Additive Manufacturing

Build bigger: The rules and challenges of building large metal AM parts
Introduction

As metal additive manufacturing (AM) technology has matured, the size, scope and scalability of its part-production capabilities has expanded at a rapid pace. By leveraging powder bed fusion technology to create large, manufacturers are able to achieve significant cost reductions at the same time they enable new product innovations in the aerospace, energy, oil & gas, marine, automotive, and general engineering sectors. A particularly complex assembly that required dozens of individual high-quality parts can be produced as a single large piece with metal AM, reducing production time and overall time to market. Fewer welds and connectors can also be an impactful factor in industries such as aerospace, where saving each kilogram is crucial, while the single-process approach offers transformative time and cost savings for many parts when compared to competing processes like investment casting.

However, building larger parts presents unique design and production challenges, even when compared to the use of metal AM for small or medium-sized parts. A robust and reliable machine platform, a complete powder management solution, optimized AM-oriented part design, proven build parameters and efficient scanning strategies are required for the highest quality and productivity, particularly in the context of days-long build times.

To make the most of this cutting-edge technology, manufacturers need an effective partner that can provide the right combination of hardware, software and expertise to enable them to produce large AM parts at scale, even in highly regulated industries.
Challenges

The printing process

From the perspective of designers, engineers and end users, the expanding capacity of metal AM equipment is a revolutionary development. Large parts lose all of the extra weight created by joining processes and assembly. Topological optimization and complex internal features allow for expanded functionality for many components. Furthermore, as a much faster process than the weeks-long workflow required for most large assemblies, research and prototyping can happen at an accelerated rate...

However, while small and medium-sized metal AM part production is quickly becoming a well-understood process, AM technology has only recently allowed manufacturers to build larger parts. This has naturally required larger build areas, but many other factors are involved in cost-effectively producing large metal AM parts. For example, producing the largest parts at the pace necessary for sustainable per-part costs has required the creation of multi-laser configurations with overlapping scanning areas to dramatically reduce build times.

Even with the required equipment, building the largest parts involves overcoming numerous process challenges. The biggest parts can take 10 or more days to build using nearly half a ton of additive-grade metal powder – and as the amount of powder grows, the build plates get thicker and the parts become much more challenging to manage manually. Dedicated, industrial-scale equipment is not optional, but required to handle the powder, preserve its original quality, and fully recycle it after a build cycle.

The build volume drastically increases with larger build envelope, leading to much bigger powder management challenges.
Effective powder management systems help manufacturers fully and safely utilize these reactive, high-value materials while preventing degradation. Additionally, a consistently low-oxygen atmosphere in the build chamber and a fully enclosed powder system can further ensure powder quality. This is especially important as degradation will lead to significant – and costly – material waste.

Given the length of time required for building these larger parts, process reliability is a key factor. The laser powder bed fusion process involves managing and dispersing the high levels of energy deposited on the powder bed to avoid stress accumulation that can lead to deformations of the part and the build plate. Parameters ranging from gas flow velocity and scanning strategies to support structures and printing order must be carefully considered for optimal process security.

Without a proven process, large AM parts are at risk of failure through a variety of factors. Iron-based alloys, for example, are particularly prone to spattering issues, and these problems grow with the thickness of the layer. High process emissions, such as smoke or fumes, can even create excessive porosities or, in the worst cases, a job crash. A wide range of issues can also lead to powder lumps, which can quickly result in scrapped parts. For these reasons, AM machines must be well-maintained and accurately calibrated, especially when they utilize multi-laser configurations.
Because of the novelty of the process, however, manufacturers deploying metal AM technology in their facilities for the first time will often be acting as pioneers as they establish optimal parameters for large AM parts. This can be especially difficult due to the lengthy build cycles and system-critical nature of many of the parts that are best-suited for 3D metal printing, as scrapping a single part can represent a major annual loss. Nevertheless, to maximize throughput, manufacturers need to be able to consistently reach the highest build speeds while maintaining part quality.

For this reason, manufacturers generally choose to partner with an experienced OEM to develop processes for large AM parts. Due to working across numerous industries – and developing the 3D metal printing equipment itself – these OEMs are often among the best sources of knowledge about the part design, orientation, support, build and scanning strategies needed for effective large AM part production. With this kind of knowledge and a fully tested and validated set of process parameters, manufacturers can avoid costly trial and error to focus on producing each part right the first time.
Post-processing

From additional machining and inspection to the final separation from the build plate, virtually all large AM parts will require post-processing. As the cost-effectiveness of these parts depends on process simplification when compared to previous strategies, an efficient, fully interoperable workflow that can maintain part reference points throughout production is critical – especially for the tight tolerances involved in the demanding industries where metal AM technology is applied.

A key consideration is separating the part from its build plate, a universal post-processing operation – in some situations, the built part must also be heat treated and machined before final part separation. Conventional solutions are difficult to utilize in this context; vertical-cut EDM equipment rarely can accommodate the large and heavy parts involved, for example. Many AM processes previously used bandsaws with the expectation of finishing the cut surface through post-separation machining, but in addition to creating workholding challenges, this process is incompatible with the nickel superalloys and other materials used in many metal AM applications.

Bandsawing and other parting-off or post-processing operations also create significant issues with heat generation. The thermal effects produced by these subtractive methods can cause microstructural changes and oxidation that damage part integrity. Of course, getting these large, heavy parts into conventional subtractive equipment can be challenging in itself, and without effective process controls, operators risk scrapping a high-value part during the final operations.

Cost-effectiveness

As state-of-the-art technology, metal AM solutions capable of building large parts are best deployed in manufacturing environments that can develop thoroughly validated processes within a holistic workflow for the lowest per-part costs. For the lowest total cost of ownership, manufacturers need systems that can scale to their needs precisely. At the same time, the system must be truly comprehensive, covering the entire production cycle to achieve the greatest productivity and ease of use.

Scalable AM systems generally require a modular design. A manufacturer may only need a single depowdering and powder cycling station to serve multiple AM machines in a parallel cycle, for example. Many previous solutions bundled all of these functions into a single platform, making it more difficult to customize for an individual manufacturer’s needs while increasing the total system complexity and the risk of fault – if one function is down, the whole system is down. Modularity also simplifies future expansion efforts, as components can be added as necessary to accommodate growth.
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Solutions

The DMP Factory 500

Featuring an industry-leading build volume of 125,000 cm$^3$ and a build chamber that maintains ≤25 ppm O$_2$ levels for superior part quality, the DMP Factory 500 from GF Machining Solutions and 3D Systems is one of the only solutions available on the market today capable of cost-effective serial production of large AM parts.

As the center of a fully modular system that includes dedicated units for powder and part management, this machine simplifies large part production and minimizes costs. This modularity also allows manufacturers to tailor their systems precisely to their needs for optimal return on investment.

In addition to its ample build volume, the DMP Factory 500 features a multi-laser configuration that allows users to maximize productivity and build speed or achieve seamless contoured surfaces. The machine’s unique three-laser optics design can use its single full-field laser for extremely smooth surfaces – without even the minor errors caused by performing contouring across laser areas – while using all three in overlapping strategies that equalize the lasers’ active workloads for optimal build times. Real-time process monitoring further allows for non-destructive quality control, leading to informed decisions on product quality.

As a result of these features, it becomes possible to overcome virtually all of the challenges created when producing large, seamless metal AM parts for the lowest total cost of ownership and per-part costs. Through its modular design, exceptional process security and simplified workflow, the DMP Factory 500 serves as a scalable solution that allows for manufacturing environments tailored precisely to shops’ application and capacity requirements.
A complete solution for large AM part production

To reduce per-part costs and achieve the lowest total cost of ownership, the DMP Factory 500 works as the center of a complete turnkey AM production solution.

**3DXpert™**

Developed to allow users to control the full AM workflow from start to finish, the 3DXpert™ software package can be used for everything from part design and support development to laser scanning strategies and post-build machining programs. For the production of large AM parts, the software’s build simulation tools allow manufacturers to perform multiple build iterations at the virtual level, ensuring that the real-world process is successful on the first attempt. 3DXpert™ even offers print strategy optimization tools that optimize the use of the DMP Factory 500’s multiple lasers with auto-balancing controls that distribute scan paths and print area merges for the shortest printing times that can be achieved given the required part quality and surface accuracy.

**System 3R pallets**

Whether used as part of an automated workflow with System 3R automation for greater productivity or manually moved between machines and workstations, the System 3R AM tooling is designed to preserve reference points for large, heavy parts throughout the entire production process. BuildPal and BuildPallet printing platforms are available in a range of sizes and materials for application-specific compatibility, while AMCarrier is designed to remain operable even in the event of limited part deformation – all of which can be easily clamped within MILL, FORM, CUT and LASER solutions.
Milling technology
The comprehensive portfolio of high-performance milling and laser machining technology offered by GF Machining Solutions covers nearly all pre and post-processing operations used in large AM part production. With 3DXpert™, these operations can even be programmed in the same software environment used to design the parts, simplifying the management of AM-specific part features like support geometry.

**CUT AM 500**
Designed around a unique tilting table that reorients even large AM parts for a horizontal-wire EDM process, the AgieCharmilles **CUT AM 500** is the fastest, most effective method for AM part separation. The EDM-level surface quality and small-diameter molybdenum wire allow for high-quality surface finishes with roughness under Ra 6 µm, which can reduce or eliminate the need for further post-processing for many parts. The machine's layout is also specifically designed for the integration of an automation-ready clamping system for consistent part reference points and the lowest risk of part damage.

**Your partner in AM excellence**
The production of large AM parts involves a truly state-of-the-art technology – many of these applications were laboratory experiments less than a decade ago – and very few manufacturers have extensive experience with these processes. Through its collaboration with customers around the world, as well as extensive in-house research and development, GF Machining Solutions can easily act as a single-source partner for AM application development and validation. This ensures that manufacturers do not need pre-existing expertise to achieve success when incorporating additive technology.

GF Machining Solutions offers a global network of Centers of Competence with applications engineers who can offer training and support for all GF solutions, including AM technology. For AM-specific support from GF, the aerospace and energy-focused **AMotion Center** in Stabio, Switzerland, offers NADCAP-accredited printing and post-processing services in addition to general AM service and support. The AMotion Center, which has pioneered many large AM processes on GF equipment and 3DXpert™ software, continues to perform large-part production on a daily basis to help prove out processes and develop the expertise necessary to help manufacturers achieve success with AM technology.
Conclusion

Bigger parts aren’t always better – but they’re increasingly necessary to meet the demands of today’s market.

Sophisticated products comprised of seamless, large AM parts are the future in numerous industries, and advancements in the energy industry, among others, are only possible due to the increased capacity of AM equipment. When large AM parts are necessary, the greatest level of cost-effectiveness requires a complete end-to-end workflow designed around overcoming the unique challenges presented by this new process – and GF Machining Solutions offers this holistic system in the form of the DMP Factory 500 and its full additive workflow solution.
Appendix 1: Rear turbine vane case study

Historically, many aerospace parts were produced exclusively through investment casting, also known as lost-wax casting. This process allows for the creation of a single crystalline structure from a wide range of superalloys, a critical factor in the production of parts intended for high-temperature environments such as jet engines or gas turbines. However, with the increased size of build chambers in machines such as the DMP Factory 500, metal AM technology has become a cost-competitive option for parts that are used outside the most extreme temperature zones.

For geometrically complex, large, seamless parts like this rear turbine vane, metal AM production has numerous advantages. Unlike investment casting, which requires expensive tooling that comes with long lead times even when handled in-house, additive processes only require programming the part and starting the job in a machine with an adequate powder supply. The in-process time is usually longer, but the building process is completely autonomous, while casting typically requires numerous time-consuming steps that must be performed in sequence.

### Rear Turbine Vane

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<tr>
<th>Technology</th>
<th>DMP Factory 500</th>
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<tbody>
<tr>
<td></td>
<td>3DXpert™</td>
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<td>CUT AM 500</td>
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<tr>
<td>Market Segment</td>
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<tr>
<td>Material</td>
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<td>Build Time</td>
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<td>Layer Thickness</td>
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### Key advantages

- Reduced lead times compared to investment casting
- Lower manufacturing costs through higher efficiency
- Better process optimization through workflow simplification
Appendix 2: IGT combustion liner case study

In view of current global trends, it is easy to see that the demand for electricity is sharply increasing. To support this growth, it is important to be able to rely on a reliable and on-demand source of energy. One of the key solutions is the use of industrial gas turbines that allow for flexible energy production complementing renewables sources. It is therefore important to continuously increase, not only the performance of the turbines but also to optimize the manufacturing process.

One of the technologies allowing this is Additive manufacturing (AM), in particular Laser Powder Bed Fusion. The use of the disruptive technology can also be a driver in the development of gas-hydrogen turbines, allowing an additional de-carbonization potential, integrating the inherent advantages of AM from the initial stages.

In conclusion, beyond the traditional advantages of AM technology, also brings improved lead time and freedom of design or performance. In the case of parts traditionally made in investment casting, we can also observe an improvement in density from using a finer microstructure and increased repeatability in part quality.

### Combustion chamber assembly

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<th>Technology</th>
<th>DMP Factory 500</th>
<th>3DXpert™</th>
<th>CUT AM 500</th>
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<tbody>
<tr>
<td>Market Segment</td>
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<td>Material</td>
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<tr>
<td>Build Time</td>
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<tr>
<td>Layer Thickness</td>
<td>60 µm</td>
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### Key advantages

- Design freedom and self-supporting geometries
- Functional integration and consolidation of parts in assembly
- Optimized part cooling through conformal channels
- Functional surface design and geometries
- High-performance materials (e.g. Nickel super-alloys)
- End-to-end manufacturing workflow
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