The Additive Advantage

How 3-D Printing is Changing the Powder Metal Performance Game

Matthew Jaster, Senior Editor

A study released in the 1995 September/October issue of *Gear Technology* examined the advantages of powder metallurgy for new and existing gear applications. "The Beginner's Guide to Powder Metal Gears," written by George Shturtz at Carbon City Products, Inc., explored why PM deserved serious consideration for gear design in areas like automotive, hand tools, outdoor power equipment and office machinery applications.

It's a fascinating read — particularly in 2019 — when you compare the role PM plays today in gear manufacturing versus its potential back in 1995. And while the Metal Powder Industries Federation (MPIF) has championed the technology — offering technical papers on powder metal since the mid 1940's — additive manufacturing has given PM even greater visibility in recent years pushing its potential from prototyping into the production environment.

Matt Sand, president at 3DEO, said that metal additive manufacturing was always outshined by plastic 3-D-printing because the process of using powder metal is very complex. Some powder metals need to be handled in careful environmental conditions to prevent explosions and some processes require sintering in order to achieve final part density.

"Currently, metal additive manufacturing is used mainly for prototyping and one-off production of complex parts in industries such as aerospace and medical devices. However, companies like 3DEO are working hard to create new metal AM processes that are optimized for high-volume serial production," he added.

The Potential of 3-D-Printed Components

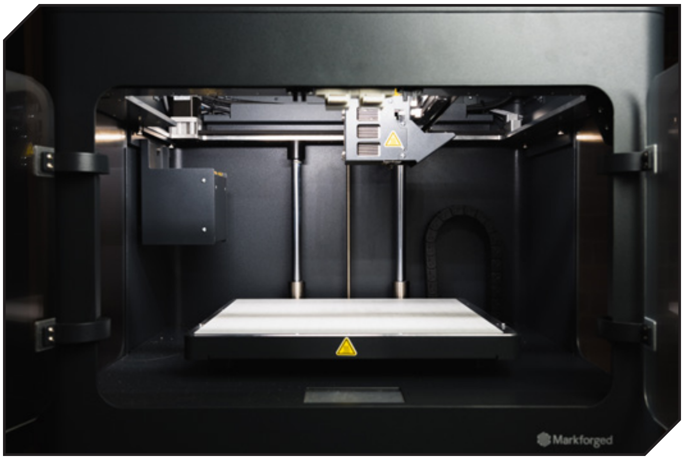
As 3-D-printing machines continue to increase their capabilities, PM components have the potential to become more than just one-off, customized solutions.

According to Tommy Lynch, senior applications engineer, additive manufacturing at Xometry, powder bed fusion metal systems have evolved to become more productive. Powder handling is becoming more user-friendly, and Lynch is seeing more systems emerge that have dual or quad laser setups that can increase build speed and through-put on smaller parts.

Lynch said metal binder jetting is also going through a revitalization stage with new players in the technology. Over the next few years, this technology could have a stronger foothold for making production metal parts with similar results as metal injection molding.

Concerning the potential of 3-D-printed powder metal components, Lynch believes that compared to traditional manufacturing methods the biggest advantage will be the speed of iteration.

A Metal X Print Farm (courtesy of Markforged).



Close-up of a MetalX bed (courtesy of Markforged).

"Engineers now have the flexibility to design, instantly quote, order, and have parts within a week. In addition, there may be cost savings by avoiding steep setup charges that typically occur with traditional methods such as CNC machining or metal casting," Lynch said.

For laser powder bed fusion, like direct metal laser sintering or selective laser melting, the ability to use the same process for both prototyping and production has provided a strategic advantage in part validation and revision releases. Lynch has seen many examples of Xometry customers solving challenges with their metal casting supply chain by moving to direct-printed metal options. Parts produced also have the benefit of being fully-dense and ready-to machine.

Additionally, Sand said that 3-D-printed metal components benefit from advanced designs and complex geometries such as internal cooling channels. These components can benefit from increased durability, reduced cost, shorter lead time and improved functionality.

Alex Crease, application engineer at Markforged, said that 3-D-printing applications have changed since the advent of high-strength metal parts and low-cost adoption. Take Markforged's Metal X, a metal 3-D printer, for example, as it introduces a safe and cost-effective method of producing parts quickly out of a variety of metals. The machine extrudes bound metal powder layer by layer to construct a part. Once built, it's sintered in a furnace, where the binder melts away and the final metal part solidifies.

"Additive technologies like the Metal X demonstrate that 3-D-printing can efficiently produce parts that can withstand the rigors and strain of the modern factory, but it also signals that such quality and effectiveness aren't just reserved for the largest manufacturers with the deepest pockets. The 3-D-printing landscape has further evolved with the introduction of artificial intelligence (AI), giving manufacturers the opportunity to make 3-D-printing more accurate and reliable.

Regarding Gear Production

While PM components come in all shapes and sizes, the readers of this magazine would probably be most intrigued by their future potential in gear manufacturing.

"Gears are very difficult due to the tight tolerances and high demands on the components," Sand said. "Most metal

3-D-printing technologies are NOT able to hit these component requirements in production quantities."

3DEO's Intelligent Layering process starts with a layer of metal powder that is then sprayed with a proprietary binder. A cutting tool is then used to cut out the 2-D design of one dimension of the part. This process continues layer by layer until the part is built. The green part is then sintered in a furnace to melt the binder and achieve final part density. 3DEO's process is able to achieve a superior surface finish which reduces post-processing.

"This is particularly beneficial for gears because gears have a complex shape with tiny grooves that may be hard to polish. In addition, gears require tight tolerances because the gears must fit together perfectly to function," Sand said.

On the polymer side, Lynch said there are significant advances in material science which include being able to print in epoxy and urethane materials through the Carbon DLS platform. Both polymer and metal powder bed fusion technologies tend to work well for medium to larger gears; and laser sintering and multi-jet fusion are great examples of this.

"There are still surface finish and resolution issues on finer features and thin gaps. Process tolerance, materials, and as-built surface finish should all be considerations when choosing additive for geared components," Lynch said.

The challenge of producing gears with additive manufacturing is two-fold: machines need to print with high enough precision to minimize backlash in the gear teeth, and the materials the machines print have to withstand torque transmission through the teeth. Plastic 3-D printers that have dominated the industry don't have the strength or the resolution to print

Metal 3-D printed gears from 3DEO.

effective gear teeth. While metal 3-D-printers have the material strength to do it, metal 3-D-printers, until now, were not affordable, according to Crease.

"The Metal X offers a cost-effective solution for creating metal parts in a variety of metals, including stainless steel and tool steels. Since producing gears often requires some amount of tooling and overhead, like extrusion dies, broaches, and more, additive manufacturing has the potential to reduce some of those overhead costs to make both prototyping and production more efficient. Functional prototypes and small-scale production parts, like gears and similar components, can be created without worry over tooling or overhead costs," Crease said.

Once manufacturers are ready for larger scale production, Crease said they can use the Metal X to create the tooling and workholding needed to make gears and other components at scale. This allows gear manufacturers to iterate quickly through designs, optimizing both the gear design and its tooling design, all while keeping costs low.

Markforged's *Blacksmith*, the first AI-powered software that makes additive manufacturing machines "self-aware," allows users to automatically adjust programming to ensure every part is produced as designed. *Blacksmith* AI software connects additive manufacturing equipment to inspection equipment. This means that parts can be 3-D scanned and their information can be relayed back to the machines making them, which in turn update their settings to make the next part more precise. This closes the loop between manufacturing and inspection to make 3-D-printed parts more accurate and repeatable.

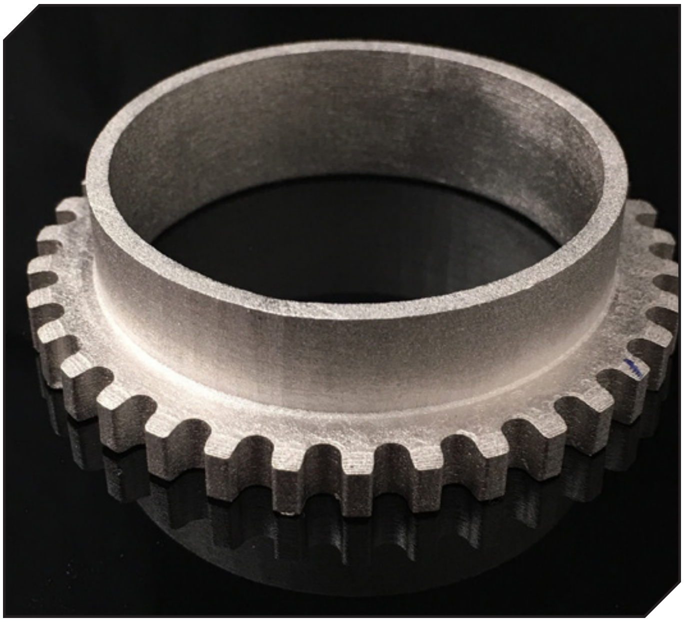
"Markforged's *Blacksmith*, has the potential to improve part precision and repeatability to ensure manufacturers receive accurate print gears or gear tooling with 'adaptive manufacturing.' Through 3-D scanning, this data is compared to the original design which AI then learns from and adapts the process settings to produce a more accurate final part. Ultimately, *Blacksmith* will produce the right part the first time and every time, and manufacturers can ensure that printers are hitting the necessary tolerances for gear components and can reduce the number of design iterations needed before a production run," Crease said.

Know Your Limits

Additive manufacturing has its own set of unique limitations. According to Lynch, this is primarily around internal stresses generated during the build process. Support structure is an absolute need in most cases, and post-processing adds additional challenges as well as surface inconsistencies.

"Educating and building reasonable expectations for our customers is a large part of working with metal printing," Lynch said. "Size and costs can also be prohibitive. Although this technology can scale, it is best optimized when a full build tray is utilized for an array of small pieces."

The greatest challenge with utilizing metal 3-D printing is the lack of quality control within the industry. "3-D-printing is mainly used for prototyping because when used for



The greatest challenge with utilizing metal 3-D printing is the lack of quality control within the industry (courtesy of 3DEO).

high-volume production, most technologies fail to achieve repeatability and typically have problems with degrading processes," Sand said.

Crease agrees that the number one challenge isn't the technology itself, but education in the industry around it. "When vendors introduce a breakthrough, new ways to make parts, it's naturally going to take time for everyone to understand the process and how it can be leveraged to improve and change their business," he said.

A Focus on Heat Treat and Surface Finish

Heat treating, specifically for stainless steel alloys, is basically controlled heating and cooling cycle(s) to obtain specific conditions or properties. Depending on a heat-treating condition, it is possible to increase hardness and tensile strength of a part and/or improve ductility and machinability. The condition is usually defined by the application and working environment of the part, according to Sand.

"Finishing processes such as media blasting improve the surface quality, as well as properties like surface hardness and fatigue resistance. Blasting also helps with removing contamination and providing a uniform surface appearance," he added.

Lynch added that heat treating is essential for many printed metal components to stress relieve the parts before removing from its supports and build plate. Post heat treating is available as well for hardening materials in built components. Typically parts are bead blast or shot-peened to remove any excess material on surfaces. There are abrasive and non-abrasive methods of surface smoothing, but each has trade-offs.

Just like with traditional metals, 3-D-printed metals can be heat-treated to certain temperatures to achieve different material properties, so the traditional processing methods for gears can carry over into modern technologies like 3-D-printing. "Smooth, precise surfaces on gear teeth allow the gears to mesh consistently without any slop or noise, which is why surface prep is so important. Any inconsistencies in the surfaces of the gear teeth make the gear less efficient: it becomes more likely to jam, and more power is needed to transmit forces through the teeth. Similarly, more backlash and slop will be introduced into the system if the gears are manufactured less precisely. So having a consistent, clean surface improves the performance of the gear and makes it more efficient. Parts printed on Markforged's Metal X can be cleaned up just like their traditional metal counterparts, making it easy to post-process if very high precision is needed," Crease said.

Taking Initiative

So where is the technology heading today?

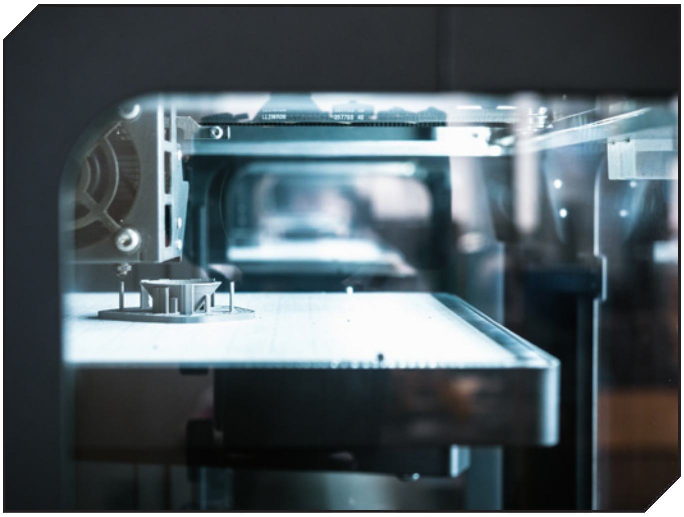
Sand said it's not trivial to move from prototyping to production. Additive manufacturing is great for rapid prototyping, but achieving the repeatability necessary for serial production is complicated. The reason being is that additive manufacturing lacks a standardized method of production. With additive manufacturing, there are hundreds of variables to control that can affect the outcome of a print. Each printer, operator, and even layer is independent of the other and can create serious problems with the predictability of performance.

"3DEO started with the idea of production in mind, so all or our systems have been developed around this. As we grow and take on larger orders, we continually discover how much additive manufacturing processes lack standardization in quality and process controls. As a result, we have to develop our own systems in order to compete with traditional manufacturing," Sand said.

Xometry is able to instantly price and provides lead times for seven 3-D printing technologies as well as traditional machining, sheet metal, and molding (courtesy of Xometry).

3DEO has a dedicated R&D team that continues to develop and improve the Intelligent Layering technology. We are currently working on expanding our available materials to others such as titanium and tungsten carbide.

Xometry continues to create meaningful engineering and design for manufacturing (DFM) tools for a variety of 3-D-printed processes and materials. We offer design guides, videos, a comprehensive online knowledge base, as well as continual release of new and revolutionary technologies. Because Xometry is a platform for manufacturing, it is able to instantly price and provides lead times for seven 3-D-printing technologies as well as traditional machining, sheet metal, and molding.



This metal test print is being run on the Metal X system (courtesy of Markforged).

Printing is only the first step of a multi-stage process when 3-D-printing metals. The best way to conceptualize the part is as a near-net-shape, meaning that additional processing is likely necessary to achieve specific tolerances or surface finishes. A great surrogate is that of metal casting, where the shape is made then typically post-machined.

"Simplicity and reliability are key for additive manufacturing, which is why we developed the full additive ecosystem -- from software to printers to materials. This tactic allows us to fine-tune every part of the process to give our customers the best user experience and reliability. We even launched *Blacksmith* to ensure customers can tell if they've printed in-spec parts. It's essential to align each part of the process under one group because one weak link will produce a poor result. For example, if a customer uses an inferior material, they'll have an inferior final part, no matter how high-quality the printer is," Crease said.

The Future of 3-D-Printed, PM Gears

Sand believes the future is bright for gear manufacturing, especially when it comes to lower volume production runs. 3DEO offers metal 3-D-printing technology in production today, but there are undoubtedly many other new, up-and-coming technologies that will make significant inroads in gear fabrication.

Lynch said that resolution and surface finish will continue to improve from direct-printed results. It may not be the case that powder bed fusion will be the primary way metal parts are additively manufactured.

"With new hybridizations of processes, both

Xometry continues to create meaningful engineering and design for manufacturing (DFM) tools for a variety of 3-D printed processes and materials.

"With new hybridizations of processes, both additive-to-additive, and additive-to-subtractive, there will be greater leveraging of strengths between processes. For example, growing a part and in-situ tuning of feature sets may be commonplace; pairing this with model-based definitions (MBD or PMI) will complement the blend of design intent, fabrication, and real-world implementation," Lynch said.

The capabilities of additive manufacturing technology are increasing at an incredible rate, especially with tolerancing and dimensional precision, according to Crease.

"Ten to 15 years from now, we expect to produce gears and energy transmission systems ranging from precision nano-drives and micro motors to extremely large-scale gears (such as mill and pulley gearing) all from a variety of 3-D printers," Crease said. "Additionally, the removal of current limitations in designs of teeth and grooves from subtractive manufacturing will create more possibilities for all new engagement and drive methods that were never considered before."

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