GMG

Asset Management Working Group Case Study

CASE STUDY: Fabricating Change Through Additive Manufacturing

Syncrude

Operated by Suncor

1.0 Traditional and Non-Traditional Manufacturing

To understand what additive manufacturing (AM) is, it is helpful to review "traditional" manufacturing methods. These methods include:

- **Subtractive manufacturing** which is when the material is subtracted/removed to create a component (e.g., machining/stamping/cutting/grinding).
- **Formative manufacturing** which is when the material is formed/manipulated to create a component (e.g., extruding/pressing/rolling/forging/casting).
- **Fabricative processes** which is when components are joined to create an assembly (e.g., welding/fastening/adhesives).

Non-traditional manufacturing methods encompass any method that deviates from the above highlighted methods.

2.0 What is Additive Manufacturing (AM)?

AM is considered a "non-traditional" manufacturing method. Most AM processes are very similar and involve adding/depositing material in many small consecutive layers to create a component or assembly of components as a single part. In a nutshell, AM is 3D printing. The term AM is typically used in the industrial/serial production of manufactured parts; of which 3D printing is a subset.

AM is a full suite of tools with over 18 different technologies in existence; with many more likely to emerge as the technology matures. Just like with any tool, the right tool must be used depending on the job. Using AM tools when there are better tools is akin to using a hammer to drive in a screw; if there is a better tool, it should be used. As a result, AM won't solve every problem.

Two key areas where AM is a particularly beneficial/cost effective tool relative to traditional manufacturing methods are as follows:

Low volume production: E.g., Obsolete parts, one-off prototypes, component replacement in an assembly. See Figure 1 for a graph highlighting the comparison of cost versus number of parts produced when comparing traditional methods with AM.

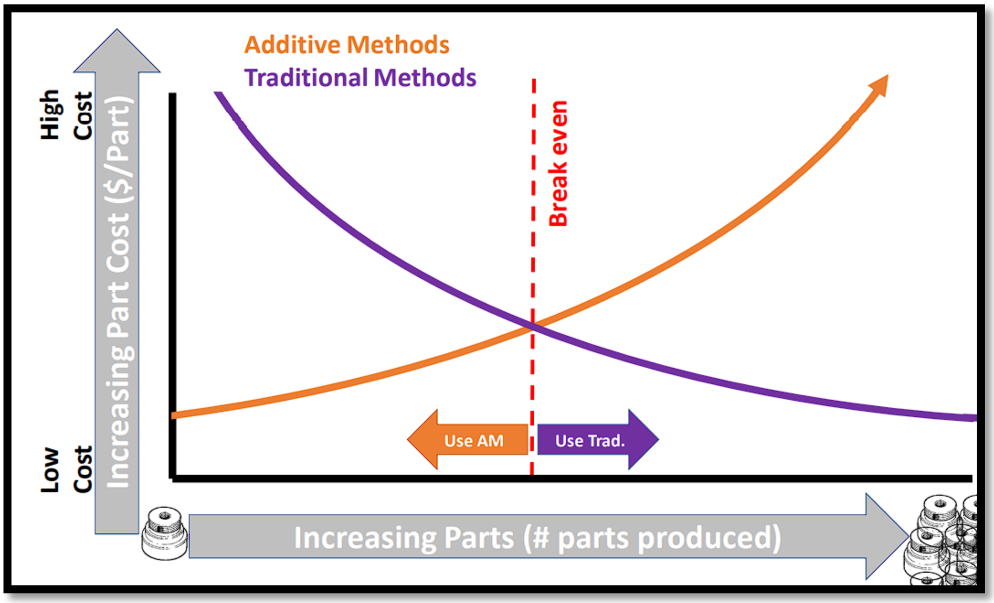


Figure 1. Cost vs. number of parts made; comparison when looking at traditional vs additive manufacturing.

High complexity: This is where AM is most beneficial because added complexity does not increase the time/cost to manufacture like in traditional manufacturing. In addition, it can enable the ability to manufacture parts that would not be possible with traditional manufacturing methods, for example:

- Very fine integral geometries for cooling channels or flow distribution pathways.
- Multi-material parts layered together or with wear resistant materials positioned in the right spot.

See Figure 2 for a graph highlighting the cost versus complexity comparison. As complexity is added to a part, costs increase more linearly with additive versus exponential with traditional manufacturing.

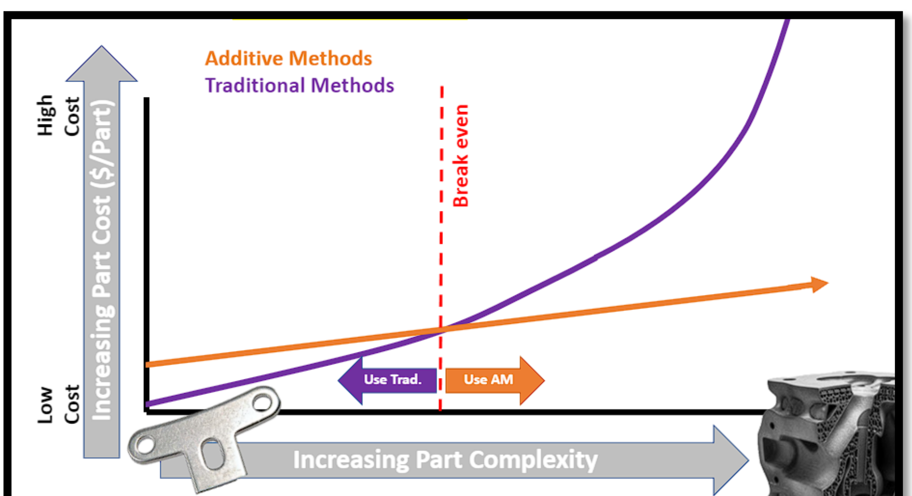


Figure 2. Increasing part cost versus part complexity.

AM technologies are already used routinely in aerospace and medical industries. However, there is still a lot that needs to be developed/improved if it is to be adopted in different industries – for example in mining and oil/gas – including:

- How to print a much larger array of wear materials, and what post processing is required.
- How to test and QA/qualifications for finished products – particularly for structural members.
- How to deal with non-ideal material properties/strengths.
- How to optimize part design for the chosen process/parts.

The two most prominent AM technologies for metals used in industry are Powder Bed Fusion (PBF) and Direct Energy Deposition (DED)

2.1 Powder Bed Fusion (PBF)

PBF creates a part by encasing a large bed of powdered metal in a machine. This powder filled bed is on a table that moves up and down. An energy source (laser or electron beam) is used to heat and fuse or melt the surface of metal powder in a pattern defined by the target shape. The bed lowers slightly, and a subsequent layer of powder (~100 um or less) is spread on top, and then another layer is fused onto the previous layer. The process repeats itself layer by layer until complete. The process can produce parts that have very fine structures and geometries/passageways with minimal surface machining to get desired surface finishes.

Current limitations of the PBF method include:

- The part size is limited (must be small enough to fit into the machine).
- The types of metals that can be used are limited (only powder feedstock designed for AM).
- Wear materials are very limited (no very hard wear materials/ceramics currently available).

2.2 Direct Energy Deposition (DED)

DED processes utilize different heat sources (e.g., electric arc, laser, or electron beam) to melt a metal powder stream or wire feed. With this, layers are built on each other to form a part. The process requires precise computer numerical control (CNC) and robotics as the process occurs in multiple dimensions unlike PBF (planar). When the complex robotics and controls are removed, DED process are just like typical laser cladding or wire arc welding process.

The big benefit of DED is that large parts (e.g., rocket booster engine shrouds the size of a silo) can be formed with this method. In addition, there is a much larger array of materials that can be printed (when compared to PBF).

The current limitations of the DED AM method include:

- The surface finish is much rougher than PBF (may require significant machining to finish the part).
- Unable to resolve fine details (cannot produce fine geometries).
- Wear materials are very limited (no very hard wear materials/ceramics currently available).

3.0 Syncrude's Applications

3.1 Coker Feed Nozzles

One of the first application areas that the Syncrude Research department looked at for AM application in the Syncrude plant was with the Coker feed nozzles. The Coker reactors are the heart of Syncrude's upgrading operation. In the reacting process, very small increases in yield can have a large benefit to production and reduce CO_2e. For example, a 1% yield improvement gives:

- An increased production of ~3 kbbl/d across all three Cokers
- Reduced environmental footprint of ~0.1 MtCO2e

The main goal of the nozzles is to create small, disperse bitumen droplets so they can contact hot coke particles in the reactor. More solid-liquid surface contact means the yield will be improved. Additionally, there can be better dispersion of the spray and a longer lasting nozzle. Syncrude Research has spent a lot of effort over the years improving the nozzles through various generations.

Currently steam and bitumen are injected/mixed outside of the reactor. One of the potential improvements being investigated is moving the steam injection much closer to the nozzle tip (i.e., inside the reactor). The predicted benefit of this injection change is that bitumen dispersion into the reactor can be improved, and there will be a reduction in bitumen agglomerates which reduces the reactive surface area.

Injecting steam right at the nozzle tip is difficult because it requires a very even, radial distribution of steam at the nozzle tip and even steam distribution is required to get the predicted uplift. To achieve an even distribution, there needs to be a form of internal flow/distribution system built into the nozzle to evenly distribute steam inside the circumference of the nozzle. AM allowed Syncrude Research to design and build test prototypes that could have an internal steam distribution system. Producing this prototype would not have been feasibly created with traditional manufacturing methods.

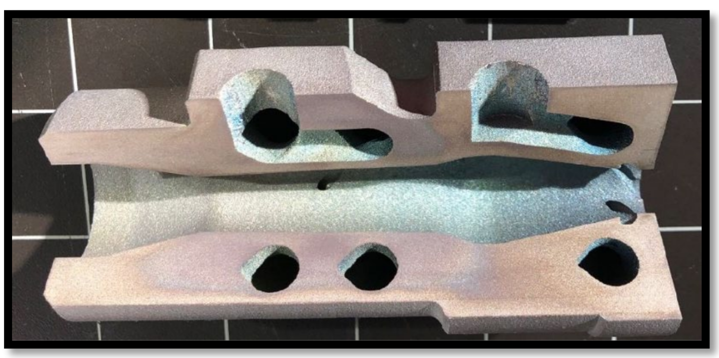


Figure 3. Cut out of one of the prototypes produced with AM.

Several protypes were built, and attachments were made so that a total of 36 different test configurations could be run with:

- Different steam injection locations.
- Different discharge angles.

3.2 Early Results of the Coker Nozzle Application

Early benchtop trials have shown some promise; however, there is still lots of testing to be done. One of the promising results so far suggests that a Gen. 3 spray pattern can be simulated with a Gen. 2 nozzle geometry. This is promising because the Gen. 3 pattern is more efficient, but prone to wear.

Once a Gen. 3 nozzle tip loses its key clover leaf geometry (see Figure 4) – surface area is reduced along with Coker yield (equivalent to the older Gen. 2 design which has lower performance).

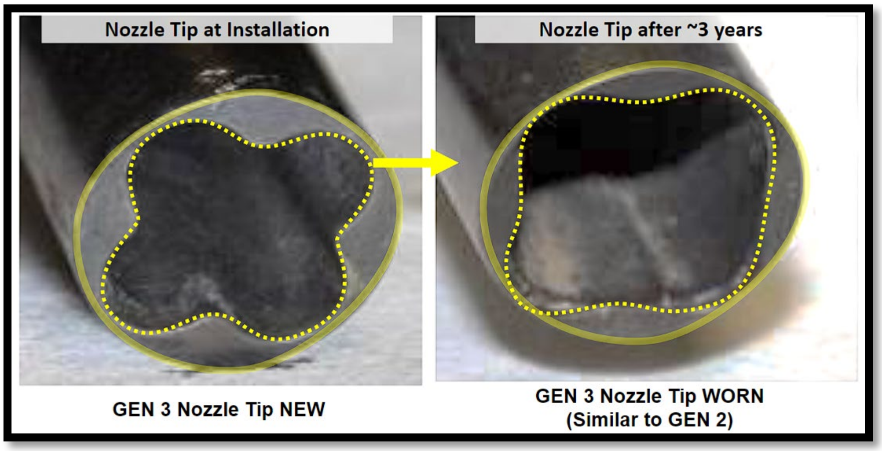


Figure 4. New Gen. 3 Nozzle Tip at Installation vs. three years later.

The potential benefit of producing a Gen. 3 spray geometry with a Gen. 2 tip design (using steam tip injection) means there could be potential to have Gen. 3 nozzle performance that is much less susceptible to wear – thus extending its performance benefit.

In addition to these early results, there is also a possibility in the future of using AM to produce multi-material nozzles. In this type of application, a very hard and brittle material can be printed on top of a tough base material. The benefits of using AM to do something like this is that the part will still be a single piece, where the body will be tough (not prone to cracking/brittle failure) while the critical orifice geometry can be preserved from erosive wear for longer due to a very hard tip. This type of technology is still in development but represents the next step in multi-material single component AM design.

3.3 Disc Centrifuge Components

Another use case of AM that Syncrude Research is working on is Syncrude's disc centrifuges. Disc centrifuges are used in Syncrude's Secondary Extraction/Froth Treatment Plant to ensure the remaining solids and water from the mining and primary extraction processes are reduced in order to limit severe erosion/corrosion in the downstream upgrading equipment.

A fleet of 81 of these centrifuges do the job, and because there are so many machines in such a highly erosive service, there is a very high consumption of replaceable parts. As a result, there is a large benefit that can be achieved if parts consumption rates are reduced, or costs are lowered.

Of the many components that make up these machines, Syncrude Research started working directly with the OEM on some of the highest consumption ones first (see Figures 5–8 with the highlighted red components being the highest consumption pieces). The components include:

The channel inlet which is a part composed of ~50 thin discs stacked as an assembly. The discs wear out in less than a year and are relatively expensive to make with traditional methods.

Syncrude Research wanted to get a “quick win” so attempted making the discs out of AM materials utilizing PBF technologies. When the AM produced discs were run side-by-side with traditionally manufactured discs, they not only lasted ~2X longer; they were also cheaper to produce.

The team at Syncrude Research took it one step further. In order to reduce AM costs even more, the individual discs were re-designed with the OEM as “blocks” of discs instead of individual discs, in order to reduce build times.

The team didn’t stop there though; they started to investigate the fluid flow through the geometry of the discs as a whole. By doing so, they realized that if they could print blocks of discs, it would be possible to also produce discs that could improve the process performance of the machine itself. This kicked off a new phase of AM based performance enhancements that is on-going.

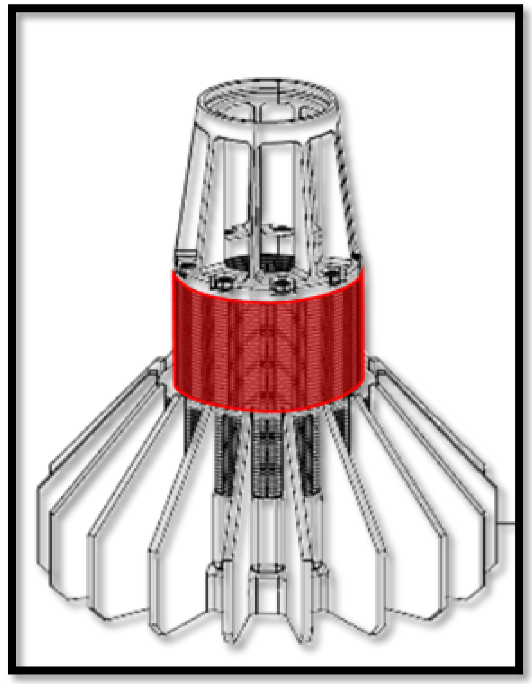


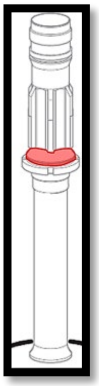
Figure 5.Channel inlet.

One of the key takeaways from the channel inlet process was how Syncrude not only realized savings right away by using AM to produce these parts but was also able to start developing additional revisions of the part design (which would not have been possible with traditional methods).

The nozzle: typically has a life cycle of 3-5 months.

The bowl body: cutting causes long and costly repairs.

The feed pipe: requires expensive repairs or replacement for very small wear zones.



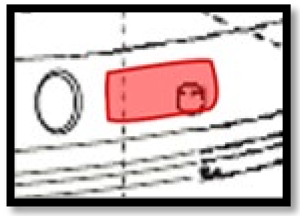


Figure 7. Bowl body

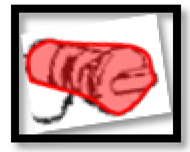


Figure 6. Nozzle

Figure 8. Feed pipe

The process for these components wasn't nearly as linear as it was for the channel inlet and was very iterative. For example, the nozzles are something Syncrude Research has been working on for decades – there's been numerous revisions and improvements. However, up until now, internal geometry or single component assemblies were a dream – but with AM they are now possible, and Syncrude Research has started to produce, and field test many different types of nozzles to see what would be optimal for them.

Syncrude Research also started a "fail quick" approach, where AM has been pivotal in turning around quick prototypes to learn what works in the field, and what doesn't. If field operations or maintenance personnel give feedback, they can turn around and implement that feedback in the next revision before going through a large and costly implementation program. Compared to traditional methods, Syncrude Research can optimize the designs much quicker using AM.

4.0 What is Next for Syncrude and AM?

"To us it's not so much 'what is next' – it's more like what 'isn't next'? We've only scratched the surface of the value that AM can potentially provide for Syncrude. At this point there are a lot of potential opportunities and applications. We need collaboration, partnerships, and ideas in order to really start realizing the value AM can give us. We've started this journey by developing a roadmap with colleagues at Suncor to lay out a plan for the future; and we're just getting started."

In the not-so-distant future, Syncrude believes they may be able to:

- Manufacture some parts in ~2-3 weeks (eliminating 3+ months wait times for critical parts).
- Build obsolete or one-off parts (reducing capital replacements).
- Replace some warehouse inventory with "built-on-demand" inventory (reducing local inventory and associated logistics/costs).
- Realize process performance benefits by leveraging AM designs.

The Syncrude authors would like to express appreciation for support of this program by OEM and vendor partners, as well as all the support from technical, operations, and maintenance groups on site for field testing & trials.

About Asset Management Working Group

The GMG Asset Management Working Group is an inclusive and global operator-driven community of interest whose primary purpose is to identify and share leading practices in asset management, reliability, and maintenance. The group is dedicated to developing asset management guidelines that result in improved safety, ESG, and operating performance for the benefit of the mining industry.

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