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The Journey to Metal Additive Manufacturing Production

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Once in a while a technology comes up that has the potential to revolutionize an industry. Even rarer is a technology with the potential to revolutionize manufacturing as a whole, and additive manufacturing holds that promise. The layer based approach to building parts has been around for nearly thirty years dating back to the first polymer machines in the 1980's, but it was rarely found outside of specialized labs in established companies. More recently the commercial accessibility to the polymer printers and the emergence of metal producing technologies has brought the technology into the public eye. However, before companies make the jump to printing their end use metal components, a lot of due diligence is required.

With great power comes great responsibility

For centuries manufacturers have primarily utilized cast or wrought raw materials produced in specialized facilities with intricate process controls ensuring consistent quality. The large capital investment required to set up a forging shop or casting foundry has limited the number of players in the market and allowed regulatory agencies to manage oversight. Additive manufacturing changes that paradigm because end part producers now have the ability to create the base material with relatively small capital investment. The big question on the minds of aerospace original equipment manufacturers is how to leverage additive manufacturing while maintaining the highest quality standards. There is no short answer to this question, but a strategic approach addressing the following areas will accelerate the process.

Material Capability

The first question asked when looking at metal additive manufacturing technologies is how the material properties compare to cast and wrought materials. The short answer is additive manufactured materials are a completely new material and need to be treated as such. There are some additive processes and material combinations that can match or even exceed wrought properties on one mechanical test, but might fall short on others. Other material and process combinations could produce material that is between cast and wrought properties across the board. Another intricacy is the fact that bulk material properties may or may not correlate to the mechanical performance of the specific geometries in a component. Due to the extreme thermal gradients in the layer based manufacturing approach, certain geometric features can have different capability than others which needs to be understood beyond basic bulk material properties. Knowing this we need to be diligent in fully understanding the performance capability of the additive manufactured material in the specific design envelope of our end use application.

Design

Many companies utilizing additive manufacturing today are at two ends of the design spectrum. Some see the technology as a cost savings opportunity over another manufacturing method and are producing the same design that they have used for years. This might provide a small economic benefit, but it is scratching the surface with regards to what additive manufacturing can do for your design process. On the other hand some stories across the news would have you believe that additive manufacturing gives you the ability to print out any geometry you want. The reality is that additive manufacturing can produce many geometries that otherwise would be impossible as long as an understanding of the productivity rules specific to the process is applied. As with any other manufacturing process, there are constraints such as build orientation, wall thickness, hole size, and surface finish that the design community needs to understand. More than ever before it is critical for designers and manufacturing engineers to work side by side to push the bounds of what can be made while still ensuring the process can produce that design. When implemented effectively on the right applications, that combination of knowledge can lead to opportunities for performance improvements from new geometries, part count reduction through combing parts of an assembly, weight reduction through computational optimization frameworks, and cost savings.

Feedstock Material

The key to creating a high quality material with an additive manufacturing process starts with the feedstock material being used. For metal processes this can be wire or powder produced to a variety of characteristics depending on the specific process being utilized including chemistry, size, density, and manufacturing method. In an ideal world the chemistry of the feedstock material would match that of the end material, but the melting processes occurring in an additive manufacturing machine can alter that chemistry. In some cases the change is small enough to keep the material within spec, but in others the feedstock material may have to be altered in order to achieve the designed chemistry in the end. Size and shape of the material also need to be optimized for the process and then controlled to minimize variation in microstructure, dimensions, and surface finish of the end parts.

Additive Manufacturing Process

Similar to the feedstock material, there are several knobs to turn in any additive manufacturing process that will impact a variety of factors. These settings are eventually combined into a build theme which is the recipe for a specific material that will determine how your parts are made. Build themes can be procured from the AM machine manufacturer or developed internally for each material to be produced. Many companies will want to optimize these build themes for speed, cost, accuracy, microstructure, or variation, and a very high level of expertise is required to understand the complex interactions between all the parameters. Once a build theme is established and material data has been collected from the material produced, it is critical to understand and control any sources of variation on a single machine and across multiple machines. Identifying all sources of variation and establishing calibration and maintenance procedures that keep those within specified limits is essential to consistent quality in a production environment.

Post Processing

An often overlooked input to a fully optimized additive manufactured part is the impact that post processing can have. After the raw additive part is built, both thermal and mechanical post processing can impact cost, efficiency, quality, and performance. The full value stream of an additive part needs to be considered by engineers from the initial design stage.

Thermal processing, such as stress relief, heat treatment, and HIP will impact microstructure and material properties. The pedigree of the thermal treatment can be the difference between parts which act like a casting, versus parts which outperform wrought material. Always consider what thermal processing steps are adding value, and which ones may not be required to meet part requirements.

Mechanical processes such as surface finish methods and machining impact the cost and performance additive parts. They may not need to be fully machined, however critical surfaces with tight dimensional tolerances and fatigue limited locations often need to be altered to meet part requirements. The most optimized additive parts consider these mechanical steps at the design stage. When the design engineers and manufacturing engineers work together, a part can be produced which meets requirements and at the same time reduces set-ups, tooling, and otherwise costly steps.

Inspection Techniques

The conventional processes for dimensional, microstructural, and defect identification can be applied to additive manufactured parts, but more unique technologies may be required for this process. With regards to dimensional inspection, if a part is designed with unique organically designed features, a structured light inspection technique may be needed instead of a conventional CMM processes. This may also change the paradigm of inspecting to a drawing and shift towards inspecting against a three dimensional model. When there are internal features which can't be measured through line of sight, some parts may require additional dimensional inspections like CT-scan. Conventional NDE techniques may be used for defect identification, however could be more difficult due to the rough surface finishes of the parts. In this case, a more detailed visual inspection may be required for surface inspection, and additionally CT-scan for internal defect identification.

Unfortunately, CT-scan can be an expensive option for low value parts, especially when a goal is to reduce cost using additive manufacturing. This warrants the expansion of in-process monitoring techniques which are being explored and adopted by external companies as well as the additive machine OEM's. With in-process monitoring techniques, the initial goal is to identify potential internal defects, eventually moving to dimensional conformance inspection as well. The ultimate opportunity for in-process monitoring is closed loop control, where the process will use the monitoring feedback to identify defects and then correct those by modifying process parameters real time.

Supply Chain

Regardless of the additive process chosen, the material, or the part, it is crucial to have a well-developed supply chain. Some companies are choosing to develop full value stream internal capabilities, which can be an expensive option for smaller businesses. More commonly, companies are looking to vendors outside to build and post process their parts. The vendors that exist in the industry have varying levels of experience, so in addition to evaluating their physical capabilities list of machines and equipment, it is important to ask questions with regards to their additive manufacturing standard practices including calibration, maintenance, build traceability, powder input and testing, and quality standards. An additive part is only as good as its inputs, so poor powder feedstock, machine calibration procedures, and traceability may lead to low quality parts, even if built on the same machine platform as another vendor.

Harness the Potential

While the road to producing high quality metal components using additive manufacturing is more than pressing the print button, it is very doable when these seven areas are strategically addressed. Understanding the complete value stream from design and feedstock material through additive manufacturing, post processing and inspection is critical to ensure the end product meets the dimensional and mechanical requirements of the specific part. When applied to the right applications, industries around the world are going to realize cost saving and performance increases as they explore new designs that additive manufacturing enables unlike ever before.