THE ULTIMATE GUIDE

BINDER JET 3D PRINTING METAL FOR MANUFACTURING

Compare the latest metal binder jetting technology to laser-based 3D printing

WHAT'S NEW?

- Print Speeds
- Design Freedom
- Low Cost and Complexity
- Superior Final Part Quality
- Scaleable for Production

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INTRODUCTION

Even in an era where we are surrounded by innovations, manufacturing many of the things we take for granted – electronics, automobiles, airplanes – still requires, and wastes, a tremendous amount of time, energy and money.

Teams of designers and engineers must create parts and products that can actually be manufactured with existing technologies. When it comes to making parts out of metal, most manufacturers still start with a billet, rod or plate. Skilled workers take these materials and use subtractive machine tools to mill, drill, and otherwise sculpt unnecessary material away, until the final part is shaped. Finally, all of these metal pieces must be shipped around the world and assembled into final products.

This metal manufacturing ecosystem is full of challenges and compromises. That's because every traditional manufacturing technology has limitations in the geometry of parts it can produce, as well as a minimum amount of time and cost it takes to make them. Oftentimes, these factors require engineers to compromise on their designs and craft many parts separately, so they can be assembled together. This is done simply because a design cannot be produced as a single unit, or fast enough, with traditional approaches.

Is an outdated manufacturing approach holding your company back from reaching its full potential and outperforming competitors?

This longstanding approach has serious downsides. For starters, subtractive processes create enormous amounts of waste that must be recycled or put into a landfill. In the aerospace industry alone, it is widely accepted that more than 95% of the material purchased to create a metal component is cut, shaved and ground away to create the final part. It's a shocking reality that has become far too easily accepted over the years: less than 5% of the metal bought to make an aircraft is actually used in the final product.

Certainly, most manufacturers work to collect and recycle as much of this waste as they can, but even the best systems return just pennies on the dollar for this so-called "metal swarf." With few better alternatives in sight, this inefficiency has long plagued the metal parts industry.

The most unfortunate part of this traditional approach, however, is how it holds everyone back. Designers, engineers, manufacturers, and really society, deals with these product limitations every day. This old way of doing things has been preventing our world from delivering more innovative and sustainable designs and products – and creating unnecessary waste along the way.

As we enter a new era focused on sustainability, a revolution is brewing in metal manufacturing. Many companies have already begun their journey with additive manufacturing – the roots of which stretch back to the 1980s. But now, after decades of development, this cutting-edge approach is ready to deliver breakout change at a time when it's desperately needed.

What is Additive Manufacturing?

Additive Manufacturing – also known as "AM" – is a highly efficient method of joining material together, usually layer by layer, to make objects from digital 3D model data. AM is the exact opposite of subtractive manufacturing, where a part is sculpted from more material than is ultimately needed.

Sometimes used interchangeably with the more common term "3D printing," additive manufacturing is the official industry term (ASTM F2792).

In its early days, AM was heralded for its ability to save time and money. This is also why many 3D printers were used for rapid prototyping and called rapid technologies. Today, there are many different AM processes – each with their own pros and cons.

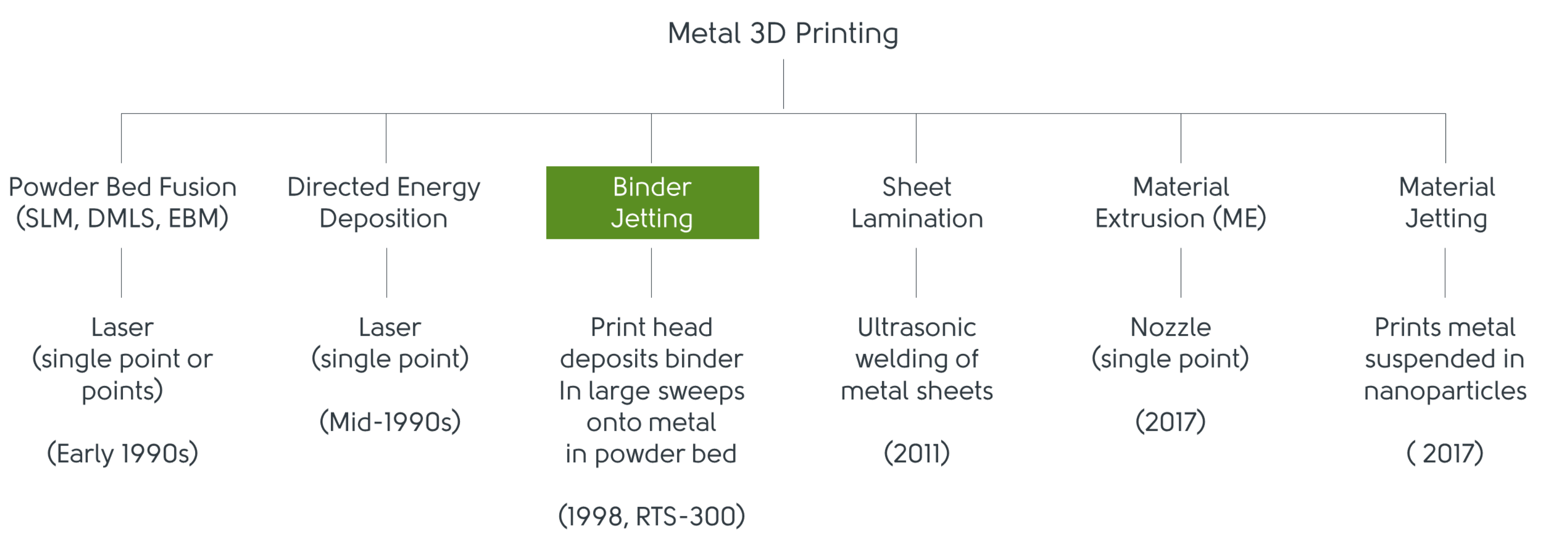
Today, there are at least six known AM processes for metals, each of which uses a different approach to join materials together into a final object. The most mature methods on the market today are powder bed fusion (PBF), binder jetting (BJ), and directed energy deposition (DED), but new methods are continually being developed. Some methods of metal 3D printing, such as material extrusion, are great for one-off production of prototypes but too slow to be considered for production.

As metal AM moves into an exciting new production era, one of its primary benefits is that it can more easily produce complex parts and systems – especially in high volumes. The simplest representation of this capability is usually a 3D printed part that has been reinterpretted with deliberate voids or empty space that reduce material and weight while preserving strength.

Yet these swiss-cheese style parts just scratch the surface of what can be done with this new approach. 3D printing technologies hold the potential to solve complex engineering challenges and deliver more sustainable products than ever before.

KEY BENEFIT

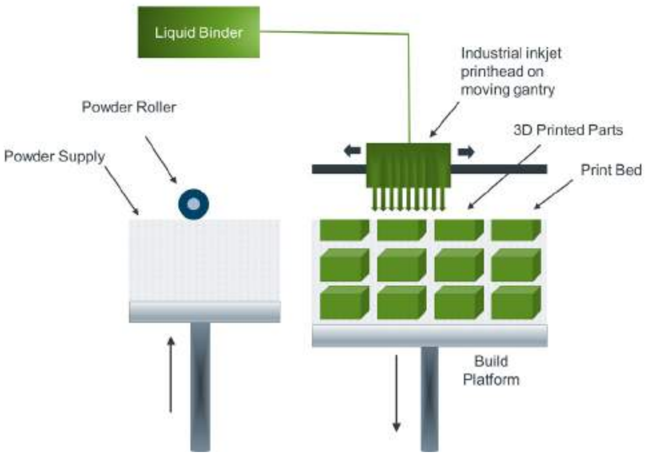
Some additive technologies can easily produce complex metal parts and systems — especially in high volumes.



Overview: Metal 3D Printing for Production

The most common forms of metal 3D printing for production in the marketplace today are also among the most mature: powder bed fusion (PBF), directed energy deposition (DED), and binder jetting (BJ). DED is also called laser cladding and is frequently used to add material to an existing part, especially for part repair.

With the exception of binder jetting, most metal AM methods print with a single point, or several fine points, within one printer, and are therefore much slower than printing with a gantry covered in print heads. This limits their ability to be considered for serial production.



Binder Jet 3D Printing

DEFINITION: A method of 3D printing in which an inkjet print head quickly deposits a bonding agent onto a thin layer of powdered particles, either metal, sand, ceramics or composites. This process is repeated, layer-by-layer, using a map from a digital design file, until the object is complete.

For metals, this process creates a "green" part that is then cured, or dried, in an oven. The part is then "depowdered" or removed from the powder bed and cleaned before final sintering in a high-temperature furnace, where the particles fuse together.

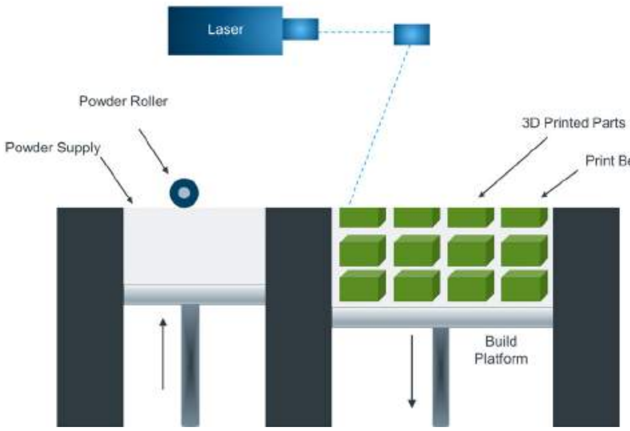
Initially developed at the Massachusetts Institute of Technology in the early 1990s, ExOne obtained the exclusive license to this inkjet-in-powder-bed approach in 1996. Two years later, ExOne launched the market's first commercial binder jet metal 3D printer, the RTS-300.

Powder Bed Fusion

DEFINITION: A method of selectively fusing regions of a metal powder bed, typically using a laser or electron-beam, one thin layer at a time, into a final part. The source rapidly melts the powder, and it solidifies as it cools.

Because printing with a single laser or fine point is slow, many systems today include several lasers within the same printer. This adds to the cost of the system, including ongoing maintenance costs. Even then, with several points drawing out parts at the same time, the systems remain relatively slow.

Common terms for this type of AM technology include: Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS) and Electron Beam Melting (EBM).



A DETAILED COMPARISON

BINDER JET VERSUS POWDER-BED FUSION

As a process, binder jetting is getting renewed attention for its ability to 3D print metal at volume-production speeds – especially when it comes to delivering precise, dense parts for high-value applications.

Some of this new attention is coming from a slate of new companies planning to enter the metal binder jetting marketplace, such as GE, HP and Desktop Metal. However, much of this interest is also coming from longtime users of powder-bed fusion processes, such as selective laser melting (SLM), direct metal laser sintering (DMLS) and electron-beam melting (EBM).

Users of those technologies have grown somewhat fatigued with the relatively slow and complex processes. What's more, the limits of those systems have also become more clear – especially when it comes to the goal of scaling them up for serial production volumes.

So, how does binder jetting really compare?

In powder bed fusion (PBF) technologies, thermal energy – applied by a laser or an electron beam – is used to fuse metal powder particles in a bed. In binder jetting, a liquid binding agent is selectively deposited by an industrial printhead to powder particles in a bed. Each process builds the part one thin layer at a time.

As a result of the different strategies, each process poses different benefits and challenges:

Thermal Considerations

When printing each layer with laser-based PBF (SLM or DMLS) or EBM, the part being printed undergoes rapid heating and cooling. In addition to leading to anisotropic material properties, this thermal stress imparted on the printed objects must be relieved before the part is used. Binder jetting is the only process where the forming or shaping of the part is executed at a consistent, low temperature. It is only after this so-called "green part" is sintered that it becomes a final part with isotropic mechanical properties.

Powder-bed fusion with a laser or electron beam requires supports during the 3D printing process.

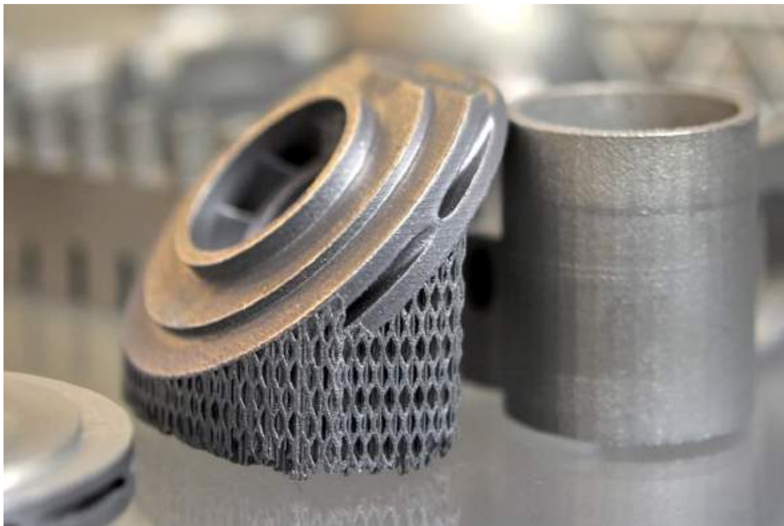
This has important consequences for the final part's microstructure, which is critical to delivering reliable functionality and performance, but it also affects other steps during the full end-to-end process.

File Preparation and Support

Because PBF methods both melt or sinter metal as they print, supports are required to build certain part features that are not yet solidified. These supports, and the part, are attached to a build plate and must eventually be removed.

PBF with a laser or electron beam requires the design of both thermal and structural supports. However, with EBM, the powder surrounding the part also slightly sinters, and the support structures needed are simpler and fewer.

Binder jetting is unique in that it requires no supports to be designed for the 3D printing process, because the build is supported by unbound powder during the lower-temperature build. However, similar to parts produced using metal injection molding (MIM), BJ parts may require the design and use of ceramic supports in the sintering furnace. These are easily removed after sintering.



Speed Considerations

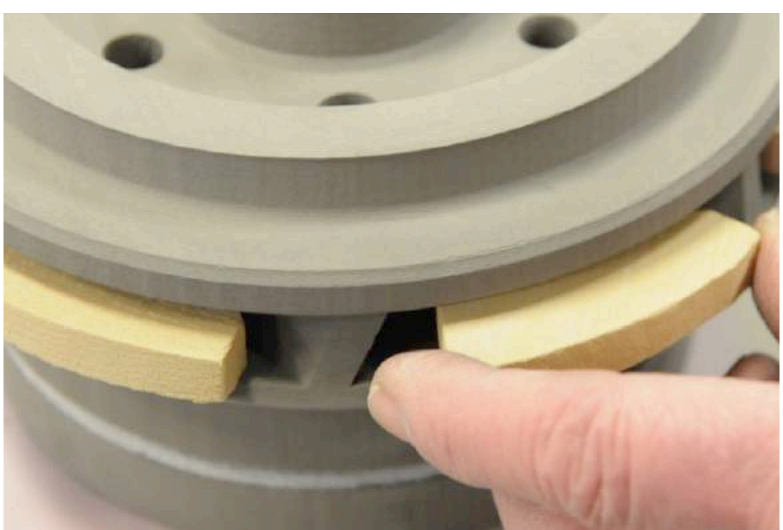
There are several ways to look at speed: time to 3D print a single layer, time to 3D print a complete part or parts, and total start-to-finish time from starting the printing process until a final, usable part is in hand.

In many cases, 3D printing may be the fastest and easiest part of the process and can decieve 3D printer buyers about the total time involved. Setup and post-print steps have their own burden in time and complexity that must be considered to truly evaluate total cost of ownership and part creation.

In printing time alone, one must also consider the number and volume of parts being built. For example, while binder jetting is regarded as the fastest printing strategy, EBM may, at times, outperform binder jetting for the printing of a single unit when one considers other necessary binder jetting process steps such as curing and sintering. However, laser-based PBF methods are often the slowest when considering total end-to-end process time.

The more parts that are added, the more advantageous binder jetting becomes. That's simply because laser-based PBF and EBM must draw out each part's layer individually with a single point, whereas the number of passes an inkjet must make to process parts in a single bed is the same, whether it contains one or many units.

While many laser 3D printing systems now contain multiple lasers, the build speed is still significantly slower than binder jetting, and it is unknown whether the additional lasers cause more thermal stress in the part. Thus, the added 3D printing time to produce four units with a laser and EBM is typically several multiples of the time it takes to print one unit. In binder jetting, meanwhile, it depends on how many units can fit in the printer's build volume, and if the four units all fit in one bed, the added time may simply be 5-10% more than the time it takes to build one unit.



Necessary Processing Steps

PBF and binder jetting processes all have unique processing steps and tasks that are required before, during and after the 3D printing is complete. All of these steps vary in terms of time required, as well as complexity and operator skill requirements.

For binder jetting, depowdering a bed to remove green parts, curing and sintering are all core to the process. Resetting the machine takes less than an hour.

Both laser-based PBF and EBM, meanwhile, require skilled machine preparation including cleaning and component changes, which takes significant time, usually about 2-3 hours. After printing, laser melting requires the part to be de-stressed for several hours at 400-800°C to relieve thermal issues caused by the rapid heating and cooling during the build. Removing supports is required for both PBF methods, with laser melting methods requiring machining.

Final Part Microstructure

When examining the microstructure of the final part, research conducted by ExOne and presented at the 28th Annual International Solid Freeform Fabrication Symposium shows that both EBM and SLM produce columnar grain structures with relatively large grains, while the binder jetting process generates a fine equiaxed grain structure. Size and shape of the final grain size is an essential factor in determining the final mechanical properties of the component. The uniform microstructure that binder jetting produces results in isotropic mechanical properties and good fatigue life.

Binder jetting does not require supports during 3D printing, but may require removable supports during sintering.

Comparing Metal 3D Printing Processes

Binder jetting is a faster, less complex process with a lower operator burden than other metal 3D processes, as demonstrated in a research study, "Operator Burden in Metal Additive Manufacturing," conducted by Oak Ridge National Laboratory and presented at the 27th Annual International Solid Freeform Fabrication Symposium. **The study is available at www.exone.com/metal3Doperation**

Machine Training Required

File Preparation

LASER-BASED POWDER BED FUSION (SLM, DMLS)

2 Weeks + 30 Hours Hands-On	Design Thermal Supports	Design Structural Supports	Vacuum and Inert Procedure	Monitor 3D Printing for Curling & Swelling

Laser melting is a complex process that delivers relatively slow print times, requires thermal destressing of the part, and also requires skiled labor for at least seven steps in this process. After support removal, no post-processing is required but may be desired.

ELECTRON BEAM MELTING (EBM)

2 Weeks + 40 Hours Hands-On	Design Thermal Supports	Vacuum is Pulled on Build Chamber	Monitor 3D Printing for Curling & Swelling	Blast Sintered Powder from Part

EBM is a complex process that delivers relatively slow print times and also requires skiled labor for at least seven steps in this process. After support removal, no post-processing is required but may be desired.

BINDER JET 3D PRINTING (BJ)

3 Days, All Hands-On	Design of Sintering Supports	Binder Jetting Process at High Speeds	Build Box is Moved to Oven for Curing	Parts are Depowdered From Build Box

While Binder Jetting has more core process steps, they are far less complex than with other processes and print speeds are much faster, especially for higher volumes. After sintering, no post-processing is required but may be desired.

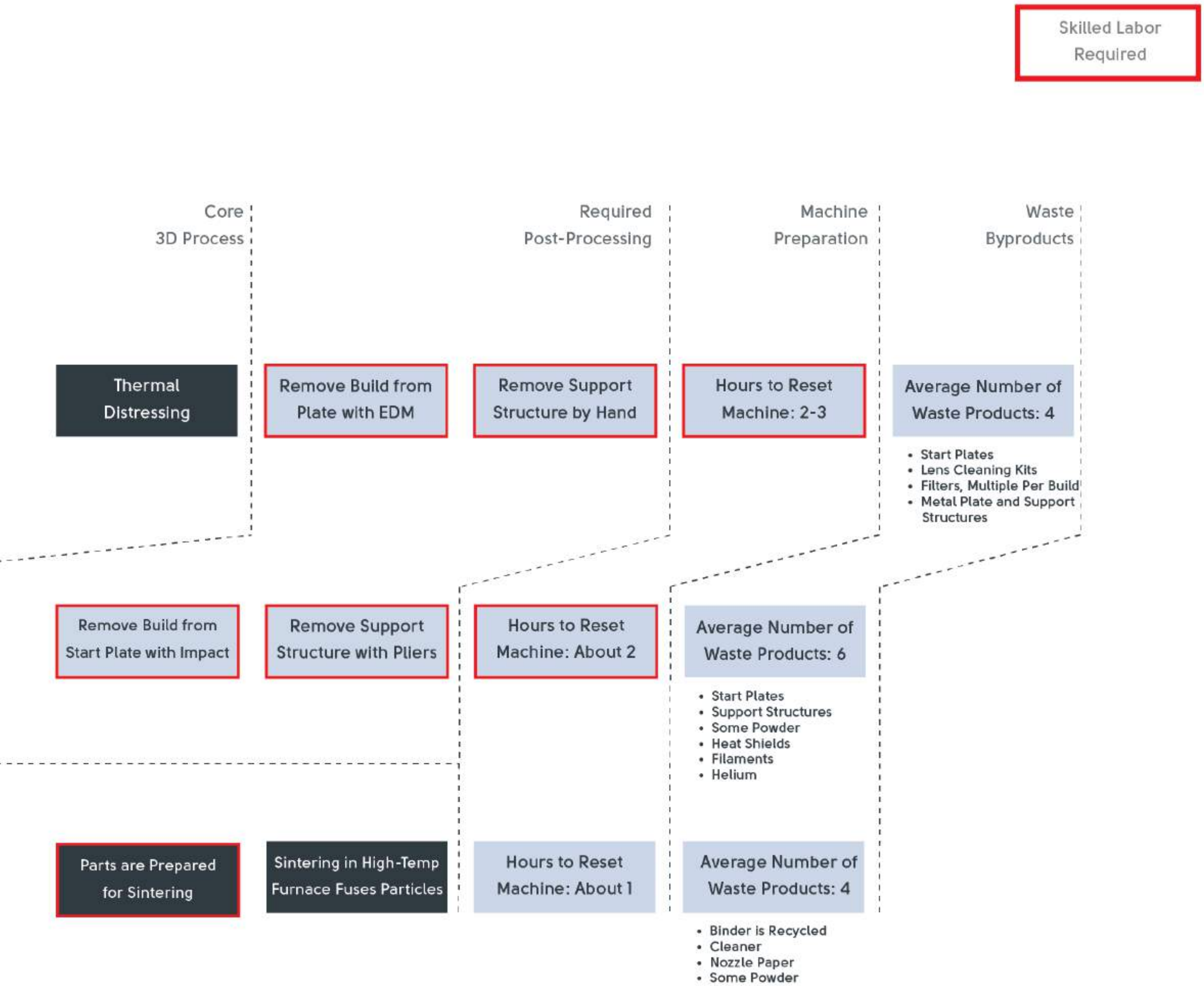
A Closer Look: Differing 3D Metal Microstructures

Binder jetting is the only form of metal powder 3D printing where a part is fully formed before any thermal energy is used to sinter or fuse the metal particles together. This has important consequences for the final part's microstructure, which is critical to delivering reliable functionality and performance.

In binder jetting, a liquid binding agent is selectively deposited through an industrial printhead onto a thin layer of powder particles at a consistent, lower temperature. This process is repeated one layer at a time until the final part is complete. It is only after this so-called "green body" is cured and then sintered at high temperatures – where the particles fuse together isotropically – that the object becomes a final part.

By contrast, when drawing out each layer with a fine laser point or points, the part is hot where the build or melt point is active and particles are being fused together. Other areas of the 3D print, meanwhile, are in a state of cooling, causing inconsistent bonding where particles are mated later during the build, especially in the Z axis. This requires the part to later be thermally de-stressed because of the inconsisent nature of the microstructure or the thermal gradients created during the printing process.

Research conducted by ExOne, and presented at the 28th Annual International Solid Freeform Fabrication Symposium, demonstrated important differences in the microstructures of metal parts 3D printed with binder jetting, SLM and EBM. The research is available online at www.exone.com/metal3Dmicrostructures



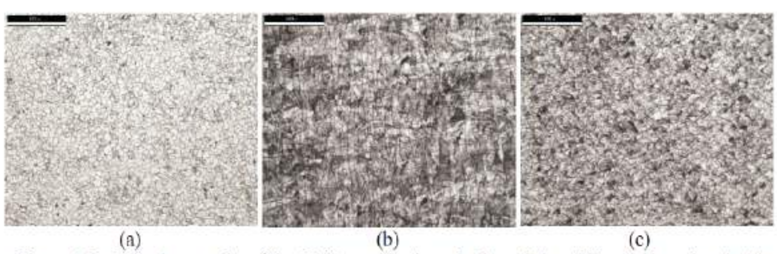


Figure 14. OM micrographs of the 316L samples in etched condition (Glyceregia etchant): (a) BJ 50x; (b) EBM 50x; (c) DMLS 50x;

CONCLUSION

When it comes to volume production of metal parts using AM, binder jetting is a superior choice. It offers the fastest and least complex end-to-end process, delivering the most affordable option for manufacturing complex geometries.

What's more, as the only metal AM process that fuses metal powders all at the same time, it delivers a superior final part microstructure.

LET'S SOLVE THE TOUGHEST PROBLEMS.
AND CHANGE THE WORLD.

ExOne™

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Meet the X1 160PRO™ metal 3D printer — ExOne’s tenth and largest metal 3D printer. Featuring the exclusive Triple ACT system for delivering industry-leading part density and repeatability with binder jetting technology.