Series A investment round of AUD $8.5 million to develop 3D printed heat exchangers. At the time, I had never talked to founder and CEO Michael Fuller. The reason why I knew I would watch this company is that its core business focuses on a pretty vertically integrated business enabled by additive manufacturing, and not just any applications, the one that most metal 3D printer manufacturers will create to demonstrate the capabilities of their technology. It seemed too simple, but it wasn't. It is not. When I recently discussed with Fuller, I couldn't help but smile while listening to his story and company's journey. Without knowing it, he gave me three more reasons to follow Conflux, and on top of that, discussed a misconception about the additive manufacturing of heat exchangers.



Three reasons that may raise interest in Conflux Technology

I don't know about you, but I am the kind of person who looks beyond the quality of a product in business. For me to remain faithful to a product or service, I need to know something about the founder or the people behind the brand, or at least there should be something I respect or value in the company's vision or values.

1- One thing I learned from **Michael Fuller** is that he is a man **who knows how to seize opportunities when they come – and in this case, how to create them.**

"There were a few different circumstances that led to a creative "ah ha" moment for me, these were off the back of a 15+ year career in the European motorsport industry, chasing my boyhood dream of designing racing cars. I found myself back in Australia for family reasons and I happened to have a broken ankle. So, I had my laptop out and I got designing", he told 3D ADEPT Media.

2- The second thing you will realize is that he brings **credibility** to the table.

"I have history as a design engineer and had early adopter exposure to additive manufacturing in the motorsport industry. I also had quite a bit of experience with the pain point of heat transfer. Occasionally you have a good idea, and I wanted to pursue this one a bit further to see if I could get to a proof of concept from a technical feasibility point of view. From here I decided to put a bit of money into getting something made and then tested, and convinced myself to continue forward in terms of commercialization. At that point I needed to figure out how to start and then run a business. So just did a whole bunch of research and got stuck straight in", he said.

3- The third thing enables you to understand the reason why Conflux focuses on heat exchangers and it is ***"a little bit more of a noble cause."***

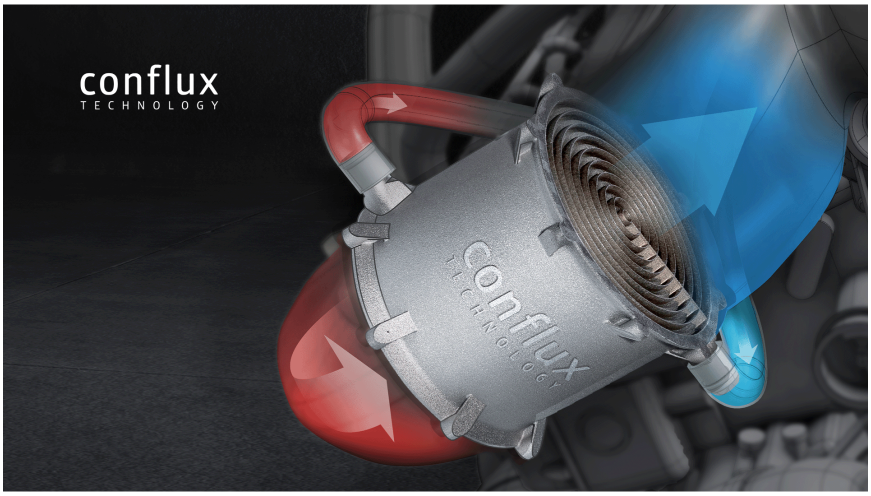
If you are new to this area, note that most of our daily electrical appliances (air conditioners, car engines, fridges, etc.) work thanks to heat exchangers. These devices are used to transfer heat between a source and a working fluid. The thing is, designing these devices used to be quite challenging given the complexity to take into account to enable fluids to cool efficiently in such a narrow space.

For Fuller, *"it's so ubiquitous, that the opportunity to improve efficiency in heat transfer means that it can be transferred across almost every sector that you can imagine. For example, improvements in heat transfer efficiency can mean that your aircraft can use less fuel for the same flight. You can achieve that whether it's in weight reduction or in fuel consumption directly. In the automotive sector, if you can package things into tighter stranger spaces, then you can improve overall aerodynamic drag and so you can improve efficiency there. In microelectronics, if you're able to take the heat away from the chips more efficiently, then you can calculate more, and you can calculate faster. This then has knock-on effects – as you can imagine in medical research and space exploration- and in all sorts of things. The fundamental impact of improved heat transfer efficiency goes on and on".*

Furthermore, when you look at the way heat exchangers are usually produced, you quickly realize that the traditional manufacturing route may involve a combination of braising, welding, extrusion, machining and molding. In one of the manual processes for example, if there's a failure between any of those brazing joints it can lead to failure of the unit. Although our goal is not to make a sort of comparison between traditional manufacturing processes and AM processes, it's fair to say that on a practical level, AM brings a number of pros that are hard to not mention: the ability to manufacture heat exchangers as a single component, the ability to manufacture smaller, lighter objects, more efficiently…However, all of this comes with its own share of challenges.

From design to production: what the manufacturing process looks like at Conflux.

As you may have understood through the lines above, designing heat transfer devices has often been challenging due to technical requirements raised by conduction, convection, and radiation. Heat is energy and, therefore, must conform to the laws of physics. Understanding the principles of heat and heat transfer is thus pivotal for the success rate of projects in the field and to address common challenges before they occur. Needless to say, challenges can increase when we know that AM is the production technology that will be leveraged.



"We have our own series of product families, which are created based off market research and market understanding of what our customers' pain points are, some of these being they need relatively off-the-shelf, yet highly configurable products. The problem definition is where we start our design process. We'll then go into either concept selection or an ideation process where we have engineers that are experts in first principles, calculations and multi-physics modelling. We also have design engineers that have got a lot of history in CAD modelling. We run our physics modelling simulations on an in-house, high-performance compute cluster, and utilize the best tools such as CATIA for our CAD modelling. We also have these teams working with the AM process engineers that are in house as well", Conflux' CEO explains.

As far as manufacturing is concerned, Fuller first recalls that *"the heat exchanger has intricate geometry with very thin walls, and fine feature distances. Quite often these are internal geometries within the device." "And so what we needed to do was make sure that we had a technology that could print very dense structures, so highly dense that we could have gas type walls separating different heat transfer fluids. We also needed to make sure that we could remove any residual material from the manufacturing process that could be removed completely. Therefore, if you are looking at electron beam melting, this is not suitable, because you can't get the thinness of walls that you need and you can't get the internal powder out without having some pretty elaborate processes. With the metal binder jet process, this results in a lower density".*

That's the reason why, their divergent study on AM processes led them to choose **powder-bed fusion technology** as the production candidate for these applications. For the most part, they can achieve the sort of heat transfer coefficients that they need to and also remove the residual material.

That being said, thin-walled internal core lattices can expand the surface area and capability of these devices. Betting on a technology like LPBF can lead to the production of walls of 0.1 millimeters of thickness or less. Achieving that requires a lot of development on the ideal process parameters that the machine will follow. And these are some of the key areas where the AM process engineers at Conflux focus.

Another interesting advantage that is very often highlighted is the technology's ability to deliver lighter parts. The advantage is so common to most AM applications that it might be easy to think that it's an absolute must in all "heat exchangers" applications. Fuller said no to this misconception:

"A lot of heat exchangers, sit on the ground, and might be mounted to large concrete slabs on the ground. Heat exchangers in the energy generation industry, or in large scale renewables, or in the nuclear industry might be as big as a house, making it smaller in that case can be advantageous because there's less real estate required, but in terms of light-weighting it's not all heat exchangers applications. If you look at different industries then you can start seeing where light weighting is important; aerospace, automotive, particularly in the motorsports sector of automotive, increasingly more and more Electric Vehicles. Anything you can do to reduce weight results in fundamental energy efficiency. If you've got less weight, then you need less energy to move the thing around. And, you know, laptops, if they can be lighter, then that's better."

Current challenges, short & long-term objectives.

On paper, Conflux Technology has everything to succeed. The partnerships the company has signed this year with Dallara Autobili, and GKN Additive, show the team is on the right path in their journey. But this journey would have been tasteless without some pitfalls on the road. In this case, despite significant investment in R&D to match the technology with their vision, the company's current challenges are now centered around commercia-lization. *"The industrialization of additive manufacturing is still quite nascent, and the cost of machines are still very high. One of the biggest challenges is making sure that we design and manufacture solutions for customers and markets that are in the right sweet spot for the sort of industrial maturity of the enabling technology which we're doing"*, Fuller notes.

For Conflux' representative, the productivity is going up and costs are coming down. However, as regards its level of industrialization, it's not near the hundreds of 1000s of units per annum, so there aren't those sorts of applications that [they] have developed yet. [They]'re constantly working to drop the asymptote on cost per unit per machine.

Moving forward, we shouldn't be surprised to see Conflux apply the expertise they have built so far to other areas – an expertise that is characterized by *"thin walls and high resolution geometries"* as per Fuller's words. Somehow, it's already happening, as one of their clients who completed a project on heat exchangers with the team is now working with them on building substrates for catalytic converters in emissions reduction technology. *"So, there is transfer there from the sort of expertise in high resolution AM geometries"*, Fuller comments.

However, in the short run, Conflux has other plans in terms of expansion and location:

"We've been lucky to have a first phase of the business housed at the back of Deakin University in Waurn Ponds, Geelong. They have a large parcel of land which is sectioned off for advanced manufacturing where young, advanced manufacturing businesses like Conflux can spend the first number of years getting settled, which is what we've done for nearly five years [now]. We'll move at the end of this year to a larger facility with more production capacity as well as more testing capabilities. We've got boots on the ground now in our key customer regions, with people based in Japan that are covering Japan, Korea, India, and non-Australia Asia region. We have a person based in Central Europe, just outside of Munich and we are also just about to have someone start in North America. So we're getting a global footprint underway. This is so that we can be near our customers, so we can share time zones with our customers, which is quite tricky from Australia. This is really an expansion on all fronts, but our commercial activities will increase significantly in the coming 12 to 18 months" the CEO of Conflux Technology concludes.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Materials

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Metal Powders for AM Applications in Aerospace

EPMA's AM seminar of 2022 was held in May focusing on AM in Aerospace with more than 20 presentations together with many fruitful discussions. One of the main outcomes of these discussions is that there is a strong need for a wider range of materials in Aerospace with optimised properties for AM. Optimisation includes developing specific powder production processes, good powder characterization such as morphology and flowability properties, as well as the optimisation of the AM process itself.

POWDER PRODUCTION PROCESSES

There are many different methods for metal powder production. In general, four main processes used in practice. These are solid-state reduction, electrolysis, chemical, and atomization. We will focus on atomization in this article as being the most convenient method for producing additive manufacturing powders regarding particle size, shape and other factors.

In solid-state reduction, selected ore is crushed, typically mixed with carbon, and passed through a continuous furnace where reduction of carbon and oxygen takes place [1]. The result is a cake of sponge metal that is crushed and sieved afterwards. The purity of the powder is dependent on the purity of raw materials and morphology is irregular. Electrolysis is the method of metal deposition in a spongy of powdery state followed by washing, drying, reducing (hydrogen reduction or the carbonyl process, which is used to extract and purify nickel and iron), annealing, and crushing. Due to its high energy costs, electrolysis is generally limited to high-value powders such as high-conductivity copper powders. Chemical powder treatments involve oxide reduction, precipitation from solutions, and thermal decomposition. The powders produced by chemical methods can have a great variation in properties and yet have closely controlled particle size and shape.

Atomisation is the method of powder formation by a spray of molten metal that solidifies as fine particles. The process can be realized by means of pressurised air, inert gas, water or even under vacuum depending on the material type and its application. Three main atomisation processes used in powders for AM in aerospace applications are plasma atomisation, vacuum inert gas atomisation, and electrode induction melting inert gas atomisation.

Plasma atomisation

Plasma is the mixture of ions, electrons, and neutral particles at very hight temperature. A high-pressure gas passes through an electrostatic field which has a sufficient amount of electron charge and will produce a plasma arc. The resulting electrons and gas molecules collide with each other so that it can lead to the formation of ion, atoms, and excited photons [3]. Plasma atomisation is a process invented by Pyrogenesis of Canada in 1995 and now widely adopted for the production of Titanium and Ti alloy powders. Figure 1 (a) shows a plasma atomization process scheme using a three-plasma arc, with titanium wire as a material feed. The plasma arc is utilized as a high-enthalpy heat source which will melt and spray molten titanium wire, resulting in a titanium powder that has a very high purity round shape

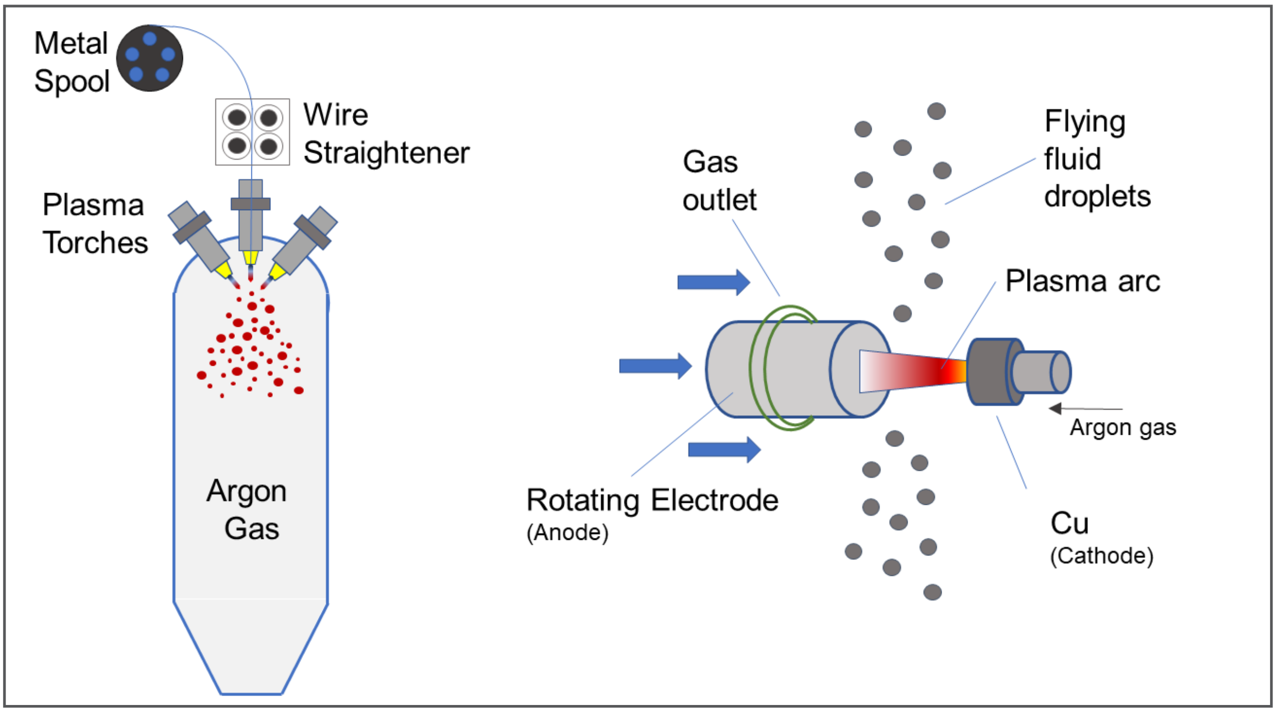


Figure 1: (a) Plasma atomisation (Source: Pyrogenesis) / (b) Plasma Rotating Electrode Process Atomization [7]

Another type of plasma technology used for metal atomization applications is the plasma rotating electrode process atomization (Figure 1b) where the rod-shaped feed material is rotated at a high speed when the argon or nitrogen plasma arc melts the tip of the rod. The liquid metal is thrown into droplets that solidify into spherical particles due to the high centrifugal force of rotation. The result is usually coarse particles.

Vacuum Inert Gas Atomisation

In a typical inert gas atomisation (IGA), the liquid metal is broken up by pressurized inert gas such as Argon or Nitrogen to get a protection from oxidation typically in the range of 100–2000 ppm, but highly dependent on alloy type. For lower oxygen contents in the range of 50-250 ppm, vacuum inert gas atomisation (VIGA) is applied where the melting and pouring of the alloy is performed in a vacuum chamber, to allow the production of the most oxidation-sensitive and reactive alloys such as Fe-, Ni- and Co-based alloys containing Al, Ti and rare earths (Figure 2).

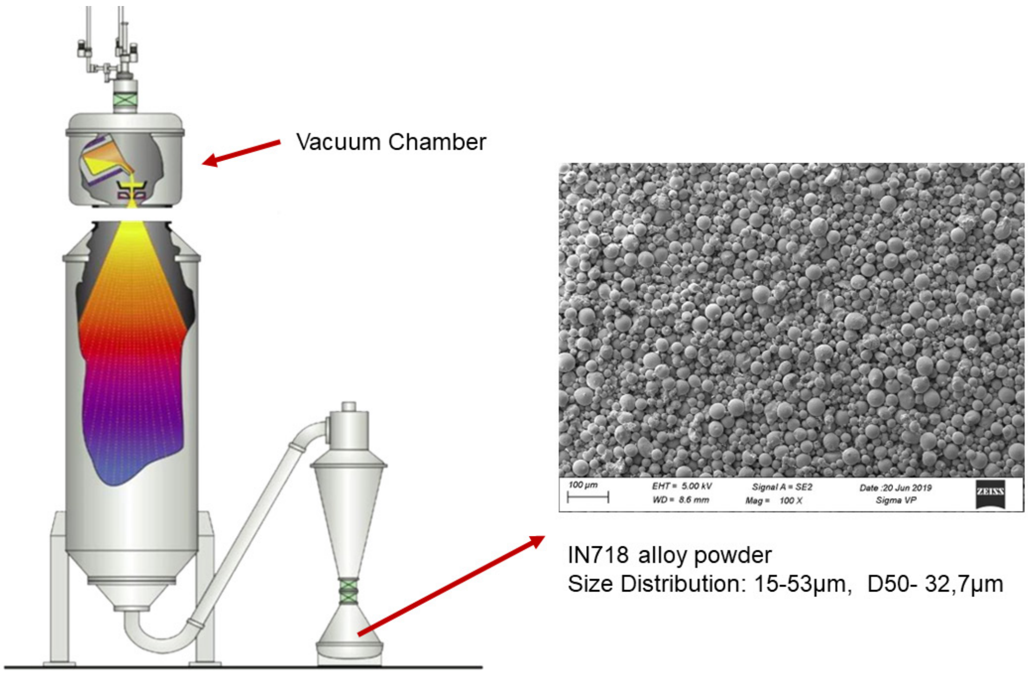


Figure 2: Vacuum Inert Gas Atomisation (Source: ALD Vacuum Technologies (left), Sandvik (right))

There are several advantages of VIGA in terms of AM, especially for powder bed fusion. These are:

· Spherical Shape (Good flow characteristics)

· Low oxide & impurity levels (Metallurgically clean, enhanced mechanical properties)

· High Tap density of more than 65% (Uniform layer properties)

Superalloys such as IN718, maraging steels and duplex stainless steels are the most common alloys used in VIGA systems for powder production of AM applications. VIGA was developed in the fifties, when there was a push to explore the potential benefits of rapid solidification to allow the production of more highly alloyed superalloys for aerospace and defence applications [4].

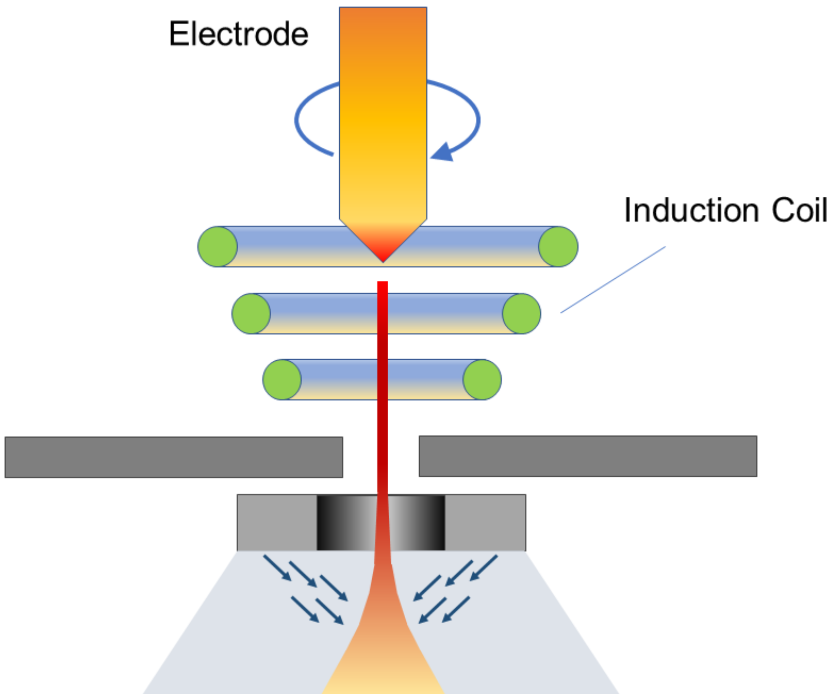


Figure 3: Electrode Induction Melting Inert Gas Atomisation (Source: ALD Vacuum Technologies)

Electrode Induction Melting Inert Gas Atomisation

This is a "ceramic-free" gas atomisation process where the stream of melt is not provided by a tundish and nozzle, but by drip melting a solid bar (the electrode) which is gently rotated to equalize the melting process around the edge of the bar. The profiled induction coil, typically working at very high frequency such as 50 kHz to avoid excessive magnetohydrodynamic forces, melts the edge of the bar into a conical shape and the resulting stream of drops of liquid metal falls into a free-fall gas atomising nozzle as shown in Figure 3. The water-cooled copper coil itself is manufactured by AM because of its unique design of a spiral shape in three dimensions.

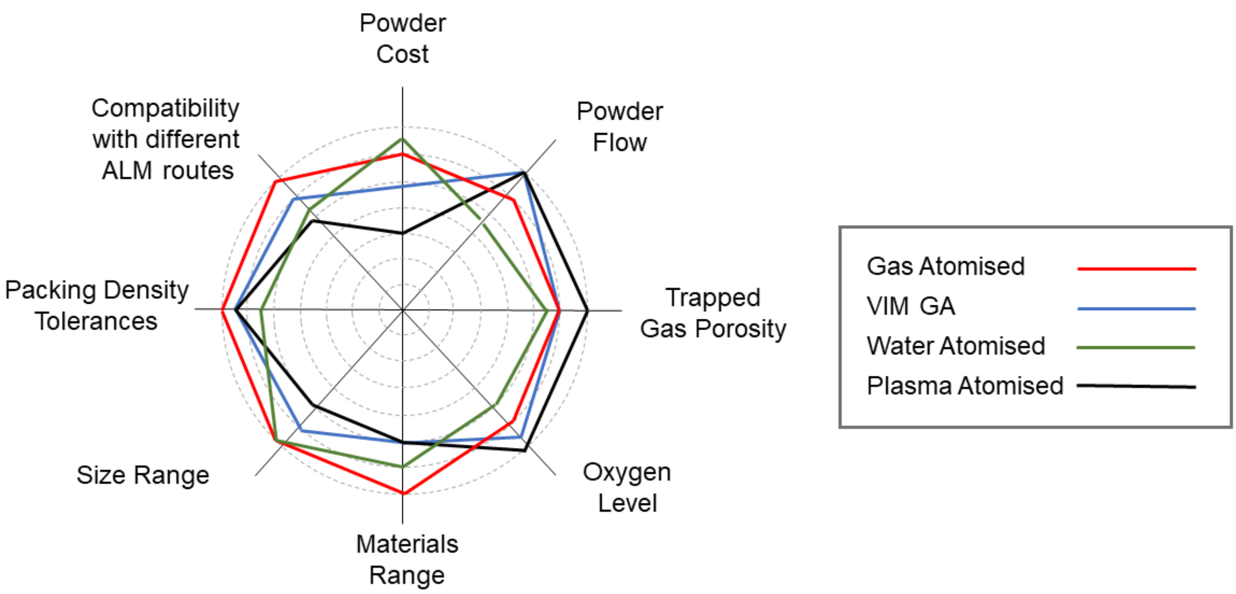


Figure 4: Comparison of different powder types in terms of production process (Source: EPMA)

The EIGA process is widely used for Titanium alloys as Ti attacks all possible ceramic nozzle materials. EIGA suffers from the fact that the stream's location is poorly defined and the melt rate rather slow, typically 10–30 kg h−1. This leads to a high gas consumption per kilogram of powder.

To compare these different methods of powder production, below is a spider chart in terms of cost, size and materials range, oxygen level and flow characteristics.

OPTIMISATION FOR ADDITIVE MANUFACTURING

Certain powder attributes need to be optimised so as to be used in additive manufacturing smoothly. These include:

· Powder shape (Morphology)

· Particle Size Distribution

· Batch Consistency

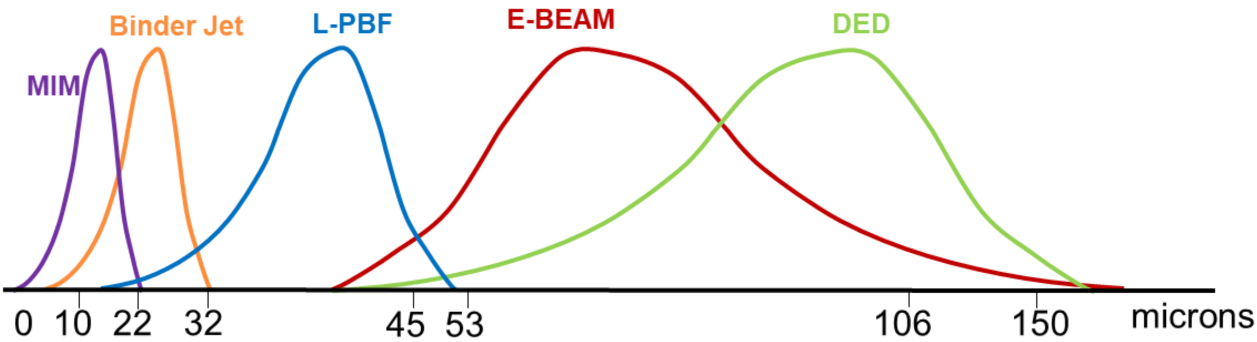
· Relative Humidity

Powder Shape (Morphology)

Spherical shape is the optimum morphology for metal powders in AM because it aids good flow characteristics. Spherical shape also increases pack density and uniform layer properties that is a prerequisite for the AM process. Satellites are especially avoided in AM because that hurt flowability.

Particle Size Distribution

Every Powder Metallurgy process has its own range of particle size distribution for metal powders. For example, metal injection moulding (MIM) requires fine particles lower than 22 µ in diameter where the median (D50) is 10 µ.



For additive manufacturing, convenient particle size distribution depends on the process (Figure 5). In general, we can classify the particle size distribution of metal powders as Fine (<30 µ), Medium (15-53µ), and Coarse (63-200 µ). Although there may be variations, it is possible to say that medium size particles are preferred in AM processes.

Batch Consistency

Metal powders are produced in batches, and this may lead to physical and chemical inconsistencies that result in variations of material properties. In terms of metal powder characteristics for additive manufacturing, it is important to ensure consistent powder bed packing and constant flow rate specifically for the AM process used.

Relative Humidity

The impact of moisture on flowability and spreadability is detrimental in terms of additive manufacturing. The effect of humidity on flowability is dependent on material type. Especially aluminium alloy powders (AlSi10Mg and Scalmalloy) are strongly affected compared to others such as IN718 and Ti6Al4V in case of an increased relative humidity [5]. Although the level reached is not a cause for concern, the moist powder also causes a higher hydrogen and oxygen content in the built material. Nitrogen content is usually unaffected.

Characteristics	Effects on AM	Common Detection Methods	Associated Test Standards
Chemical Composition	Differences in chemical composition will influence the final part properties. Compliance with existing material standards pertaining to different industrial applications is necessary	Inductively coupled plasma, optical emission spectroscopy, X-ray fluorescence	ASTM E1019, ASTM E1409, ASTM E2465,
Particle Size Distribution (PSD)	The minimum layer thickness that can be built in AM is a function of powder particle size. The range of PSD influences the energy requirement and the packing bed density	Laser diffraction and sieve analysis	ASTM B214, ASTM B215, ASTM B822, ISO 4497, ISO 13320
Flowability	Influences the homogeneous distribution of powder bed. Flowability will be poor for powder batches containing a large proportion of smaller particles less than 6 microns	Hall flowmeter, Carney flowmeter, powder rheometry	ASTM B213, ASTM B855, ASTM B964,
Density	Effective packing of powder is required to ensure minimum porosity in the final part. Packing density has a significant effect on the thermal conductivity of the powder bed	Hall flowmeter, Carney flowmeter, Scott volumeter, gas pycnometer	ASTM B212, ASTM B417, ASTM B527, ASTM B923,
Powder Morphology	Influences homogeneous distribution of powder and the packing density. Powders with spherical shapes that spread easily in the powder bed are required for AM	Scanning Electron Microscopy (SEM)	ISO/ASTM 52907
Microstructure	Important to understand the grain morphology of the powder and to correlate it with microstructural characteristics of the final part	Optical microscopy or SEM	ISO 13322-1/13322-2
Thermal Conductivity	An important Thermo-physical property of the metal powder which affects the consolidation behaviour of powder	Guarded hot plate method	ASTM E1447, ISO 8302
Humidity	Poor processability of powder. Mainly introduced during handling, transportation, and storage. Causes porosity and uptake of oxygen in the final component.	Relative humidity sensor; Loss on drying	ISO/ASTM 52913-1 (Under Development)

Table 1: Key powder characteristics and their significance in AM processes [8].

ALLOY POWDERS FOR AEROSPACE

The main advantages for metal additive manufacturing in aerospace applications are significant cost and lead-time reductions, use of novel materials, mass reduction of components through highly efficient and lightweight designs, and consolidation of multiple components for performance enhancement or risk management which also means reduced number of suppliers and rationalised quality assurance process due to the reduced number of parts and fabrication processes, i.e. especially less welding & joining. As an example, using internal cooling features in thermally loaded components or eliminating traditional joining processes can be counted. These opportunities are being commercially applied in a range of high-profile aerospace applications including liquid-fuel rocket engines, propellant tanks, satellite components, heat exchangers, turbomachinery, valves, and sustainment of legacy systems [6]. Figure 6 shows various application cases of AM in Aerospace.

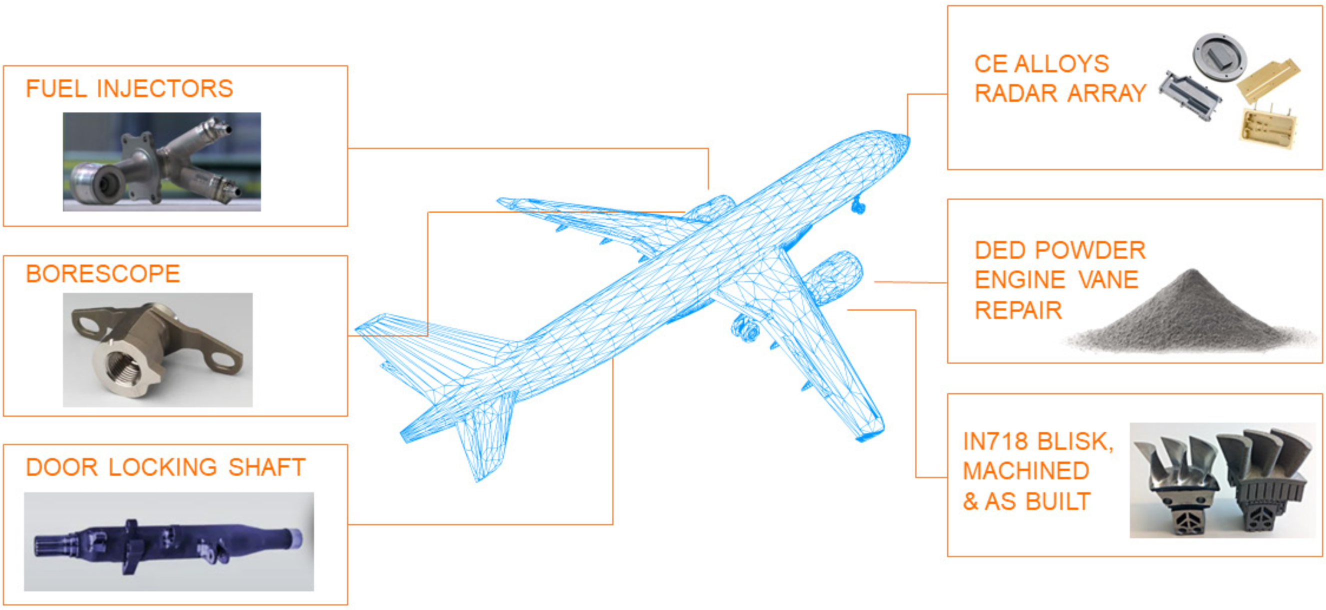


Figure 6: Application cases of AM in a typical passenger plane (Source: Metal AM & Sandvik)

In this article, three major types of alloys from different powder production processes will be examined with respect to their mechanical and metallurgical properties. These three alloys are some of the most common alloys used in Additive manufacturing for Aerospace. These alloys are Inconel 718, Hastelloy H-X, and Ti6Al4V.

Inconel 718

This is a nickel-based superalloy heat treated for AM. Inconel 718 powder can be produced by using inert gas atomisation process without vacuum, but for better performance and mechanical properties, VIGA is the preferred process. It has high mechanical strength in combination with high corrosion resistance. The mechanical properties are especially attractive at high temperatures up to 650 oC. Figure 7 shows a typical Inconel 718 powder with its as built microstructural images produced by IGA and VIGA

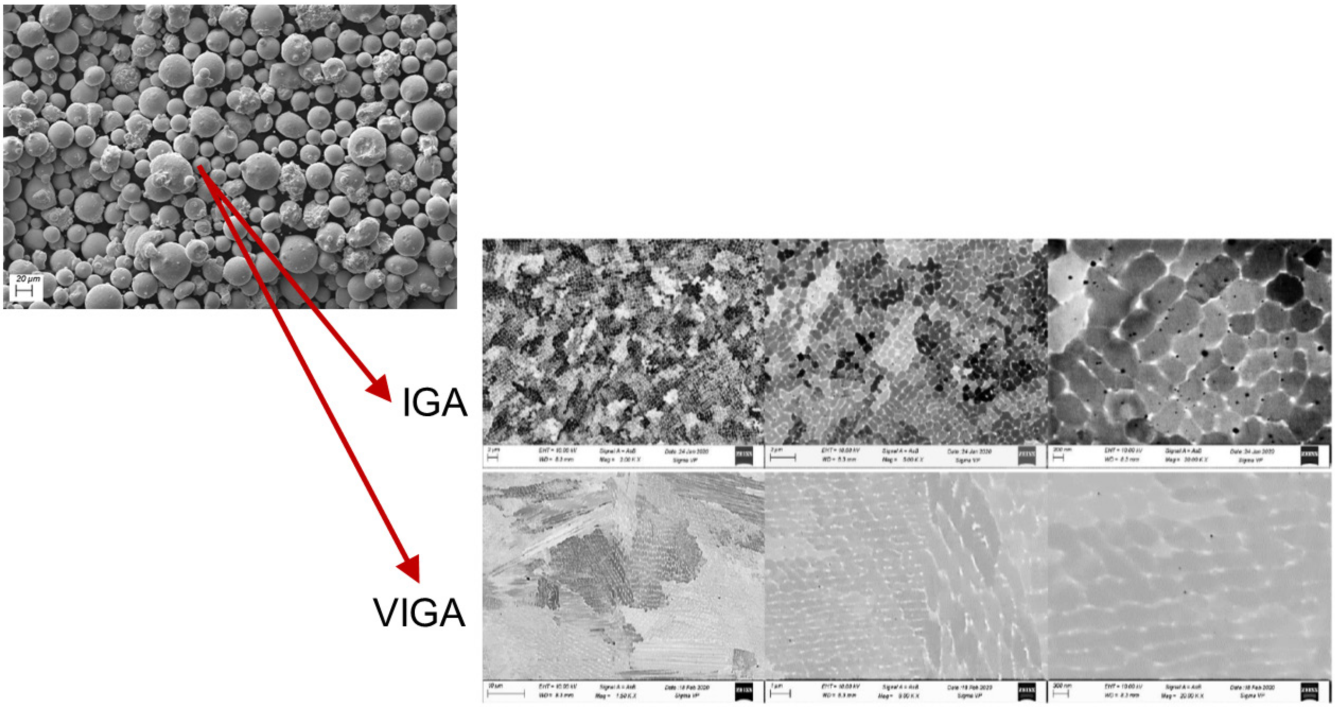


Figure 7: As-built microstructure of Inconel 718 (Source: Sandvik)

Mechanical properties of L-PBF material based on IGA powder compares well with VIGA powder route. For solution annealed and aged conditions, Yield strength and Tensile strength values are given in figure 8 with respect to room temperature and at 650 oC. In terms of elongation, VIGA at 20oC (22%) is greater than IGA material (19%), but difference is reversed at high temperature. Impact toughness of VIGA material (29 Joules) is superior to IGA material (17 Joules) in vertical direction, but similar in horizontal direction ~16 Joules). Fatigue and creep performance of VIGA powder likely to be superior to IGA powder

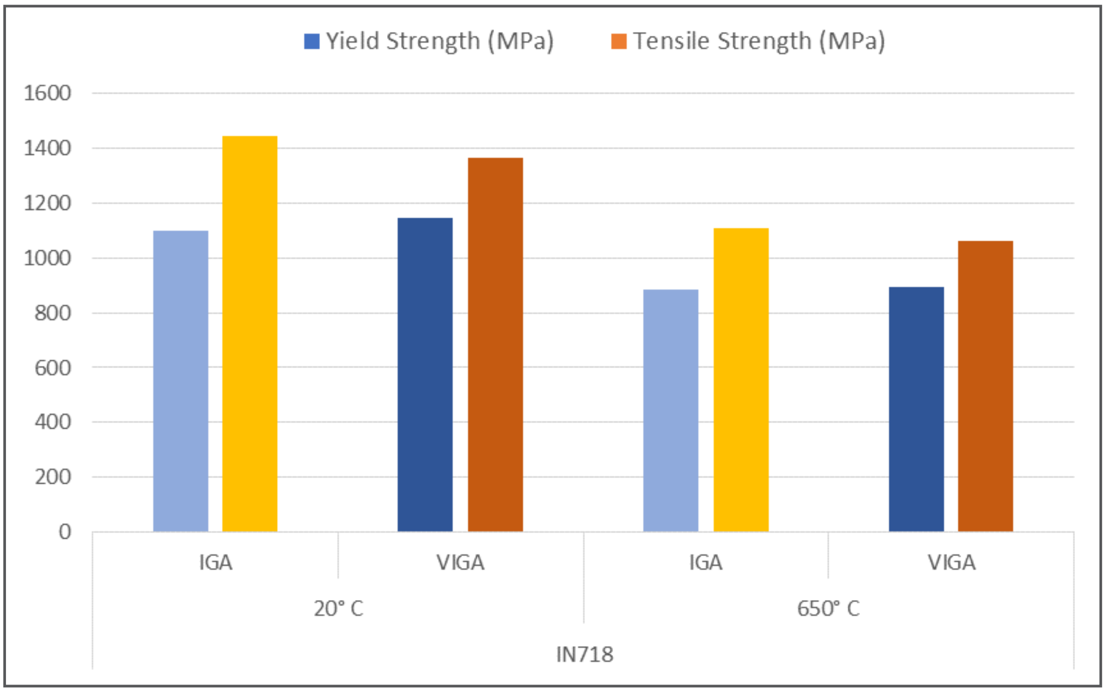


Figure 8: Mechanical properties of Inconel 718 in vertical direction (Solution annealed and aged)

H-X alloy

H-X alloy, or Hastelloy-X is a high-temperature nickel-chromium iron-molybdenum alloy with good oxidation resistance and strength. It is used for components such as combustion chambers, afterburners and tail pipes in aircraft and land-based gas turbine engines, fans, roller hearths and support members in industrial furnaces, as well as in nuclear engineering. In case of AM, cracks in the microstructure can be observed if the process parameters and the composition are not optimised. These crack formations are often due to presence of Manganese and Silicon (Figure 9).

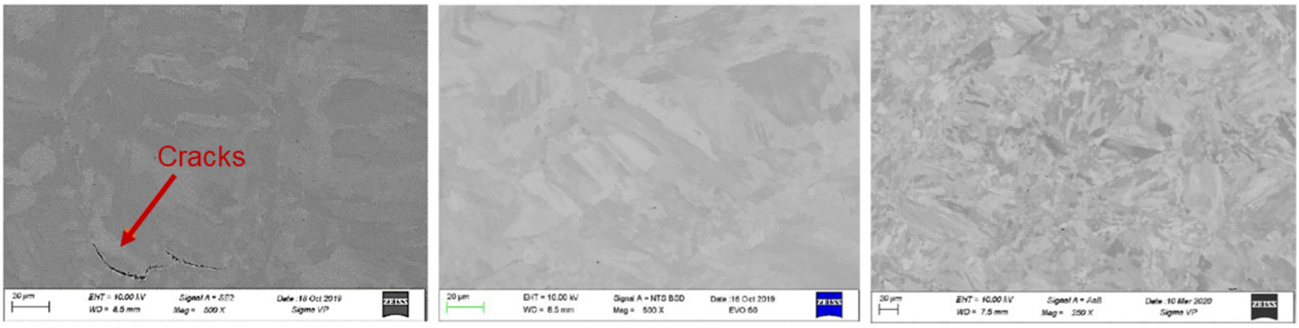


Figure 9: Microstructure of H-X alloy, as built – IGA standard composition (left), IGA optimised composition (middle), VIGA optimised composition (right) (Source: Sandvik)

In terms of mechanical properties, optimised composition significantly reduces presence of cracks. Elongation is comparable between IGA & VIGA powder routes around 33% and it is enhanced by heat treatment. High impact toughness both for IGA and VIGA powder are possible and a good high temperature performance for strength at 850 oC is achieved by VIGA (Figure 10).

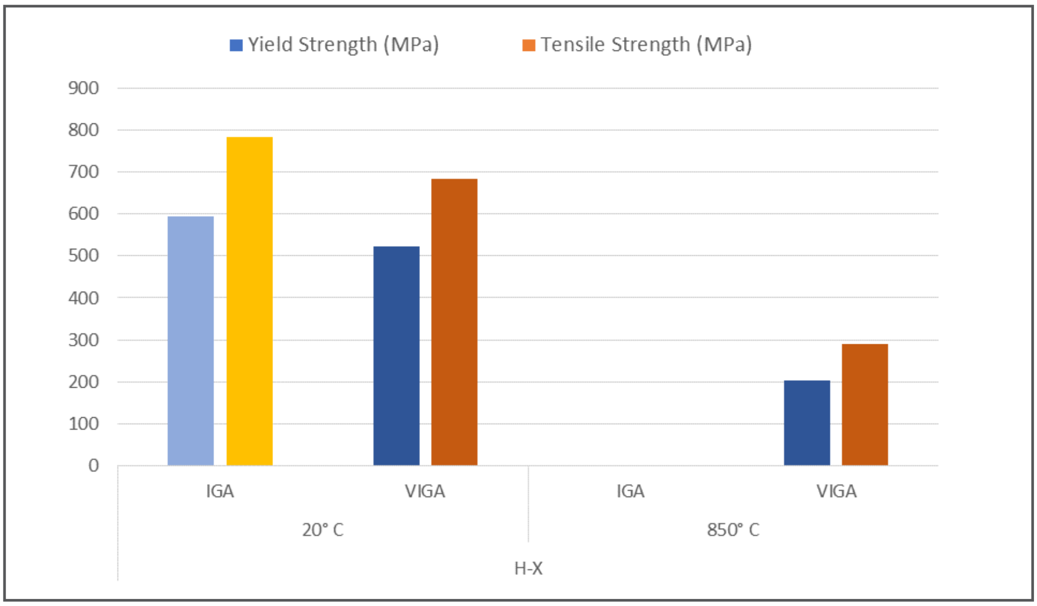


Figure 10: Mechanical properties of H-X alloy in vertical direction (Source: Sandvik)

Ti6Al4V

Ti6Al4V is a titanium alloy with high strength, low density, high fracture toughness, excellent corrosion resistance and superior biocompatibility. Most important aspect of Titanium to take care is that it attacks and combines directly with many nonmetals, such as hydrogen, the halogens, nitrogen, carbon, boron, silicon, and sulphur at elevated temperatures. Therefore, EIGA and plasma atomisation are appropriate powder production methods for Titanium alloys where any contact during melting and spraying phases of atomisation are eliminated. Regarding particle size, flowability, Oxygen and Nitrogen content levels both processes have similar values. (Table 2)

Powder type	Flow time 50g (s)	Size by laser (µm)	O (ppm)	N (ppm)
EIGA	38	d_{10}=19.4 d_{50}=33.1 d_{90}=50.8	1090	165
PLASMA	30	d_{10}=21.7 d_{50}=34.0 d_{90}=45.4	1100	100

Table 2: Characteristics of TiAl64V powder under different production processes (Source: Sandvik)

Plasma atomized and EIGA type powders have similar yield strength values. Impact toughness of EIGA powder is higher than plasma type and this is improved particularly by HIP (Figure 11). Elongation is around 15% which slightly increases in case of increased thickness layer. This may bring in the advantage of reducing production time but suffers from higher surface roughness.

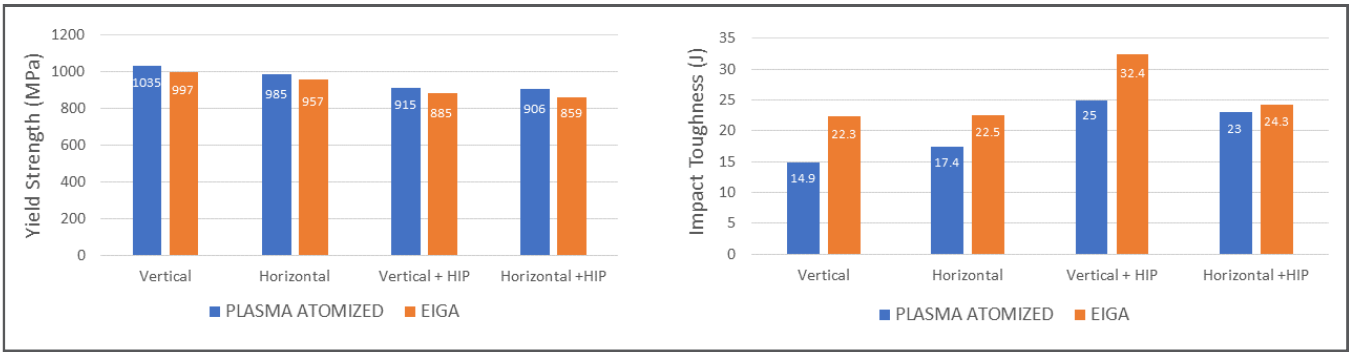


Figure 11: Mechanical Properties of Plasma atomized and EIGA type Ti6Al4V at 30µ (Source: Sandvik)

CONCLUSIONS

Certain gas atomisation processes introduced a clean induction melting technology optimised for AM in terms of powder size ranges, modified compositions, and process parameters. Today there are many different types of AM powders available for aerospace applications in the market, but there is still long way to go for the development of new alloys with specific properties optimized for better performance, lightweight structure and longer life cycles. Scientific research and development is important to achieve such progress that leads to an industrial application in a very short period. The WorldPM Congress of 2022 in Lyon-France this October will be the main meeting point for industry experts, researchers and academicians working on AM. Aerospace will be one of the hot topics in the technical sessions, Industry Corners and Special Interest Seminars during the congress that needs to be followed by all related parts from the industry and the academia.

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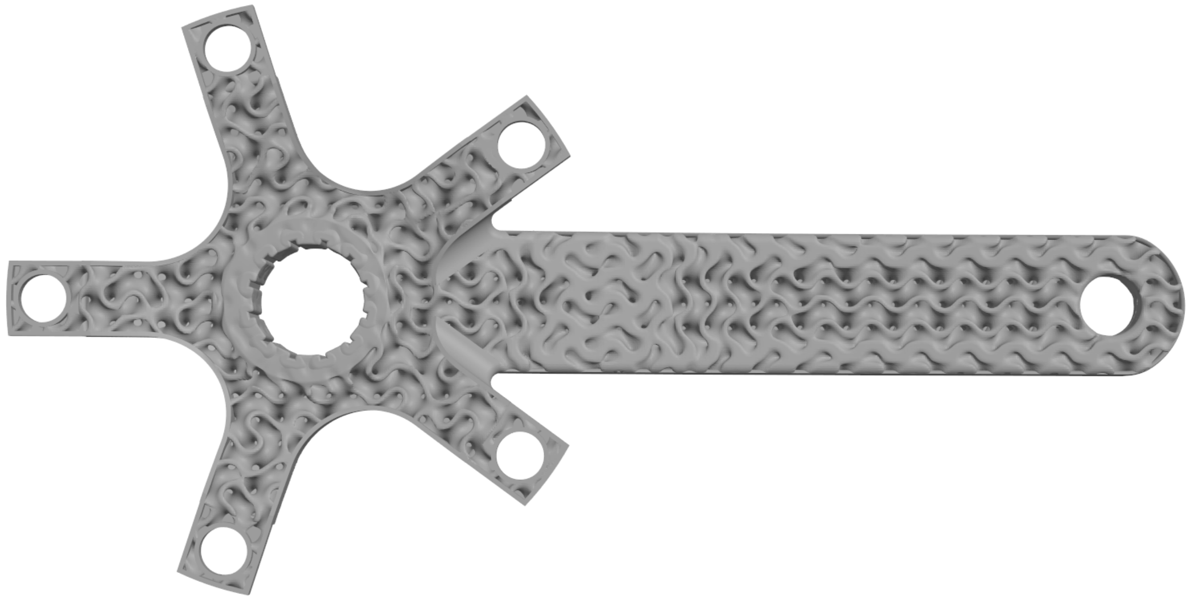


Figure: Infill Optimizer result

SOFTWARE

4 SOFTWARE STRATEGIES THAT CAN BE EXPLORED TO ENABLE LIGHTWEIGHTING WITH ADDITIVE MANUFACTURING

How many times have you seen the word "lightweighting" used next to "additive manufacturing"? When one looks beyond the buzz that this combination of words might create, we'll come to realize that this manufacturing concept involves value equations for specific types of parts, which can lead to improvements on existing products, new business models and new markets.

"Doing more, with less" has always been (and somehow still is) the primary purpose of lightweighting – a manufacturing concept that requires to leverage a wide range of methods to make industrial parts and products weigh less while retaining or improving their technical and mechanical characteristics.

Interest in this manufacturing concept started with aerospace companies that were looking to decrease part size, part count and part weight. At the time, the idea was pretty simple: every gram removed from the weight of an aircraft equates to a reduction in fuel. In another area, they saw that reducing part size for satellites could provide more space to add battery power, thus augmenting the amount of time the satellite could remain in space. Over time, R&D teams have explored the advantage of this concept in AM for other applications and industries, and found out that the benefits in terms of **materials, performance, costs, and manufacturing lead time** can also be of paramount importance.

The article below aims to understand **the basics surrounding *"lightweighting of parts using AM"***. With a key focus on the software standpoint, the article will discuss the decisive factors that lead to lightweighting of parts, as well as the software strategies that could be explored in this process.

The decisive factors that may lead to lightweighting of parts

Let's note that *lightweighting* is primarily often understood as the removal of material from an assembly or part to **reduce its weight**. In theory, that's exactly what happens. That's also the reason why, an emphasis is usually laid on "material reduction" and/or the replacement of some materials by other materials which are lightweight or which can deliver incremental gains.

"It is possible to reduce the overall weight of a part by selecting materials with a higher specific strength. For example, if we compare a stainless steel, an aluminum alloy and a titanium alloy, the higher specific strength of the titanium alloy will enable the use of less material to achieve the same performance level", **Rhushik MATROJA**, CEO & Co-Founder of software company Cognitive Design Systems notes.

This focus on "materials" therefore impacts the design of the part that should reflect how the fundamental design changes operated help to minimize material consumption, and eventually build time.

This need for reducing weight using the right material is often addressed alongside another pressing issue: ***waste***. While it increasingly raises questions on how sustainable the production process is, it also raises a number of challenges that are worth considering at the design level. That's in any case, what **Rhushik MATROJA** explains:

"Since lightweighting of any structure will impact directly on the mechanical performance of the part, it should be done keeping in mind the mechanical performance of the material.

Manufacturability is one of the most influencing factors for lightweighting. One can have the most lightweight and performant theoretical design, but this design becomes useless, if it is not manufacturable.

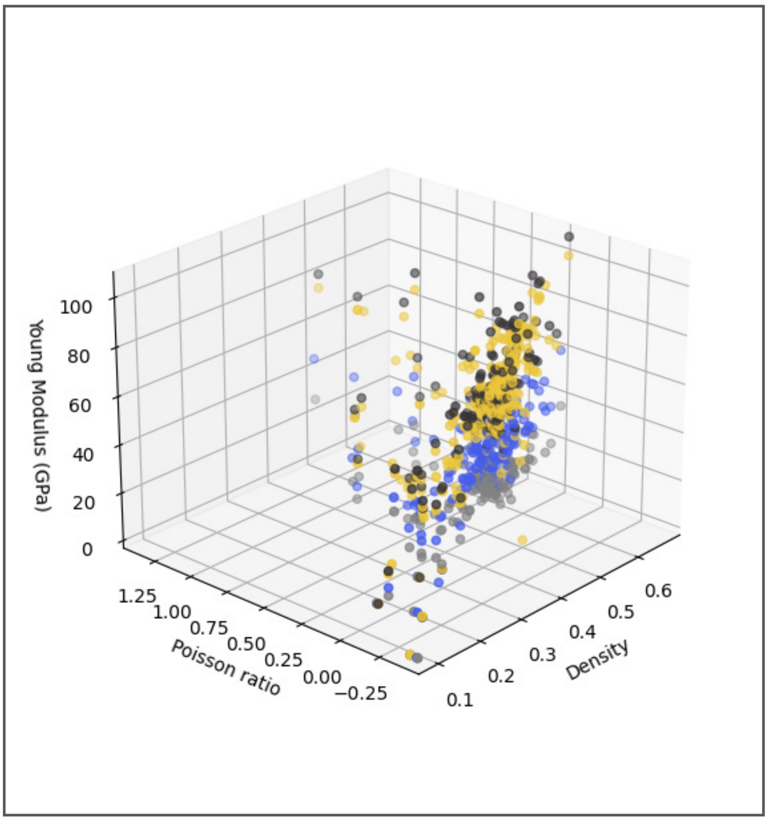
Another important factor is the cost of the part. If the lightweighted part using topology optimization is not well designed, then there will be additional costs for the removal of excessive support structures and for the added surface treatment. On the other hand, printing lattice and TPMS structures could increase printing time which leads to increased price of the part".

Software strategies at the heart of lightweighting

It's been two decades that manufacturers have been leveraging Additive Manufacturing but advancements in lightweighting of parts have only been seen recently with the utilization of new software strategies designed to address this challenge.

One of the first software strategies often explored at this level is **topology optimization**. The capability to optimize part topology towards stiffness or strength targets based on Finite Element Methods (FEM) enables purposeful lightweight design of parts. This design strategy optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints.

The **use of lattice or TPMS infill structures** is another interesting method to explore. These are hybrids of solid material and empty space that are created in such a way that they dictate the mechanical properties. Using intelligent lattice structures can help explore interesting thermo-mechanical properties. *"Knowledge about the performance of those kind of structures is highly critical. Design and simulation processes are required to obtain insights on the performance. Cognitive Design Systems has created a large database of such meta materials with their mechanical properties. Our tool "Infill Optimizer", which is part of our additive software* ***"Cognitive Additive"****, intelligently places such structures based on the stress path to reduce the overall weight without decreasing mechanical performance"*, Matroja explains.



Legend: Light weighing structures such as lattice, also bring additional mechanical properties such as shock absorbance. In the image below, you can see such structures applied on a rock-climbing helmet design.

According to Matroja, usually, topology optimization is best suited for powder/resin-based technologies, while the infill strategy works best for FFF or DED processes.

Part consolidation is a strategy that requires solid expertise and ability in bringing several parts into one. If well designed, the part can deliver an improved functionality. A few years ago for instance, Airbus Defence and Space and 3D Systems, developed the **first air-worthy metal printed Radio Frequency (RF) filter**, tested and validated for use in commercial telecommunication satellites. RF filters are traditionally designed using standard elements such as rectangular cavities and waveguide cross-sections with perpendicular bends, with shapes and connections dictated by standard processes such as milling and spark eroding. Typically, cavities for RF filters are produced by machining two halves that are bolted together, increasing weight, adding assembly steps and extra quality checks. Using **CST MWS software**, a 3D electromagnetic simulation tool, the 3D Systems team developed a depressed super-ellipsoidal cavity to channel RF currents and reject out-of-band signals. The design was driven by pure functionality, and not dictated by manufactu-rability and resulted in a single-build part that was faster to produce, reduced production costs and reduced weight by 50%.

Conformal ribbing comes next. The technique is very prevalent in aerospace. According to software company nTopology, whether built from polymers, metals or composites, conformal ribbing aims to enable thinner walls while improving buckling resistance.

New software solutions based on artificial intelligence enable design engineers to "program" algorithms so that they take into account the various constraints of what can (and can't) be made with a specific type of manufacturing process. This way, their designs evolve and develop into something that can easily be fabricated by AM.

Concluding thoughts

The desire to leverage the full capabilities of AM to reduce time to market or save costs, inspire engineers to develop alternative part geometries resulting in innovative technical solutions portrayed in final applications.

The truth is, what was once considered to be "light" is now obsolete. And this trend will continue, arguably indefinitely, as software solutions continue to evolve.

Rock climbing helmet – It is a prototype Cognitive Design Systems has developed with OberAlp an Italian mountain sport gear brand.

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You can pick up your print copy of the 2022 AM Solutions Catalogue at the following partner events:

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Ceramics UK, 29-30 June, NEC, Birmingham, UK

Additive Manufacturing Forum, 5-6 July, Berlin, Germany

World PM2022 Congress & Exhibition | 9-13 October 2022 | France

Metal Madrid – part of Advanced Manufacturing Madrid 19-20 October 2022 | Spain

AM Medical Days 19-20 October 2022 | Germany

Formnext 15-18 November 2022 | Germany

7th Military Additive Manufacturing Summit February 2023 | USA

Additive Manufacturing for Aerospace and Space Conference February 2023 | Germany

Additive Manufacturing Strategies | Q1 2023 - Date to be confirmed - | USA

credit: Helene Cascarinod

ADDITIVE MANUFACTURING SHAPERS

CONSUMER GOODS INDUSTRY : 3D PRINTING IS AT THE HEART OF THEIR BUSINESS

It's easy to see glasses, shoes and bikes as top applications in the consumer goods industry, but there are more…And what's even more interesting is that sometimes, the founders do not necessarily always have an engineering background. In this edition of "summer specials", we shed light on three businesses that rely on 3D printing to thrive:

1. Wyve, the 3D printed surf

Surfboard shapers have had cut boards from foam blanks for over half a century. Several companies are now seeking new alternatives for building boards that reduce environmental pollution. For French company WYVE, 3D printing has been salutary in their quest as the company relies on this process to design and produce surfboards that are more environmentally friendly. The journey started with Léo, Sylvain and Mylène, a group of friends – engineers by training and passionate about surf.

"By buying traditional surfboards, the surfing community inadvertently supports a process which uses petrochemical materials and generates toxic waste," **Wyve states**. *"Whether in the local small shaper's warehouse or in the famous Californian factories, for the last 60 years, polyurethane and polyester have been polluting our air and oceans."*

A local manufacturing and distribution model

As engineers, digital modeling and optimization have been part of their training at an early stage, but starting with prototyping their first surfboards helped them to gain solid expertise in 3D printing. At the manufacturing level, the company leverages the FDM process to print its hexagonal cores from PLA, a bio-based recyclable plastic made from fermented corn starch. The manufacturing process follows five steps:

- Definition of the adequate surfboard outline thanks to the company's data optimizing software, based on shapers' knowledge, measurements, surfing habits and goals.

- Optimization of the honeycomb pattern, thanks to Computer Aided Design (CAD) to match high performance criteria.

- 3D printing of the core of your surfboard with bio-plastic. To limit its emissions profile, the company pledges to gather materials and manufacture boards on a local basis.

- Glassing of the hollow 3D-printed core with fiberglass and a 50 % bio-based resin (ecoboard gold label), with a final hot coat to make it shine.

- Carboard eco-packaging for a safe and eco-responsible transport.

So far, Wyve is surfing well on the road of success as it recently secured € 1.1 million. With this funding round, the team will continue R&D to produce high-performance and eco-designed boards in line with the professionalization and democratization of the practice; grow their local manufacturing micro-factory by combining the best of craftsmanship and technology; accelerate their commercial development and grow their team.

2. The Future of Jewelry (TFOJ)

"Life takes us to unexpected places sometimes. The future is never set in stone, remember that". These words from the writer **Erin Morgenstern** could apply to so many routes in anyone's life, but today I feel that they really embody the creation journey of TFOJ. We first heard about sisters **Janine** and **Casey** Melvin in 2018 as they were introducing a custom 3D printed jewelry line and **BEZEL**, an ecommerce mobile application – when in fact, they had been training to become attorneys.

"We never had any plans to become entrepreneurs or start our own business", **Casey Melvin** told 3D ADEPT Media. *"In 2016, my sister and I both had just finished up our first year of law school in Ohio and because we had worked in the law for a few years before we entered law school, we wanted to take advantage of that summer as our last opportunity before the real world hits and you have to start studying for the bar exam to become a certified attorney. And you need to start lining up a job for once you become accredited.*

So this first summer, we decided we wanted to study abroad. So we both applied and were accepted to a comparative law program in Oxford, and this was the first time that we had ever studied abroad -- or really traveled anywhere outside of the United States. So we were really, really excited for it. It was the summer of 2016 and the first day we actually touched down in London, before we traveled up to Oxford, it was the day of the 'Brexit' referendum. So it was just…like absolute chaos, and just… really a crash course in geopolitics of the region. So, we actually had a few field trips, we went down to Westminster Abbey and we basically got to see some really interesting things in real time."

One thing led to another, the sisters found themselves in Mallorca, Spain looking to buy a souvenir that would help

Casey Melvin on the right and Janine.

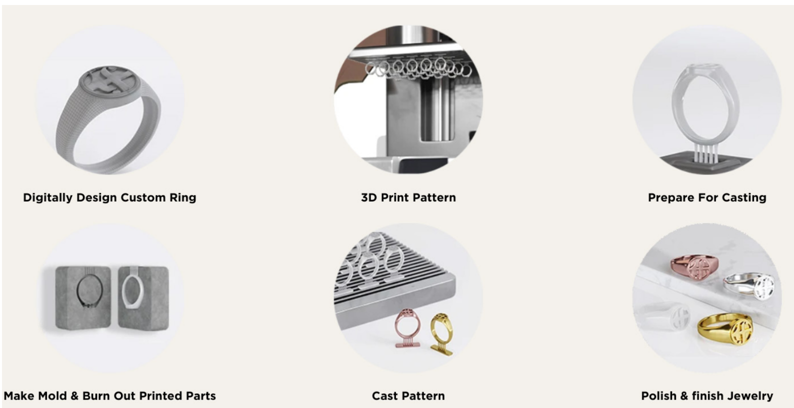
them remember the bond they have deepened during this journey. Given the fact that they were meant to become lawyers, a standard jewel sounded more appropriate, a jewel that was not obnoxious and that they would easily wear every day. It turns out that the plain **14K gold Signet Ring** that raised Casey sister's interest was too big on her – yet a perfect fit for Casey. The latter thus bought the ring for her and back to Ohio, started doing research to find a similar plain gold Signet Ring for her sister. Fortunately, she didn't find anything, and together, they decided to look for other ways to bring this product to life for her – and potentially for masses. That's how THEFUTUREOFJEWELRY came to be.

Today, the brand aims at simplifying the creation process of jewels – making it easier, affordable and accessible to all. To do so, they have created a platform that requires no advanced skill set to create one-of-a-kind designs, select a material, receive an instant quote, and have the product delivered to the doorstep. As you may guess, only 3D printing can be the ideal production candidate in such tailor-made processes.

The design and manufacture of one-of-a-kind pieces in sterling silver and 14K gold

"THEFUTUREOFJEWELRY holds no physical inventory, 3D printing and casting each piece to order from a 3D CAD file of the ring generated algorithmically on the backend in 155 distinct ring sizes" Casey Melvin told us.

The interactive 3D ring design web application works equally well on a phone, tablet or laptop. It enables users to design and manufacture jewels in sterling silver and 14K gold. Advanced 3D printers based on **DLP technology as well as casting equipment** are at the heart of the manufacturing process. According to TFOJ's spokesperson, this 3D printing process where we 3D print into a wax resin enables to deliver highly detailed prints and the best surface finish. 3D



printing serves *"for creating the 3D printed base of the ring"* and with **investment casting process**, *"we'll cast it into the selected metal-- .925 Sterling Silver or 14 Karat gold"*.

Looking back, Melvin recognized that building out the team of people with the very specific skill set needed to develop these key innovations was challenging. This is completely understandable when we know that they are bridging the digital-physical divide while addressing the pain points relating to online jewelry customization, automatic size generation, 3D modeling, and integrated supply chain.

Moving forward, the biggest challenge the brand will have to overcome is **changing the customer mindset**. People are so used to just walking into a jewelry store and picking from what exists already. Their growth journey will therefore focus on education, educating the customer about the fact custom pieces are not necessarily out of their price range; educating the customer about the fact they can finally have a product designed and made by them, that does not require a highly skilled master artisan.

3. Little You

Unlike other businesses, **Christina Guo** – the founder – was committed to bringing 3D printing technology into the realms of the children's toys market from the very beginning, as she believes that cultivating creativity at an early age is more critical than ever. To do so, she developed an application where children can now design their toys as per their desired features.

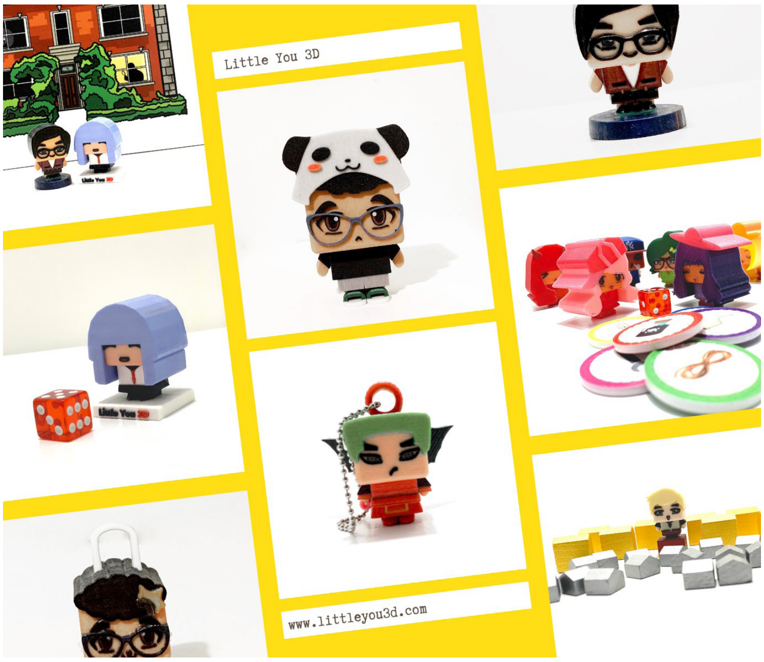
"The company has spent a year on development and research before launching the product. At first, we validated the market with 100 one-on-one interviews with our target market aged 12 to 18 and survey research with more than 1,000 kids. After we launched our website, we conducted ten user interface interviews with our target customers, and the feedbacks were majorly positive. After validation, we started building the product", **Christina Guo** told 3D ADEPT Media.

Little You ambitions to help children develop social skills and pride from showing their real-life creation to friends and family; feel represented with over 800 templates that allow them to choose skin color, outfits, facial expressions, eyewear, etc. and feel confident in their ability to do anything.

The user-friendly platform that allows children to create real-life anime figures and characters using 3D printing

Customization is at the heart of the creation process here. The "Little You" application supports more than 800 templates with more than 1000 creations giving way to the endless imagination of kids and students.

Toys are made of different durable materials like glass fiber composite from **Palitra** (Used to be Rize), acrylic resin from **Mimaiki**, and full colour sandstone from 3D Systems. These materials are durable and safe for hands-on play for young kids.



"Our goal is to build an eco-friendly business and accelerate the 3D printing industry by offering 3D printed green products made from recyclable materials. Our game is free to play and the price of a 3D printed toy ranges from $15 to $100 depending on the complexity and size of the final product. To download the obj file and print at home, we charge $10 per model. Little You has established connections with 3D printing suppliers that will fulfill all 3D printing orders that the company receives within 5 business days. These will be printed on demand and delivered to customers. Shipping within North America take about 1 to 3 days" Christina Guo states.

The next step for the company is to bring its application to classrooms through partnerships with schools. "We have planned a series of activities that you can use for your students as part of the virtual classes that help them enhance their creativity. Other activities involve the technology of 3D printing which will allow your students to design and create 3D characters with customizable features. These activities will help the students tickle their minds and bring out their best in the form of their own created 3D characters", Guo says. If you are a school representative and you read these lines, make sure to reach out to Little You here.

Second half

OF THE YEAR

YOU CAN PICK UP YOUR PRINT COPY OF 3D ADEPT MAG AT THE FOLLOWING PARTNER EVENTS :

- AM Summit 2022 Copenhagen | 07th September
- Formnext+ PM South China | 14th – 16th September
- World PM2022 Congress & Exhibition | 09th – 13th October
- 5th annual Advanced Manufacturing Technology Conference (AMTC) | 11th –12th October
- AM Medical Days 2022 | 19th – 20th October
- Advanced Manufacturing Madrid 2022 | 19th – 20th October
- Formnext (in Frankfurt, Germany) | 15th – 18th November.

AM Summit 2022 Copenhagen

WORLD PM2022 CONGRESS & EXHIBITION

formnext SOUTH CHINA

Powder Metallurgy EXPO SOUTH CHINA

Shenzhen International Additive Manufacturing, Powder Metallurgy and Advanced Ceramics Exhibition
深圳国际增材制造、粉末冶金与先进陶瓷展览会

6th Additive Manufacturing Forum Berlin 2022

AM 101 : TIPS FROM THREE INDUSTRY EXPERTS TO REDUCE COSTS AND LEAD TIME IN 3D PRINTING.

Engineers and designers have been manufacturing prototypes for decades, but the tools, materials and processed used to create them continuously evolve. The truth is, in order to close the gap between as designed and as manufactured, there is a wide range of processes that need to be understood, mastered and optimized. Sometimes, achieving satisfying results in an AM production remains very dependent on the holistic experience of users as cost factors, efficiencies and design rules do not (always) directly translate from one project to another. However, it never hurts to learn from others' experience. In this opinion article, we have decided to collect insights from three experts who have built up expertise in various sectors of activity: space, R&D and pedestrian management systems. Today they share a few tips they wish they'd known sooner in their 3D printing journey.

Sabrina Kerber is a space architect and analogue astronaut. She currently works as UAV Pilot at Avy and was part of a lunar simulation at the renowned HI-SEAS habitat, where she acted as crew engineer. She has always been working on leveraging the benefits of additive manufacturing for extra-terrestrial habitation.

*"My favorite tip on optimizing the additive manufacturing workflow and ensuring a cost and time efficient process is 'Get to know your machine!' Invest time in learning anything you can about your hardware and software, but also about your specific use case and the exact environment you will be operating in. This might cost you some hours and material in the beginning, but in the long run, really knowing the quirks of your tool will result in a streamlined process with optimal results. Every 3D printer is a little different; every environment has a different set of parameters – the outcome of your prints can be influenced by the altitude you print at, the humidity and temperature and how well you are able to control these factors with your machine. At the same time, every use case calls for different aspects and results. Make sure you know where the weak points of your print are – metaphorically speaking, as well as quite literally. In which areas can you save on time, which points will need special attention during the design and print process? **I'm investigating the advantages of additive manufacturing for space exploration**, the most important of which is the possibility to reduce payload and lower the necessity for resupply missions – both of which will result in a more time and cost efficient mission. However, in an isolated environment, such as a space mission or analog simulation, successfully using 3D printing heavily relies on the crew knowing every detail about the workflow of their specific machine, as well as what to expect of it in such an extreme environment."*

Juan Carlos Cruz Robles has spent the last 10 years in R&D of additive manufacturing technologies. Out of those years, 6 have been dedicated to developing hardware and material process development for VAT photopolymerization technologies at 3D Systems. Most recently, he made a transition to PPG, where he is bringing his additive experience to strengthen their capabilities. Below, he points out **an important factor to increase productivity for VAT photopolymerization AM technologies:**

"There are several approaches on how to be as efficient as possible on a workflow when using any of these AM technologies. A big part of the workflow is post-processing. Many people think speed in 3D printing is the bottleneck. However, most of the times, a functional part in any AM technology must be subjected to a post-processing cycle, which sometimes can even take longer than the printing step. Therefore, it is crucial for an efficient AM process to consider the potential bottlenecks in the post processing cycle to get as much throughput as possible.

For VAT photopolymerization post processing especially, cleaning is key to not only remove excess of resin but also sometimes to treat surfaces from not getting sticky. Depending on resin viscosities mostly and cleaning solvents, the cleaning cycle can increase overtime if the cleaning solvents are not monitored constantly. Typical cleaning solvents are IPA, TPM or a combination of both. A hydrometer is recommended to constantly check the saturation of the solvents and make sure a threshold is not reached. Otherwise, the cleaning process will just take longer and eventually not work at all."

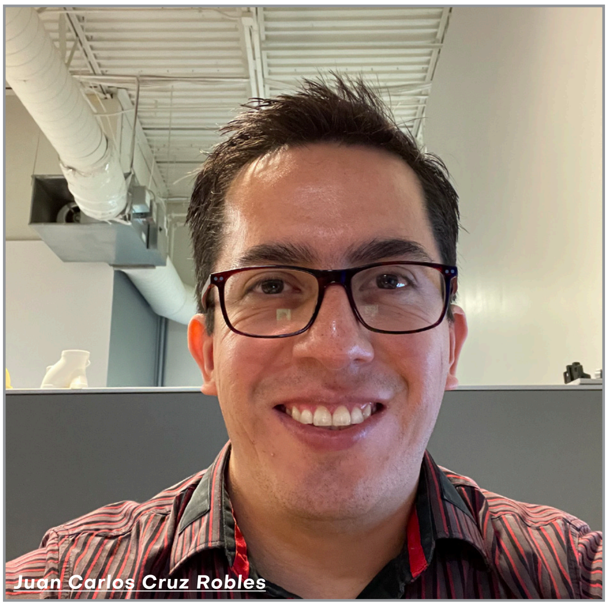
Whatever AM process you use, there is a great chance that post-processing remains one of the most time-consuming stages of the manufacturing process. Some technologies require less post-processing than others, but all 3D printed parts require a certain degree of post-processing. It can be interesting to know the variety of stages that 3D printed parts have to undergo under this big umbrella term, but what will help you reduce labor time and costs, is to find the ones that can be automated.

Josep Maria Salvador Morón is a designer and technical manager at DLIMIT, a company that has over 15 years of experience in the manufacture and distribution of pedestrian management systems.

*"If you want to optimize your 3D printing workflow, I always recommend a **little planning**. It's super important to know how long the parts take to print. If I will have enough material for a particular print or if the part will be finished tomorrow when I get to the office. These types of questions lead you to answers such as, it is sometimes better to print fewer pieces and be able to make two prints within your working day, than to fill the surface completely and have your print stop at 19:00, when there is no one in the office to make a new print.*

On the other hand, if we are talking about a large number of parts to be produced, there are technologies and 3D printers such as BCN3D's IDEX technology that prints two identical or symmetrical prototypes at the same time, optimising production times. For example, it is not the same to print 40 units on a printing surface with one extruder as it is to print 20 + 20 with two extruders working simultaneously. It is the same 40 units, but we have reduced the production time by half.

At the design level, it is always advisable to reduce the size of the parts as much as possible in order to save time and material. Sometimes, internal departments tend to oversize parts to give them more mechanical consistency. I recommend trusting the technology, without asking for the impossible. It may seem complicated at first, but with practice you learn a lot."


Juan Carlos Cruz Robles

So far, a few best practices for optimizing schedule that have become trending include:

· Batch multiple parts into one build.

· Print small, shorter runs during the day and large builds overnight.

· Use multiple printers to distribute the workload and increase same-day throughput.

· Use dashboards to receive alerts when a print finishes and to manage and watch multiple printers remotely.

That being said, you may read thousands of tips per day, but if you don't understand your needs and the reasons why you choose a specific AM process over another, chances are that you won't be satisfied with your results. As you may have realized, finish and details won't necessarily matter for basic concept models, while real-life prototypes may need technologies and materials designed for fine details and high-quality surface finishes.

And you, what 3D printing process do you use and what's your tip to optimize your production workflow?