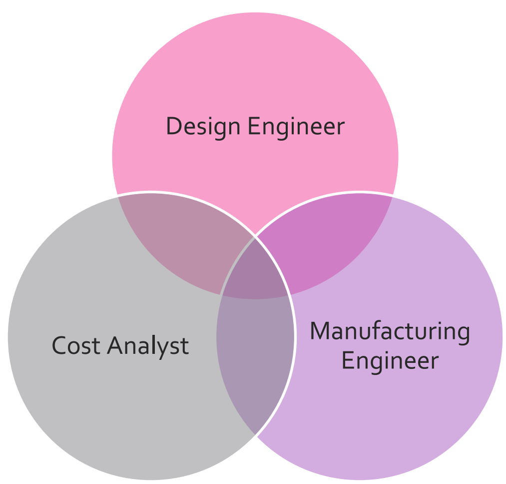
ADDITIVE MANUFACTURING DESIGN: CONSIDERATIONS FOR THE FULL VALUE STREAM

By
Caitlin Oswald
860.729.9642
COswald@LAIco.com

INTRO

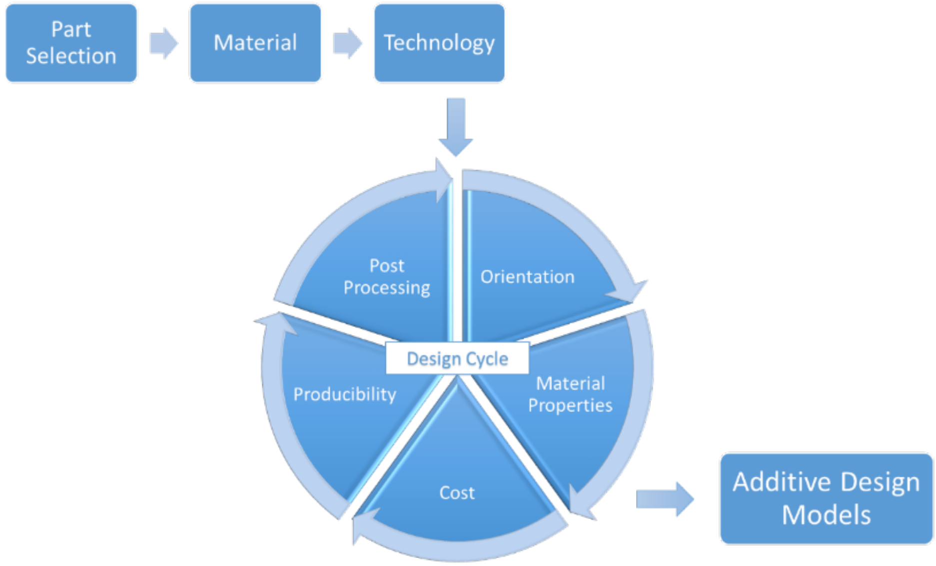
As additive manufacturing continues to mature and begins to transfer from a fad to a robust production process, complimentary methods of designing for additive manufacturing need to develop in parallel. Today the majority of design engineers were trained under conventional education methods of subtractive manufacturing. Switching that paradigm will take more than adjusting a few rules, but an evolution in education and practice. When designers are urged to be creative and innovative, the design space box which meets fit, form, and function requirements expands exponentially. This new idea of starting from nothing instead of starting from a block of material, while overwhelming for some, becomes limitless for students and young design engineers without decades of strict rules and guidelines hanging in the midst. However, the fast pace of additive manufacturing adoption requires those who previously trained for conventional to rapidly retrain and rethink the way they design to meet the vast new options afforded by additive. It's important to realize that while "complexity is free" there are still guidelines and instruction that can make your additive design the most efficient when considering the parameters of cost, time, and quality. The following paper follows Part A of a two-part series focused on Additive Manufacturing Design. The series will condense some of these limitless possibilities and capture the advancing strategies of additive manufacturing design.

THE OPTIMAL ADDITIVE DESIGN ENGINEER



For decades, the three ideals of design, manufacturing, and cost have lived in silos. While it's clear even in the conventional design cycle how important it is for these three skillsets to collaborate and understand each other, it is magnified in an additive manufacturing environment. Where conventional designs take weeks maybe months to be realized and manufactured, the additive cycle is quick (sometimes overnight), and design faults can be identified immediately. With these design, manufacturing, and cost iterations happening so quickly, it's reasonable to see how these three skillsets can start to learn from each other and meld into one optimized approach. By integrating the impact on post processing operations and cost considerations up front, combined with the design opportunities that additive manufacturing provides with regards to complexity, the ideal design can be found rapidly and significantly reduce the development timeline for products.

THE ADDITIVE DESIGN PROCESS



Today, the design process for additive manufacturing often starts with an existing design, especially when the goal is to remove cost or weight from a current product. The part selection process, material decision, and technology down select could represent an entire discussion and article on its own, but we will fast forward to after those decisions have been made and it's time to open a CAD package and create the additive design.

The design cycle is not linear. The decisions made during each piece of the design will affect and contribute to the others. There are many possible outcomes to the cycle depending on what parameter needs to be optimized. For example, a one-off development piece where lead time is the most important factor may lead to a flat and low orientation which reduces build height and does not consider the quantity of parts which could nest together. This would be inefficient in a production environment because the number of builds needed to meet production quantities would equally increase with labor costs for set-up and tear down, build-to-build consumable costs, and machine down-time between builds. The one-off development piece design will be completely different than one that optimizes for a production volume which maximizes parts per build, nests multiple layers of parts, and reduces post processing steps with unique features. Investigating each of these puzzle pieces separately is difficult since they are related by cause and effect, however there are some basic guidelines and considerations which should be drawn upon when in the design cycle.

MATERIAL PROPERTIES

It is essential to understand that the material properties of additive manufactured metal are not equivalent to wrought or cast. Additively manufactured metals have their own design system, and should be treated as such. Due to the temperature gradients during metal additive manufacturing process, material properties and microstructure can be anisotropic in nature before performing post thermal treatment. Thermal processing can alter the microstructure to become more isotropic, but there still may be some orientation and geometric effects which remain. The effects may be seen on monotonic or dynamic properties. It's important to have an understanding of how significant the effects are within the material/process combination chosen. If there are design features that would be limiting if not built in a certain direction, it's important to design engineer integrates that design rule into the beginning stage of their orientation decisions.

POST PROCESSING

In the additive manufacturing process, there are two types of CAD models which exist. One is the final geometry which is what the final produced part will be inspected to. The datums are identified, machined tolerances will be called out, surface finish requirements will be zoned, assembly notes, etc.

The equally important CAD model is the as-built model, or the model which is input into the additive machine, which will look different than the finished models. Holes may be filled in, support structure will be added, machining stock will be added, and more. To understand what considerations should be put into the "as-built" model, a generic process map is provided.

The required post processing steps will look slightly different depending on the material and technology utilized. For example Electron Beam Melting (EBM) does not require stress relief or mechanical removal of the parts from the build plate, but does require powder removal of the partially sintered powder that surrounds the parts. Laser Powder Bed Fusion (LPBF) requires stress relief and either wire EDM or a band saw procedure to remove the parts from the plate. Thermal processing for all metal additive manufacturing often includes a Hot Isostatic Pressing (HIP) process to reduce voids and porosity within the material with parameters based on material choice, and additionally some materials may require a heat treat to alter to the desired microstructure.

BUILD AND POWDER REMOVAL:

As an expansion to the example above, different additive technologies offer advantages and disadvantages when it comes to build and powder removal considerations when designing a part.

Electron Beam Melting

The considerations for EBM with regards to build plate removal surround two aspects. First, it is identified as a best practice to not build directly on the plate, especially if the parts have strict chemistry requirements. There could be some influence of the stainless-steel plate for the first few layers of the build, so it is advised to start parts at least 3-5mm from the top of the build plate. Those 3-5 mm can be filled by either support structure, or solid material to be later cut-off, whichever is more efficient for the part. One advantage for the EBM process is that due to low residual stress from the entire build area at elevated temperature less supports are required and the parts usually “pop” off of the plate easily with slight pressure or a rubber mallet.

The biggest consideration during part removal of an EBM build is powder removal. On one hand the pre-heat step in the EBM process provides better part integrity, but for powder removal it provides a challenge that must also be considered when designing your part. During the pre-heat step in the EBM process, the powder surrounding the solid material is partially sintered making it difficult sometimes to remove from long cavities. This partially sintered powder does not flow, however it is crucial the powder is removed before sending the parts through any thermal processing like hot isostatic pressing (HIP) or heat treatment. Designing sweeping radii while maximizing line of site cavities into a part can make powder removal more successful.

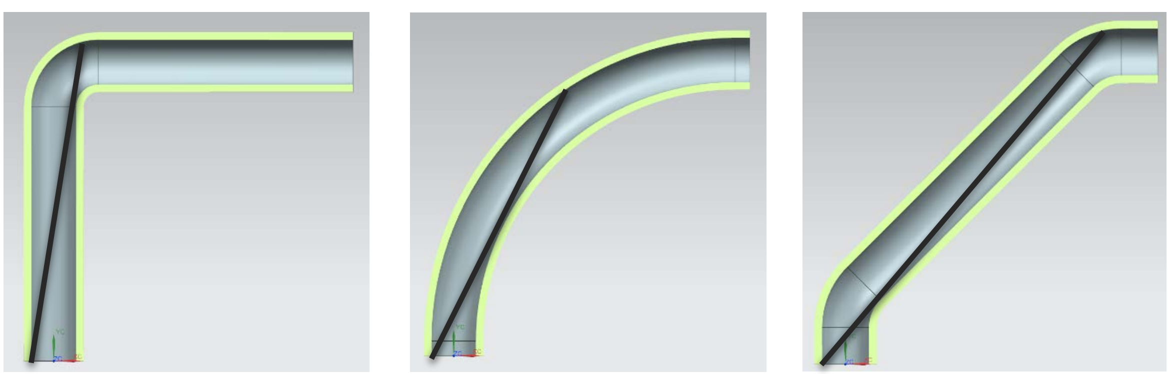


Figure 1(a) Figure 1(b) Figure 1(c)

Figure 1 shows line of sight powder removal examples: A) simple radius B) elongated radius C) straight center with radii on exits where the black line depicts how far the compressed air in the powder recovery system would be able to reach into the cavity with line of sight. It is not always intuitive as to which geometry would be best.

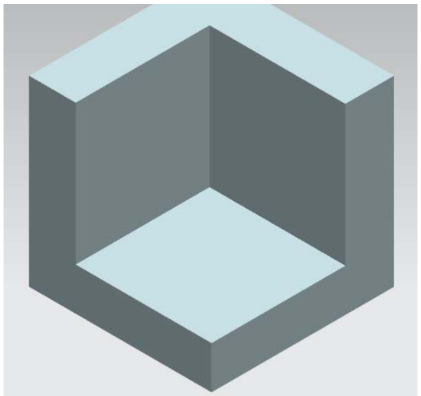


Figure 2(a)

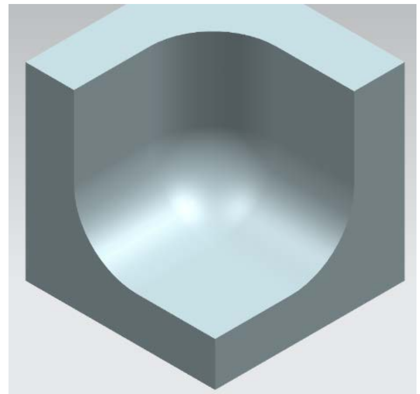


Figure 2(b)

Figure 2 shows the advantage of large radii instead of corner points. It is much easier to remove powder from a smooth surface than one with many discontinuities.

Laser Powder Bed Fusion

Considerations in laser powder bed with regards to build removal are slightly different, but no less complex. In the laser systems, there is a benefit to the "cool" build process as the powder does not become sintered and thus flows easily. When building intricate interior cavities is required, the removal process in laser provides an advantage. However, even though the powder flows more easily out of cavities, it can still be complex due to the requirement of removing the powder before stress relief and before the parts can be removed from the plate. Therefore, if the internal cavities are buried within the support structure or cannot be reached by the vacuum, powder removal options must be designed into the parts. If an orientation cannot be constructed to allow for full powder removal, it is common to add holes to the as-built model to ease the powder removal process of cavities, as seen in Figure 3 below. These holes can then be plugged later on by a weld.

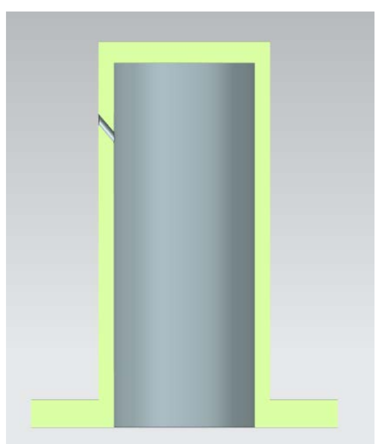


Figure 3

In laser systems, the parts and the plate are essentially welded together making it a bit more complex to separate adding time to the overall process. Parts must be removed by mechanical methods such as Wire EDM or a bandsaw.

Wire EDM is a more accurate process, so the additional stock needed underneath the parts may only be (3mm), whereas with the band saw, it is recommended to add at least (5mm) underneath of solid material or support structure.

THERMAL PROCESSING

Thermal processing in most cases does not define or change many designs, unless there is significant distortion during the thermal process due to drastically varying thicknesses compared to the part length or height. This is another area where choosing the right additive technology may be required. Large parts can be difficult to produce on laser systems due to the "cool" process that may struggle with residual stress. Stress relief is required on most Laser builds, but even more so on parts that span the build area. EBM may be a better choice in general for large parts in both the horizontal and vertical orientations since the stress relief step is not required. If geometric distortion is still issue for a part, there are a few options which can help the parts hold their shape through the thermal processing. For instance, adding a sacrificial gusset or frame around thin walled components to later be machined off can provide stability during the thermal processing steps.

SURFACE FINISH METHOD

The surface finish of metal powder bed fusion technologies is rougher than a casting, and also depends on the orientation of the surface. Top surfaces can be fairly smooth. Vertical surfaces normally have a rough but consistent surface finish, and surfaces which are orientated at angles less than 90 degrees from the build plate can be the roughest. In general, the laser powder bed systems have powder and laser parameters that are optimized for a smoother surface finish. EBM has focused on optimizing for cost via build speed, and therefore is rougher with the build time trade-off. It is optimal for cost to keep these surface finishes as-built, but many times structural and flow requirements or part aesthetics can drive the need for various surface finish methods to bring down the surface finish measurements.

The surface finish method chosen influences the impact on design changes, but the ultimate goal is to understand the material removal rate and compensate for the removal in the as-built model. For example, if a tumbling process removes 0.005" from the surface, it would be recommended to add a 0.005" envelop to the as-built CAD file so after post processing the features will come into conforming thicknesses.

When attempting to compensate for surface finish methods, designers must additionally consider the physics of the process itself. For example, corners will have a more aggressive material removal rate in a vibratory bowl than a flat surface, so profile tolerances may have to open in those locations, as seen below in Figure 4. For any critical features or tolerances, different masking techniques during the surface finish process may aid in maintaining the as-built surface so the material does not degrade or can be later machined.

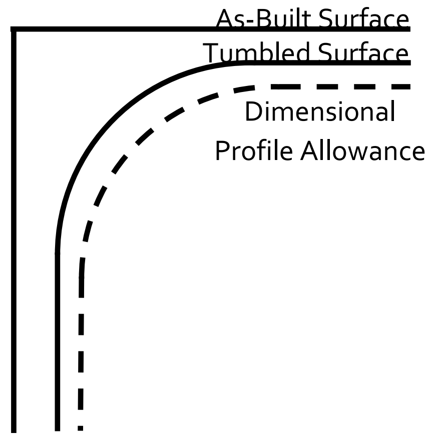


Figure 4

In addition to external surface finish methods, internal cavities many times require surface finish methods to smooth out channels for flow requirements. Similarly, the designers must consider the material removal rates of those methods and compensate for them in the model.

MACHINING

As discussed previously, most parts need to be machined at some level before becoming final product. Critical features and tight tolerances which can't be achieved by the printing process usually must be brought into conformance by conventional CNC processes. There are a few design considerations up front which makes the CNC process more effective.

First, the design engineer and the manufacturing engineer should collaborate to understand how the part will be held during the CNC process set-ups. Utilizing the advantages of the Additive Manufacturing process, datum features can be added to the as-built model to reduce custom tooling, or at minimum provide consistent tooling across a part family of similar geometries. Tabs, pins, holes, slots, or even a temporary handle can all be added to the printed part to help align any fixtures and tooling, and can be later cut-off. Having those conversations up front will reduce development iterations and speed up the setup and actual development time.

Another design consideration with regards to machining is wrap stock. Just as with surface finish methods, there will be some material removal in order to bring critical tolerances into conformance. Adding wrap stock to those features will ensure there is enough material there for the CNC process to remove. The amount of wrap stock added should be enough to reduce risk of there not being enough material, but limited so as to not add too much time and cost to the CNC process. This will vary depending on the material, the geometry of the parts, as well as the technology being used. Figure 5 below shows the difference between the (a) final part geometry and (b) the as-built geometry with the holes filled in, and bottom stock added for post machining.

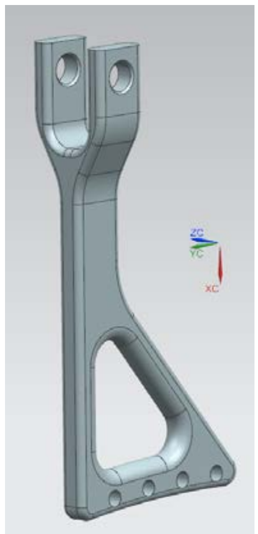


Figure 5(a)

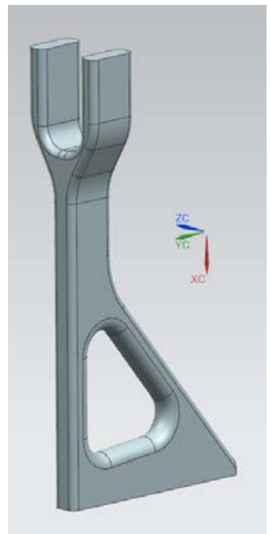


Figure 5(b)

In summary, the optimal additive manufacturing designer must wear multiple hats. They need to have an understanding of the full manufacturing value stream, cost analysis, and even structural and materials engineering. One step better is to have experts available to provide insight into the design process as it's proceeding in a collaborative atmosphere. The design cycle was discussed, where the pieces are all interconnected and include cause and effect correlations between them. Focused first on material properties, and post processing there are many design considerations which are dependent on material, technology, and required operations. In the next series, some producibility rules/guidelines will be reviewed, along with topology optimization, and other design for function opportunities as well.

For more information on Design for Additive Manufacturing and other Additive Manufacturing training opportunities, contact Caitlin Oswald at LAI International. coswald@laico.com 612.300.8722