3DEO

METAL 3D PRINTING
THE ULTIMATE GUIDE

ONE-STOP SHOP
For precision stainless steel components

3DEO is a high-volume production supplier of precision stainless steel components, made with our patented metal 3D printing technology. With no molds, tooling, or lengthy setup times, 3DEO delivers production parts in weeks, not months.

Based in Los Angeles, 3DEO supplies small, complex stainless steel components to customers in the medical, defense, aerospace, and industrial equipment markets. 3DEO is an employee-owned company.

ISO Certified

CERTIFIED ISO 9001:2015 COMPANY

Parallel to its production business, 3DEO also operates an R&D center which is continually striving to improve and advance its manufacturing technology.

Reimagine Manufacturing® with the power of 3D printing—design freedom, flexible production, immediate turnaround, and no up-front costs.

METAL 3D PRINTING: AN INTRODUCTORY GUIDE

3D printing, also known as additive manufacturing (AM), is one of the most exciting manufacturing technologies talked about today. We are now seeing a second modern wave of interest and enthusiasm for 3D printing with advances appearing in news feeds everyday across markets including consumer, industrial, automotive, aerospace, medical, and many more.

Surprisingly, the technology is over 30 years old, but the first modern wave of public excitement occurred around 2012 when media outlets touted the technology as ready to revolutionize the entire manufacturing landscape. Additive manufacturing had come a long way over three decades, but it wasn't quite ready to live up to the massive hype. Fortunately, the technology has developed dramatically in the intervening five years -- especially the 3D printing of metals. This guide will provide information on the different metal AM processes available today including advantages, disadvantages, and applications.

The purpose of this guide is to help the manufacturing leaders and engineers learn about the exciting new technology and how to best leverage it. The potential benefits of AM are too great to ignore: previously impossible design possibilities, on-demand manufacturing, reshaped supply chains, and much faster product development cycles. For example, AM gives you the ability to create internal chambers, nonlinear cooling channels, and other extremely complex geometries. It's possible to consolidate many parts into a single design, subsequently reducing the number of parts that need to be designed, created, tracked, and stored.

BENEFITS OF METAL 3D PRINTING

The popularity of 3D printing is directly related to the technology's exciting possibilities and benefits. When 3D printing is used to create metal parts, the layer-by-layer approach allows for the creation of parts without the use of a mold or casting. Typically, the time required to make the tooling for different traditional manufacturing processes can range from a few weeks to several months, with no parts being produced in the meantime. Machining a part can be done more quickly, but it can be very expensive for complex geometries and difficult to scale to high quantities.

To summarize, the four main benefits of metal 3D printing include: lowering costs, quickly innovating, new design possibilities, and on-demand manufacturing.

LOWER COST

3D printing dramatically lowers the cost of manufacturing complex or custom parts. Also, by removing the need for a mold or tooling you take away the associated investment required to get the manufacturing line up and running.

BE INNOVATIVE

Engineers and product designers can iterate on part designs quickly to test new ideas and concepts. Increasing the speed of innovation allows companies to get new products to market with faster than ever before.

NEW DESIGN POSSIBILITIES

The layer-by-layer approach of metal 3D printing enables previously impossible designs and customization opportunities by stretching beyond the limits of traditional manufacturing. Lightweighting and parts consolidation are two very popular design applications of metal 3D printing.

ON-DEMAND MANUFACTURING

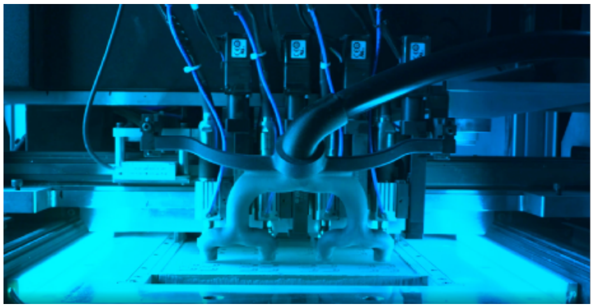
With 3D printing, it is possible to order only the quantities needed and with short turnaround times. The concept of a digital inventory refers to part files being stored electronically, and then created as desired to match demand. This includes legacy parts where the tooling is unavailable or prohibitively expensive.

METAL 3D PRINTING PROCESSES

The additive part of the name comes from adding layer upon layer to create the part, as opposed to subtractive technologies such as CNC machining which mill and grind away material to reach a final part. How these additive layers are formed and the parts are created is what separates the different additive manufacturing technologies. Some processes use a heat source to immediately turn the feed material into solid metal, and others create parts with metal powder that are first bound in a “green” state and later placed in a sintering furnace to achieve final part density. Regardless of how these layers are ultimately created, the AM process of building one very thin layer after another has a significant number of advantages to traditional manufacturing.

New metal additive manufacturing processes are constantly being developed, but today most can be divided into six categories:

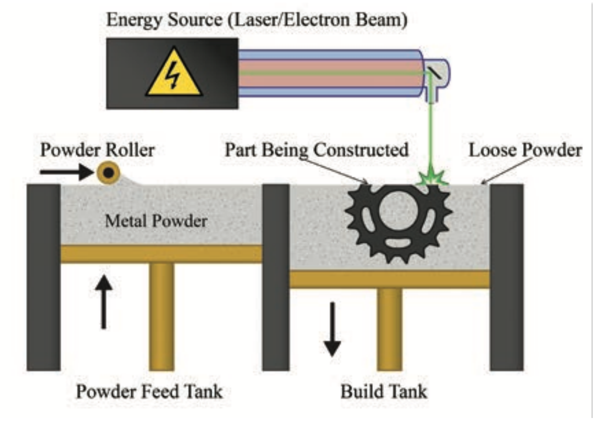
1. **POWDER BED FUSION**
2. **BINDER JETTING**
3. **EXTRUSION**
4. **DIRECTED ENERGY DEPOSITION**
5. **MATERIAL JETTING**
6. **INTELLIGENT LAYERING®**



POWDER BED FUSION (PBF)

Powder Bed Fusion is a popular technique for metal additive manufacturing and includes two main technologies: Laser Sintering and Electron Beam. These techniques are grouped together since they each begin with a layer of metal powder being rolled onto the build tray, and then an energy source (laser or electron beam) fuses or melts the powder into deliberate 2D designs. These 2D layers are fused on top of each other to create the 3D object. Electron beams produce more energy than lasers and are chosen to fuse the highest temperature metal superalloys for parts used in extreme conditions such as jet engines and gas turbines.

There are several branded names for different PBF processes, so it's important to know that while they might sound different, they are essentially the same process. For example, direct metal laser sintering (DMLS) is one of the best known names for laser sintering. Other synonyms for laser sintering also include selective laser sintering (SLS), selective laser melting (SLM), laser metal fusion (LMF), direct laser melting (DLM), and direct metal printing (DMP). Electron Beam Melting (EBM) is one of the most common processes utilizing an electron beam as a heat source and is patented by Arcam -- a company that was recently purchased by GE.



a. Diagram of Powder Bed Fusion (PBF)

Advantages of PBF

PBF is currently the most common and well known form of metal additive manufacturing. There are a number of reasons for the popularity of PBF, most notably that the high-precision lasers and electron beams can create intricate parts using a wide range of materials. PBF is also capable of creating larger parts than some of the other technologies like binder jetting or material jetting. The practical advantage is that very few other metal additive manufacturing techniques can produce fully dense parts with properties approaching wrought material. The sheer number of companies making PBF machines is also beneficial because the technology is widely available for the companies willing to invest in these systems.

- **High precision with tight tolerances**
- **Widest range of materials**
- **Larger parts**
- **Good material properties**

Disadvantages of PBF

The PBF process is quite complex, which results in very expensive machines. A high-quality laser sintering machine can cost well over $1 million, and that does not cover maintenance and post-processing of parts. The high machine cost is amortized with each build, and passed through to each part created. For most applications, machine amortization alone for PBF causes part cost to be prohibitively expensive. The rare production scenarios where the costs can be justified include high-end applications such as aerospace and turbine components, but they are not practical for more mainstream metal applications. Beyond cost, PBF is a relatively slow process and it can take days or even weeks to create large parts. This precludes it from being useful in most production scenarios due to the low throughput and high cost.

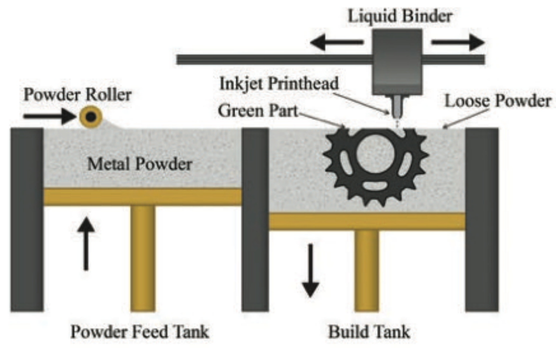
While PBF is popular because of its ability to work with a wide variety of materials and create relatively large parts, there are also issues with the material properties in the vertical direction (Z axis) due to the layers being melted together. Typically, the Z-axis strength is only 50-70% of the X and Y axes and must be accounted for in part design. Using lasers is also considered to be a degrading process since the last part you create in a manufacturing run typically differs from the first, if the laser hasn't been carefully watched and recalibrated along the way.

- **Parts are very expensive**
- **Degrading process makes repeatability difficult**
- **Generally slow and expensive to scale**
- **Weak Z axis fatigue properties**
- **Supports need to be removed**

Applications of PBF

PBF is the most commonly used metal additive manufacturing technology today. The machines are expensive, but they are capable of creating high-resolution parts with large build envelopes. PBF is primarily used today as a prototyping platform for engineers to test out new design ideas without waiting a significant amount of time for a part to be created by traditional manufacturing technologies. Production PBF parts are beginning to be used in end-use applications primarily in aerospace, but the volumes are low and it only makes business sense in situations where the high cost is competitive or even lower cost than traditional manufacturing for that specific part. There is currently no PBF technology available today that can mass produce metal parts and compete with traditional manufacturing in high-volume applications on a price-per-part basis.

BINDER JETTING



b. Diagram of a Binder Jetting system

Binder Jetting is a powder bed process that utilizes inkjet technology and a binding agent. The liquid binder is used to "glue" the metal powder together within and between layers. A layer of metal powder is first rolled onto the build tray, and then an inkjet print head moves along the x and y axes and deposits binder in the shape of the part for each respective layer. After each layer is created, the build platform is lowered incrementally to make room for the next layer. The part being printed is supported within the powder bed by the unbound powder, which is then removed to complete the process. The result is a "green part" which then needs to be placed in a sintering furnace to achieve final part density.

ExOne was the original metal binder jetting company, but there is a flurry of activity to release new machines using the technology since the patents have expired in the last few years. Höganäs has recently released a very capable binder jetting printer under the Digitial Metal brand, HP has announced a move to metal that is very likely use binder jetting given their inkjet core competency, and Desktop Metal's production system due out in 2019 will use binder jetting.

Advantages of Binder Jetting

Binder jetting introduced a faster and novel way to create metal parts in an additive process as compared to existing technologies such as laser sintering. PBF processes were among the first additive technologies but the high costs and slow build times prompted the need for a higher volume technology that could be cost competitive. The binder jetting machines represented a cost reduction when compared to PBF machine costs, and the throughput proved to be higher as well. The inkjet print heads offer a high level of precision and parts can be created with minute details. The build volume with binder jetting is moderate and comparable to other technologies.

- **Lower cost than PBF**
- **Fast process**
- **Established process**

Disadvantages of Binder Jetting

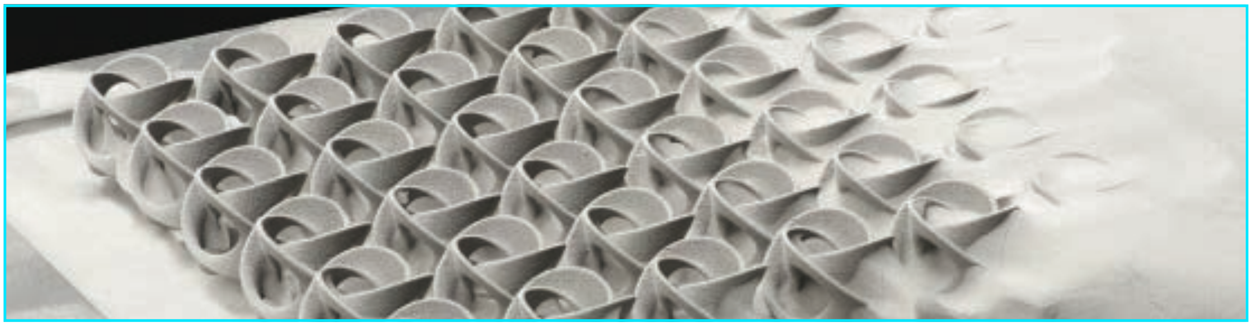
Due to use of composite materials and binding method, the material characteristics are not always suitable for structural parts. Also, despite the relatively high printing speed, the surface finish usually requires post processing and can add significant time and cost to the overall process. Often, a different metal is added to the part to stabilize it during the sintering process to prevent shrinkage when making larger parts. This metal is typically bronze and the process is called infiltration. If printing in 17-4PH stainless steel for example, up to 40% of a binder jetted part will be bronze infiltrated. This has significant implications on material properties and often precludes parts created with binder jetting from being used in many production applications. The need for infiltration is perhaps the single biggest reason for why binder jetting did not see widespread adoption when it first debuted.

- **Non-engineering material composite**
- **Degrading inkjet process**
- **Significant part shrinkage without infiltration**
- **Parts are lower in density**

Applications of Binder Jetting

While bronze infiltration might scare away engineers from trusting binder jetted parts in production, the technology has been receiving a lot of attention from new companies looking to put their own spin on binder jetting and push it to it’s full potential.

For smaller parts that do not require infiltration, binder jetting can be a very attractive option due to the high speed and detail they are able to achieve while offering lower cost parts than laser sintering. Binder jetting is in a good position to be useful for high-volume, low-cost applications.



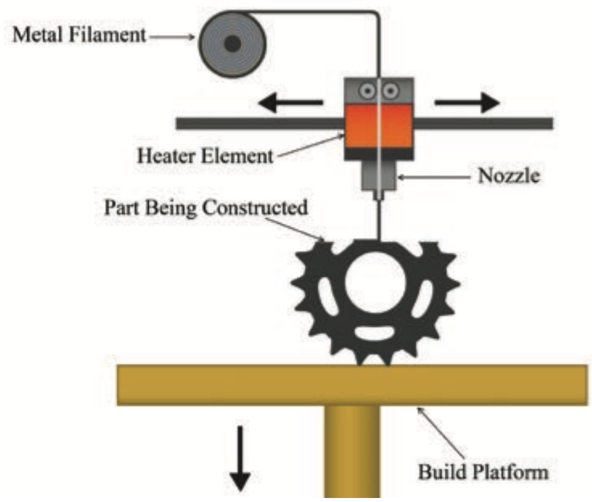
Binder Jetting by Digital Metal

METAL EXTRUSION

Metal extrusion in additive manufacturing is a fairly new process. Similar to the wildly popular plastic-based FDM process, filament is heated and drawn through a nozzle and then deposited layer-by-layer. This filament is a combination of thermoplastic material and metallic particles. The nozzle moves in the x and y axes across the part for a given layer. The build platform then lowers to make room for new layers. After the part is complete, it is placed into a sintering furnace to burn out the remaining plastic and sinter the metal particles together. Extrusion-based additive manufacturing has been widely used for plastics and polymers, but only recently has developed to create metal parts. Fused Deposition Modeling (FDM) is the name for the plastic extrusion process which was originally patented by Stratasys. Similar to binder jetting, the patent expired several years ago and the market saw a huge influx of new FDM-like processes from companies such as MakerBot, Ultimaker, and others.

Markforged uses a filament-based process in their Metal X machine, and Desktop Metal will use a similar process in their lower priced Studio System.

Advantages of Extrusion



c. Diagram of Metal Extrusion

The metal filament extrusion process benefits from the significant investment in its sister plastic-based process with regard to the advances achieved in precision and low-cost components. Building on this popular existing technology has allowed for faster development in using metal filaments instead of plastics. This FDM-like process shines when used as a prototyping technology because it can print very fine layers and achieve the precision similar to plastic models, all while being relatively low cost.

- Very low cost process
- Great for prototypes
- High precision with fine layers

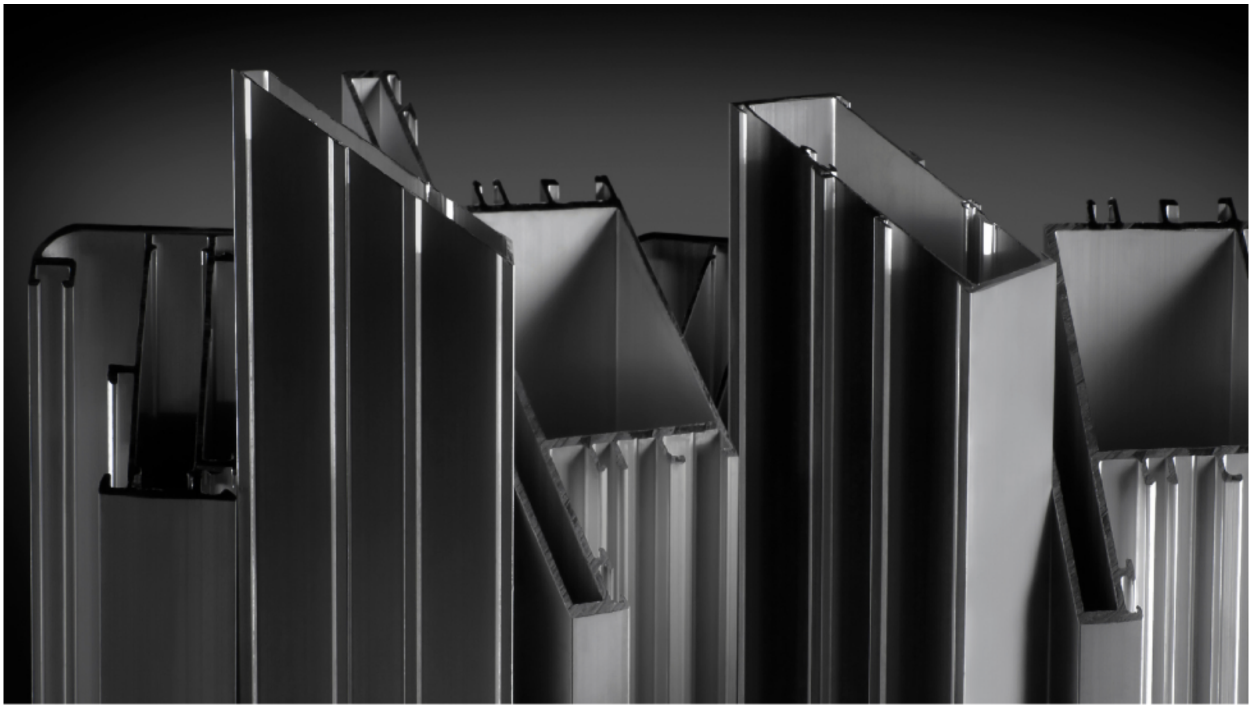
Disadvantages of Extrusion

While metal extrusion is similar to all other 3D printing processes by building its parts layer by layer, it varies due to the material being deposited through a nozzle under constant pressure and in a continuous stream. This pressure must be kept steady and at a constant speed to enable accurate results. Unfortunately, the actual application of the technology tends to leave small voids and bubbles in the part resulting from the melted mixture leaving the nozzle as it's applied in different directions. This has a significantly negative impact on final part properties and porosity. It is because of these final part limitations that manufacturers of FDM-based metal machines rarely advertise any production part applications.

- **Limited production potential**
- **High binder content makes sintering difficult**
- **Significant part shrinkage in furnace**
- **Supports may be required**
- **Parts are lower in density**

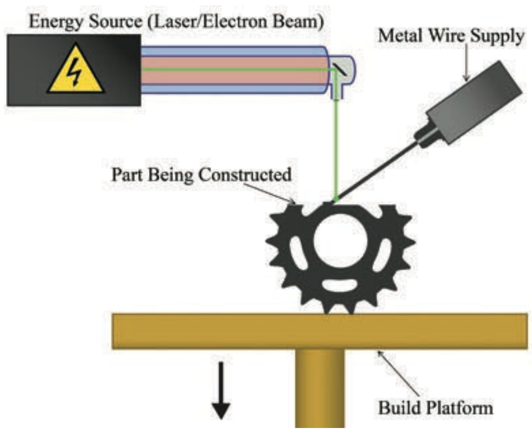
Applications of Extrusion

Though the previously discussed disadvantages preclude this technology from seeing widespread adoption for production metal components, it is not without its place in the additive manufacturing ecosystem. This is an extremely capable prototyping technology because of its fast build times and significantly reduced cost as compared to laser sintering. Metal filament extrusion 3D printing could very well become the go-to technology for cost-effective metal prototyping.



DIRECT ENERGY DEPOSITION (DED)

Directed Energy Deposition (DED) is an additive manufacturing process where metal wire or powder is combined with an energy source to deposit material onto a build tray or an existing part directly. Parts chosen for DED are typically large without the need for tight tolerances.



d. Diagram of Direct Energy Deposition

DED methods are capable of building very large parts and are popular because of the rapid deposition speed. Because it closely resembles welding, DED is commonly used to repair and maintain existing parts.

DED machines usually mount a nozzle on a multi-axis arm, which then deposits the metal feedstock to the surface. When used with 5 or 6 axis machines, the material can be deposited from nearly any angle and is melted upon deposition with a laser or electron beam. This process means DED can be used to build objects very quickly and is only limited in size by the reach of the robotic arm.

There are several branded names for both wire and powder-based DED technologies. Powder DED includes Laser Engineering Net Shape (LENS), Laser Metal Deposition-powder (LMD-p), and several others. Wire DED machines have been released to the market including Electron Beam Additive Manufacturing (EBAM) and Laser Metal Deposition-wire (LMD-w).

Advantages of DED

The rapid material deposition rate allows DED to claim the title of fastest additive manufacturing technology by a wide margin. The metal material is also melted before it cools and hardens, meaning the parts are fully dense and usable in production applications. Complex geometries can be achieved when 5-axis or better robotic arms are used and do not require supports for overhanging features like other 3D printing processes. Also, DED is the only additive technology that can effectively be used to add metal material to existing metal parts, including use in welding and repair applications.

- **Fast builds with rapid material deposition**
- **Fully dense parts**
- **No need for supports**
- **Best process for part repair**

Disadvantages of DED

The drawback with this process is the poor surface finish resulting from the melt pools cooling in low accuracy bands. DED processes use wire or powder -- wire is less accurate due to the nature of a pre-formed shape but is more material efficient when compared to powder, as only the required material is used. Speed is the greatest benefit of DED allowing for the rapid creation of large parts, but it comes with a cost. As the metal melt pools cool, they leave a very rough surface finish not dissimilar from paste coming out of a tube. For this reason, most DED parts require significant post-processing, usually in the form of secondary machining.

- **Poor surface finish**
- **Wire process is less accurate**
- **Significant post-processing requirements**
- **Limited materials**
- **Parts are very expensive**

Applications of DED

DED is an excellent choice when large parts need to be built quickly. When electron beams are used in DED processes, exotic high-temperature super alloys can be melted to create large components for industries such as aerospace and industrial power generation. DED has been used to quickly create rough approximations of large rocket motor nozzles that then undergo CNC machining to reach the final product. DED has also found use for repairing critical high-temperature components such as fan blades on large gas turbines.

MATERIAL JETTING

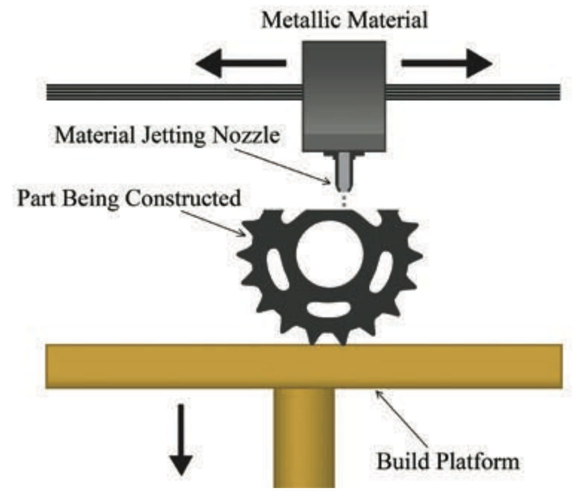
Material Jetting is relatively new and similar to binder jetting, with one key difference -- instead of a binder being jetted through the printhead, a metallic material is jetted. This material is jetted onto the build tray directly using either a continuous jetting or Drop on Demand (DOD) process. The jetted metal is deposited on the build tray in the cross section of the part for that layer. This process continues as it builds up layer after layer. The resulting part still needs to be sintered in a furnace to achieve final part density.

Previously, material jetting was limited to plastics and polymers, but recent advances have seen new companies attempting to commercialize the process for metals. XJet currently shows the most promise for material jetting with its patented NanoParticle Jetting technology and recently shipped its first commercial machine to a customer.

Advantages of Material Jetting

The metal particles being jetted are nanoscale and the resulting layer thickness is extremely thin as compared to other additive technologies. These ultra-thin layers produce very high-resolution parts where the layers are nearly invisible to the human eye. Much like metal extrusion-based additive manufacturing, material jetting does not used safely since many common metals such as aluminum and titanium are extremely combustible in powder form and require significant precautions when being handled.

- **High resolution due to nanoscale jetting**
- **Safer and easier to handle with no loose powder**
- **Very nice surface finish**



e. Diagram of a Material Jetting process

Disadvantages of Material Jetting

The downside to using very thin layers is that many more are needed for a given part size as compared to other additive technologies with thicker layers. Adding more layers takes more time, and most of the parts shown as examples of metal material jetting appear to be rather small. Since the machines are just now coming to market, the machines are still expensive with limited throughput.

- Very slow process
- Most applications limited to small parts
- Parts are very expensive

Applications of Material Jetting

The first applications of this technology appear to be in creation of small intricate parts requiring the high-level of resolution offered by the thin layering process. Small flow control valves and devices are good candidates for this technology, along with other metal parts requiring complex internal geometries and tight tolerances. Being a nascent technology, metal material jetting needs more exposure and excitement surrounding it to drive further innovation.

INTELLIGENT LAYERING® BY 3DEO

Intelligent Layering® is a new additive manufacturing process developed by 3DEO that enables medium-to-high volume metal part production. The process begins by spreading a thin layer of metal powder onto a build tray, and then uses a spray system to apply binder over the entire layer. A micro end mill is then used to cut into the bound powder at the perimeter of all layer features. From then on, the process is a layer-by-layer CNC operation until a precision green part is created. The green part is then sintered in a furnace to achieve final part density of 99% or greater. Intelligent Layering® unlocks the potential for high volume metal AM with a highly repeatable process that produces low-cost metal parts.

Advantages of Intelligent Layering®

Intelligent Layering® was specifically designed to tackle the cost and low throughput problems typically associated with metal additive manufacturing. The result is an ultra-low-cost machine that virtually eliminates machine amortization as a part cost driver. It also attacks cost through the use of commodity metal powders, which are five to ten times less costly than powders used in PBF. This process addresses both the high-cost and low throughput challenges of metal additive manufacturing. Also, there are no degrading processes in Intelligent Layering® so first part looks the same as the 10,000th. As a result of the tightly packed fine powder, 3DEO claims to have the best surface in all of metal additive manufacturing in the as-sintered state.

- **Ultra low-cost process**
- **Very nice surface finish**
- **Meets high industry benchmark MPIF Standard 35**
- **No degrading processes**

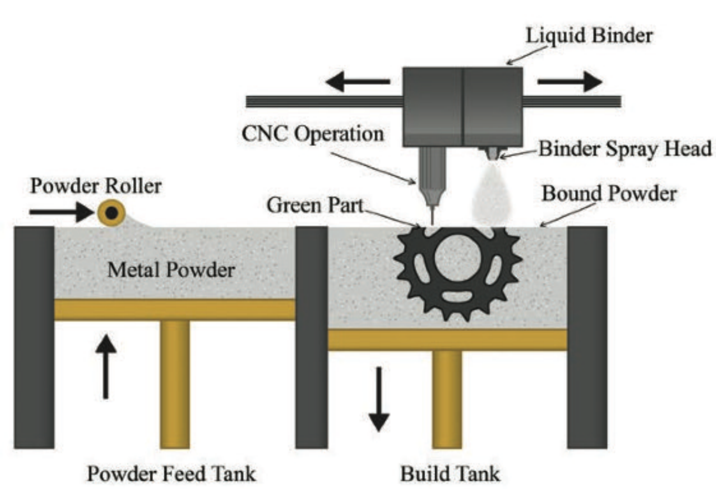
Disadvantages of Intelligent Layering®

Similar to other bind-and-sinter technologies such as binder jetting, Intelligent Layering® is currently limited by the size of parts that can be created. When metal powder is bulk sintered in a furnace, there is a certain amount of shrinkage that takes place as the voids between metal particles disappear and the particles fuse together. This shrinkage is predictable and can be dialed in for each part geometry that is encountered.

- **Significant part shrinkage in furnace**
- **Process is ideal for smaller parts**
- **Company sells parts, not machines**

Applications of Intelligent Layering®

Intelligent Layering® was created to bring metal additive manufacturing into the world volume production. The technology is a complement rather than a competitor to PBF since it is best used in higher volume applications, but is not well-suited for one-off production like PBF. The applications of this technology are vast and include many of the markets currently being served by metal injection molding including medical and dental applications, firearms components, precision gears, and many other complex metal part of limited size. The future of Intelligent Layering® lies in applications such as medical components and other industries where high volumes of complex metal parts are required on-demand and at competitive pricing.



d. Diagram of Intelligent Layering®

METAL ADDITIVE MANUFACTURING meets LOW COST

3DEO MANUFACTURING CLOUD

The demand for a low-cost metal additive manufacturing technology is extremely high. Advances in bind & sinter technologies have given new hope for metal additive manufacturing to compete on a cost-per-part basis. Bind & sinter is a category of metal 3D printing that uses a binder in a layer-by-layer process to create a “green part” that is then placed in a sintering furnace to reach full density. It’s expensive to reach over 2,400 °F no matter what process is used, and reaching it every layer is what drives up the cost of powder bed fusion. By printing green parts in high volumes on lower cost machines and then bulk sintering all the parts at once, the cost is significantly reduced. What separates different bind & sinter technologies is how the green part is created. Binder jetting uses an inkjet print head to place binder precisely on the powder bed, while 3DEO’s process Intelligent Layering® sprays binder over the powder bed and then machines each layer to create the green part with the precision of CNC.

For the first time, the part cost of metal 3D printing is so low that it can compete directly with MIM.

3DEO'S INTELLIGENT LAYERING®: BREAKING THE MOLD OF PRICE PER PIECE

Welcome to the brave new world of large-scale additive manufacturing. 3DEO's breakthrough Intelligent Layering® technology unlocks the potential of metal 3D printing in serial production by being directly competitive with traditional manufacturing in terms of part pricing, material properties, and quantities. 3DEO's part properties exceed the high industry benchmark MPIF Standard 35 while achieving tight tolerances and a superior surface finish. 3DEO's revolutionary Intelligent Layering® can reduce the price per part by as much as 80 percent compared to other production options – and reducing costs is something everyone can agree on.

Work with us to realize the benefits of Moldless Manufacturing™.

METAL ADDITIVE MANUFACTURING WITH 3DEO

True Design Freedom

With 3D printing, you have unprecedented design freedom to update and change your design nearly as quickly as you can redesign it in CAD.

Short Lead Times

Respond to market demand quickly, allow your designers to iterate swiftly, and manufacture on demand, only as necessary.

Flexible Manufacturing

Scale quantities up or down to match demand; avoid setup and minimum quantity costs with traditional manufacturing.

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