METAL BINDER JETTING VS. LASER POWDER BED FUSION

AZOTH INC.

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ABOUT US

Azoth is a world-class, vertically integrated manufacturing company founded in 2018, and headquartered in Ann Arbor, Michigan. We specialize in manufacturing small and complex parts leveraging production-capable additive (3D) manufacturing technology. We offer over 45 different polymers and metals to ensure the right material, process and technology is used in every application.

Azoth's additive technology is a disruptive force in traditional manufacturing through its quick production lead times and **TOMO®** (Take One Make One). The TOMO process is designed to convert physical inventory to digital inventory eliminating supply chain disruptions, inventory obsolescence and saving its partners significant inventory costs and cash flow.

Not just another service bureau – **Azoth is your dedicated manufacturing partner**.

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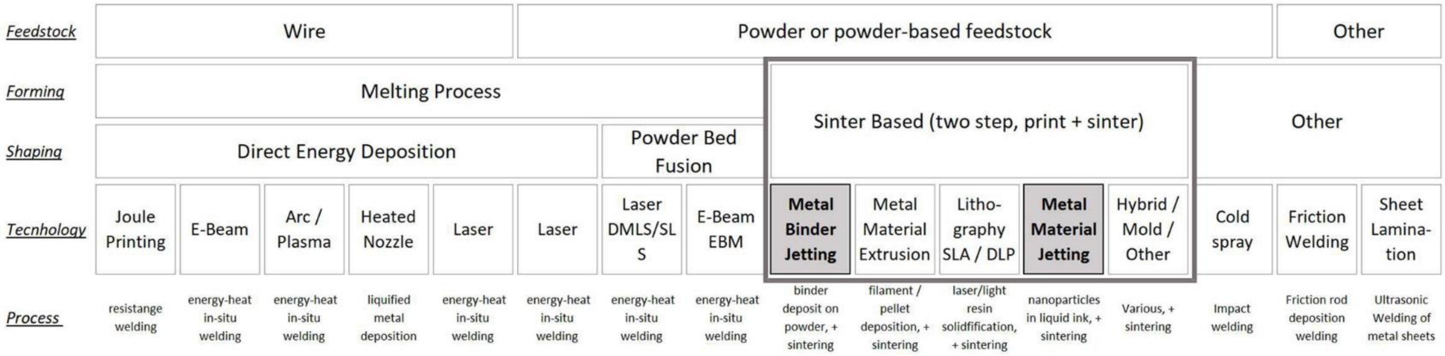
INTRODUCTION: METAL ADDITIVE MANUFACTURING

Additive Manufacturing (AM), also uniformly known as 3D printing, is a manufacturing method of joining material together, usually layer by layer, to make objects from digital 3D model data.

Today, there are many known AM processes for metals, each uses a different process to fabricate a final object. Although many of the technologies are still very limited or in development, each one has their own advantages for their own niche application field. The most common and mature additive manufacturing technologies are those that have proved to be the most efficient in delivering engineering solutions across many different industries and applications. These are namely Metal Binder Jetting (MBJ), and Laser Powder Bed Fusion (L-PBF), also known as Direct Metal Laser Sintering/Melting (DMLS / DMLM).

Metal Additive Manufacturing Technologies Overview



Feedstock	Wire					Powder or powder-based feedstock									Other	
Forming	Melting Process								Sinter Based (two step, print + sinter)					Other		
Shaping	Direct Energy Deposition						Powder Bed Fusion									
Tecnhology	Joule Printing	E-Beam	Arc / Plasma	Heated Nozzle	Laser	Laser	Laser DMLS/SLS	E-Beam EBM	**Metal Binder Jetting**	Metal Material Extrusion	Litho-graphy SLA / DLP	**Metal Material Jetting**	Hybrid / Mold / Other	Cold spray	Friction Welding	Sheet Lamina-tion
Process	resistange welding	energy-heat in-situ welding	energy-heat in-situ welding	liquified metal deposition	energy-heat in-situ welding	energy-heat in-situ welding	energy-heat in-situ welding	energy-heat in-situ welding	binder deposit on powder, + sintering	filament / pellet deposition, + sintering	laser/light resin solidfification, + sintering	nanoparticles in liquid ink, + sintering	Various, + sintering	Impact welding	Friction rod deposition welding	Ultrasonic Welding of metal sheets

METAL BINDER JETTING

The metal binder jetting process is a two-step process where the components are printed and densified in separate steps. The printing step consists of high-precision binder jetting printing on metal powder bed. Metal Powder is bonded together when binder is selective dispensed on the powder bed. In a cyclical way, the powder bed is lowered and recoated with additional loose powder on top to form the next layer. This is done layer by layer until the whole build box is used and filled with metal powder. The printed components are now located in three dimensions inside the build box, supported by loose metal powder. The printed components are at this stage in a green state (powder components that have not yet been sintered for final strength). The green components are then cleared from powder with vacuum and compressed air in a closed environment. The green components are then placed on ceramic plates and densified in a following sintering step. The components will shrink during the sintering. It is in this step that the metal particles fuse together, and the component receives its strength, density, and material properties. The shrinkage is usually very well controlled and does normally not need to be compensated for by the designer. The compensation is done by Azoth's software. There are however a couple aspects to take into consideration, since in some cases there can be risk of deformation and distortion during the sintering if the design is not suitable.

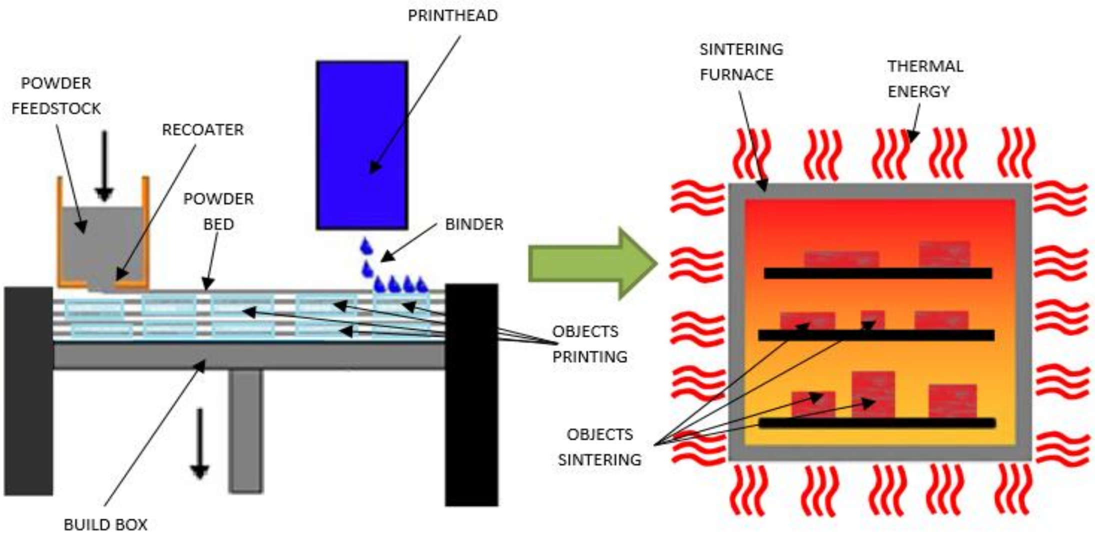


Figure 1 Metal binder jetting: Process consists of low temperature printing followed by uniform sintering (Image: Azoth).

LASER POWDER BED FUSION

The laser powder bed fusion process is a one-step process where the components are printed by melting powder one point at the time. Specifically, in this process a laser provides thermal energy to melt the powder in a point in the powder bed. The laser operates selectively across the powder bed until a full region is melted together. Subsequently the powder bed is lowered and recoated with additional loose powder on top to form the next layer. The process repeats in a cyclical way fusing together the metal powder point by point, and region by region, and layer by layer. In this process, a great amount of thermal energy is applied in a single point, there are many important aspects to take into consideration. The printed components need to be attached to the build plate and supported in such a way the withstand the process. The components will deform and distort during printing if not properly designed and supported.

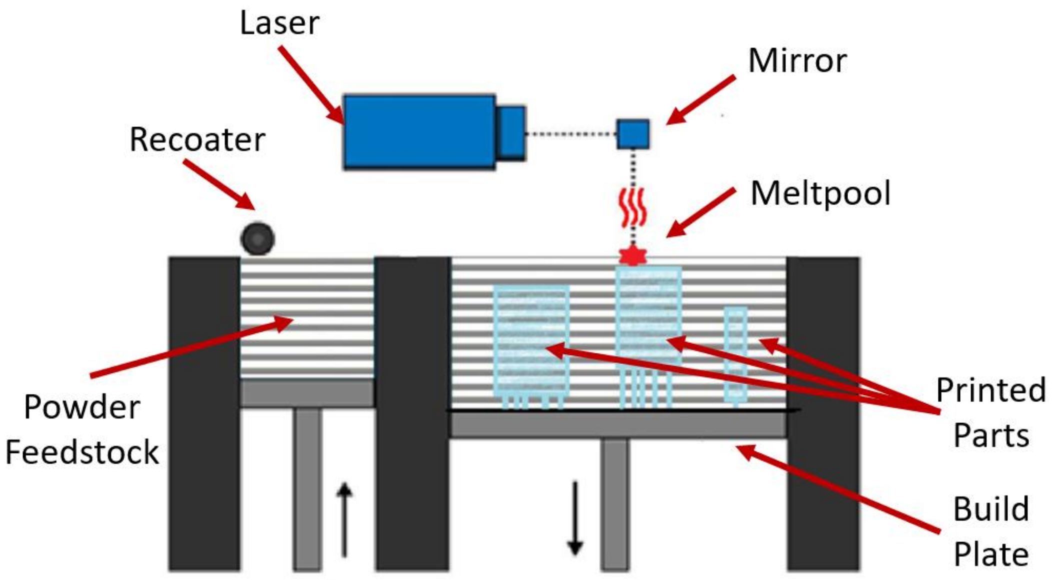


Figure 2 Laser powder bed fusion: Process consists in high temperature single point melting (Image: Azoth).

COMPARISON: METAL BINDER JETTING VS LASER POWDER BED FUSIONS

Metal binder jetting is getting a lot of attention for its capability of printing very complex components that do not follow the normal rules of other standard manufacturing processes. The process is ideal for low to high volume manufacturing of small complex components with high tolerances and fine surface roughness with minimal need for post processing. The process is suitable for many industries and applications.

Laser powder bed fusions (L-PBF) have proven advantageous for applications in which innovative designs are required, especially in high value applications. Due to its maturity, many excellent applications have been successfully pursued across multiple industries. Generally, the process is most advantageous for printing medium-large size components pushing the engineering limits for advanced applications, as in aerospace. Laser Powder Bed fusion is largely used for functional prototypes and low volume production. However, the limits of this technology have also become clearer, especially when it comes to the goal of scaling up serial production volumes.

To summarize, the main difference is that laser powder bed fusion thermal energy applied by the laser is used to fuse metal powder particles in a bed. In metal binder jetting, a liquid binding agent is selectively deposited by an industrial printed to powder particles in a bed, and the following sintering step is used to uniformly fuse the particles together. 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

In laser powder bed fusion, each point of the printed part undergoes rapid heating and cooling. This local heating and cooling lead to anisotropic material properties. Moreover, the printed object is subject to high thermal stress and must be relieved via a high temperature heat treatment before the part can be used. Due to the nature of the L-PBF process, it is limited to weldable materials.

Instead, metal binder jetting is a unique additive manufacturing process in which the part is formed at a uniform low temperature process. After the part is formed, the part is fully sintered in a high temperature furnace under controlled atmosphere to become a final part with isotropic material properties.

This process affects many other steps during the full end-to-end manufacturing process. Most significantly, this has consequences to the metallurgical microstructure, which is critical to deliver the proper mechanical properties necessary for the part performance and functionality.

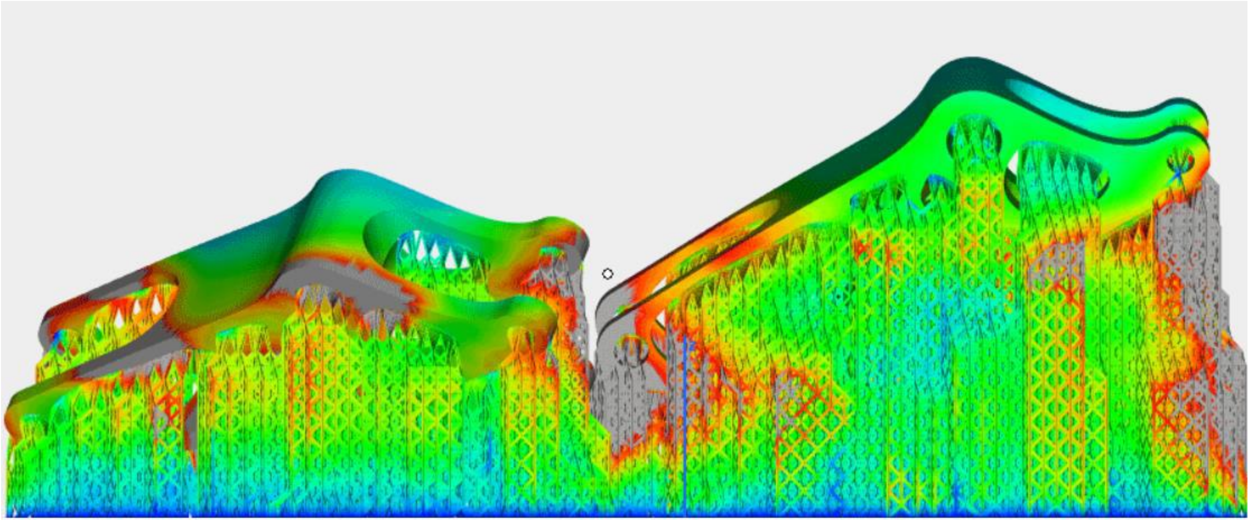


Figure 3 Laser powder bed fusion: thermal supports required for printing (Image credit: Materialize).

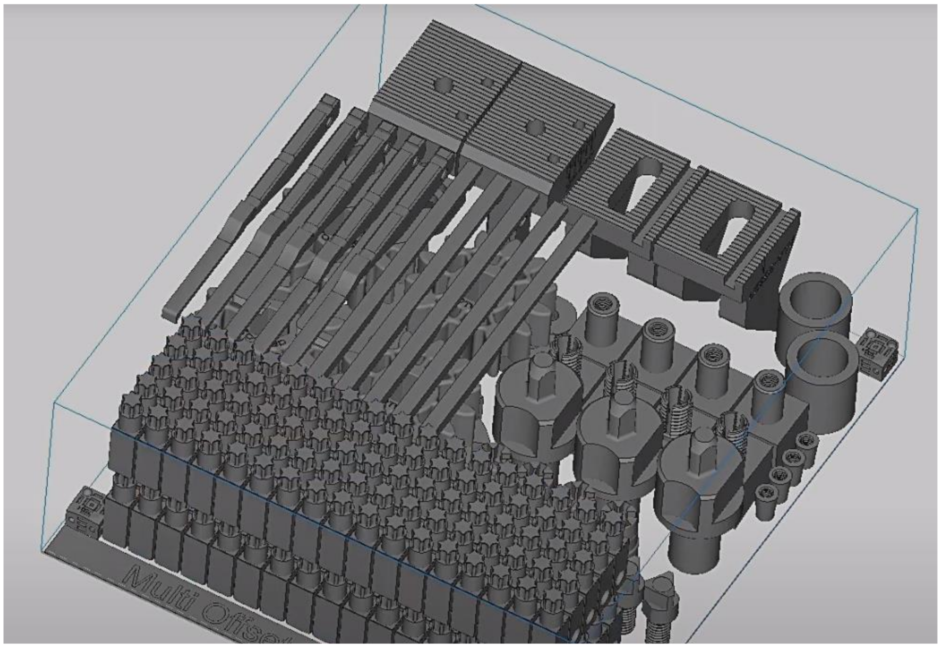


Figure 4 Metal binder Jetting: Parts are printed floating in powder, no support required. (Image: Azoth)

FILE PREPARATION AND SUPPORT DESIGN

In laser powder bed fusion, supports are required to build and sustain features that are not yet solidified. This is because the process melts metal as it prints. The parts must be attached to the build plate with these supports, that eventually need removed via machining or other mechanical methods. To prepare a digital part for printing, powder bed fusion requires the engineering and software capabilities to design both thermal and structural supports.

Metal 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 low-temperature build. However, particularly intricate parts may require the design and use of supports in the sintering furnace. These are easily removed after sintering. The sintering supports can be made of ceramic or separated by other metal 3D printed components. Azoth has expertise in the design of these sintering supports.

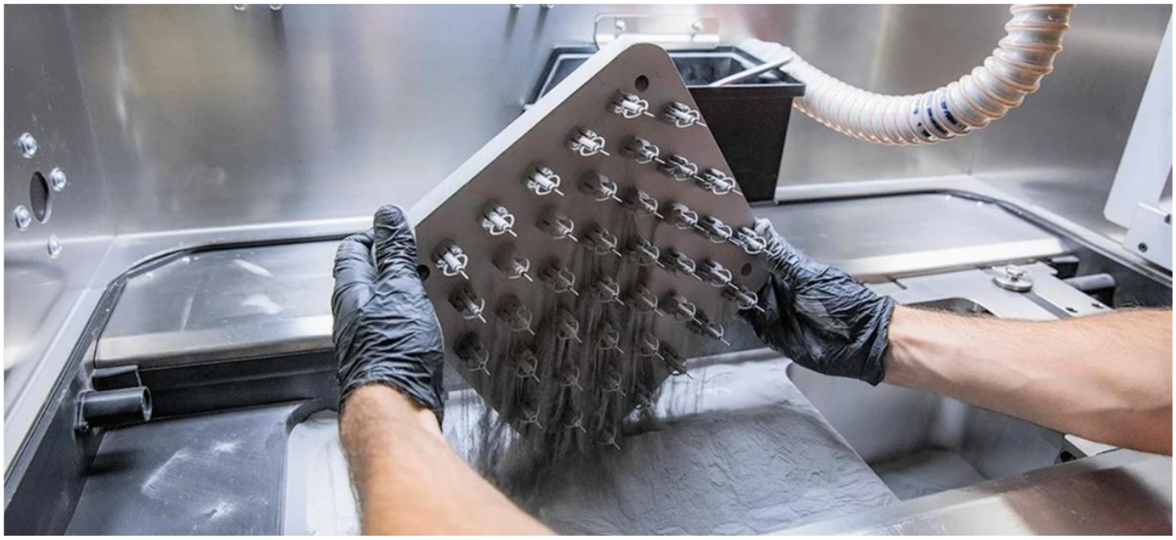


Figure 5 Laser powder bed fusion: parts must be supported and attached to the base (Image credit: Fabaloo)

Figure 6 Metal binder jetting: Parts are printed floating in powder, no support required. (Image: Azoth)

NECESSARY PROCESSING STEPS

Same as any traditional manufacturing process, both metal binder jetting and laser powder bed fusion require a set of processing steps and tasks before and after printing. These steps vary in requirements and complexity.

For metal binder jetting, printed parts are removed from the build box simply by blowing away the loose powder and are then moved to the sintering furnace.

For laser powder bed fusion, after printing, parts need to be de-stressed for several hours at high temperature via heat treatment to relieve thermal stress caused by the rapid heating and cooling during the build. Moreover, removal of the supports is required via machining or other mechanical methods.

Figure 7 Laser powder bed fusion: supported much be machine away (Image credit: Conteo AG)

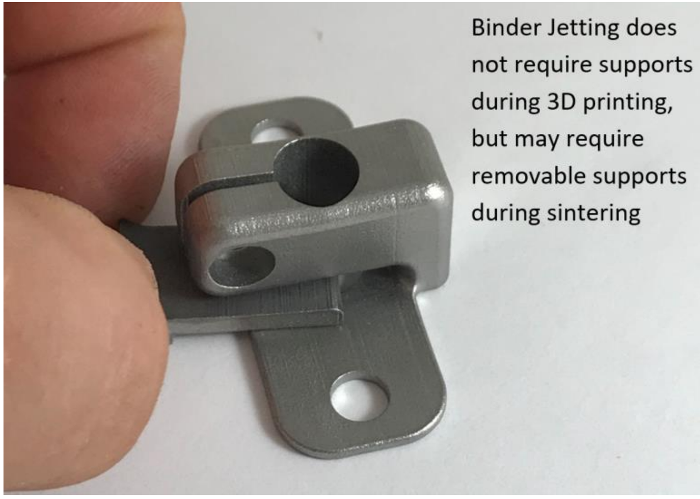


Figure 8 Binder Jetting: does not require supports during printing, but may require removable supports during sintering (Image: Azoth)

FINAL PART MICROSTRUCTURE

When examining the microstructure of the final part, laser powder bed fusion produces columnar grain structures with relatively large grains, while the metal binder jetting process generates a fine equiaxed grain structure. Size and shape of the final grain size is an essential factor in defining the final mechanical properties of the component.

The uniform microstructure that metal binder jetting produces results in isotropic mechanical properties and good fatigue life. The typical microstructure of type 316-L stainless steel produced via binder jetting stainless steel consists of austenite grains and annealing twins. The metal binder jetting material shows superior grain isotropy compared to most competing 3D metal printing technologies.

In comparison, a cross-section of a part produced by laser powder fusion shows anisotropic grain structure, which will introduce orientation-dependence physical properties (e.g., tensile strength may be different along X and Y axes in the powder bed and along the Z-axis). During the laser powder bed fusion process, the part is hottest where laser is active and particles are melted together, meanwhile other areas of the part are in a state of cooling. This causes inconsistent bonding where particles are melted together later during the build, especially in the Z-axis. This requires the part to be later thermally de-stressed by a high temperature heat treatment because of the inconsistent nature of the microstructure and thermal gradients created during the printing process.

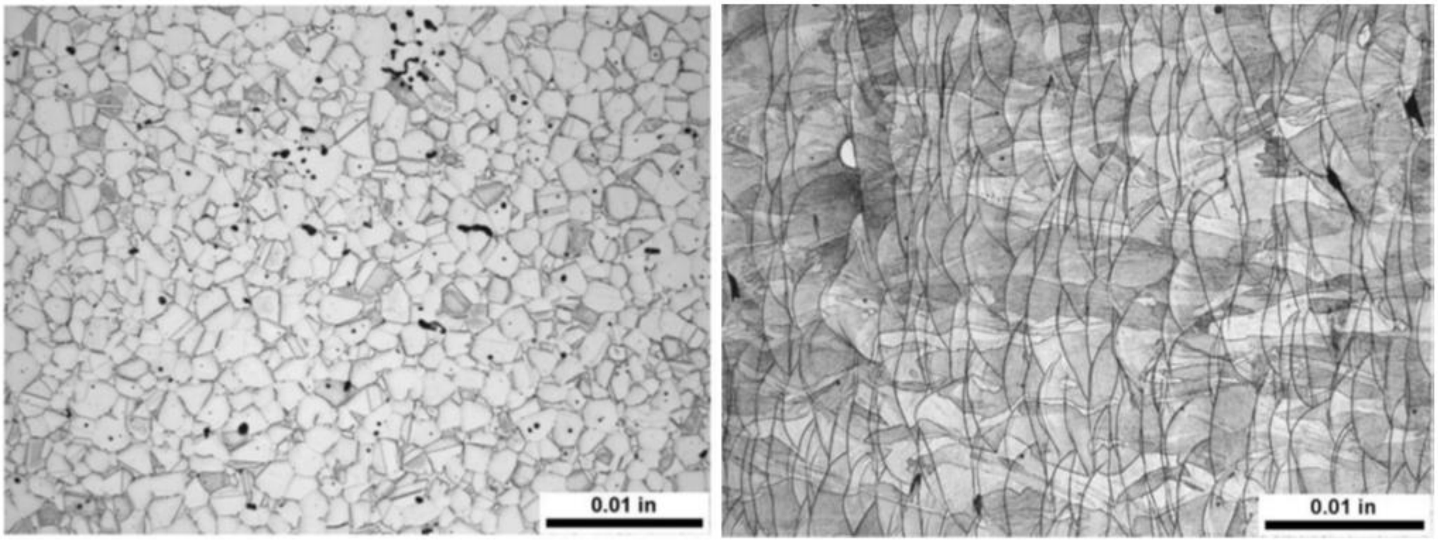


Figure 9 Microstructure comparisons of 316-L manufactured via Binder Jetting (left) and Powder Bed Fusion (right) (Image credit: Element Materials Technology)

RESOLUTION AND TOLLERANCE

The high-precision metal binder jetting process is capable of printing very fine and detailed components. Surfaces can contain text, logos, and textures. The resolution is 35μm. Minimum features size as low as 0.1mm can be printed. Metal binder jetting typically reaches a dimensional tolerance of ± 1.5% for outer dimension and at best ±0.75% for well-defined parts (± 0.05mm at best).

Laser powder bed fusion is capable for well-designed parts to reach tolerances of ± 50μm at best, or typically ± 0.5% of outer dimensions. The typical resolution is 50μm. Many design considerations may be required to make a part suitable for the process, and generally the minimum feature size must be above 0.35mm.

In both processes, features requiring higher tolerances can be milled after printing.

SURFACE FINISH

In laser powder bed fusion, the thermal energy is provided by a laser. The laser provides energy directly to the melt pool, however, some of the energy scatters around the melt pool, causing a rough edge and loose powder to partially melt to the part without being completely fused. This causes a rough surface finish, typically around 10μm Ra. Moreover, the loose metal powder partially melted to the part could be become loose while the part is used in the field. Parts manufactured via powder bed fusion require detailed cleaning for any loose metal powder before use. However, some features, such as internal channels, are difficult to clean and powder detachment from the surface could occur.

Differently, in metal binder jetting the light scattering issue is not preset. Moreover, the metal particles are fully fused together during the sintering step, including all the surface particles. Metal binder jetting leads to 3μm Ra surface finish in the condition supplied by Azoth, Isotropic Super Finishing (Polishing) options are available for final surface finish <1μm Ra.

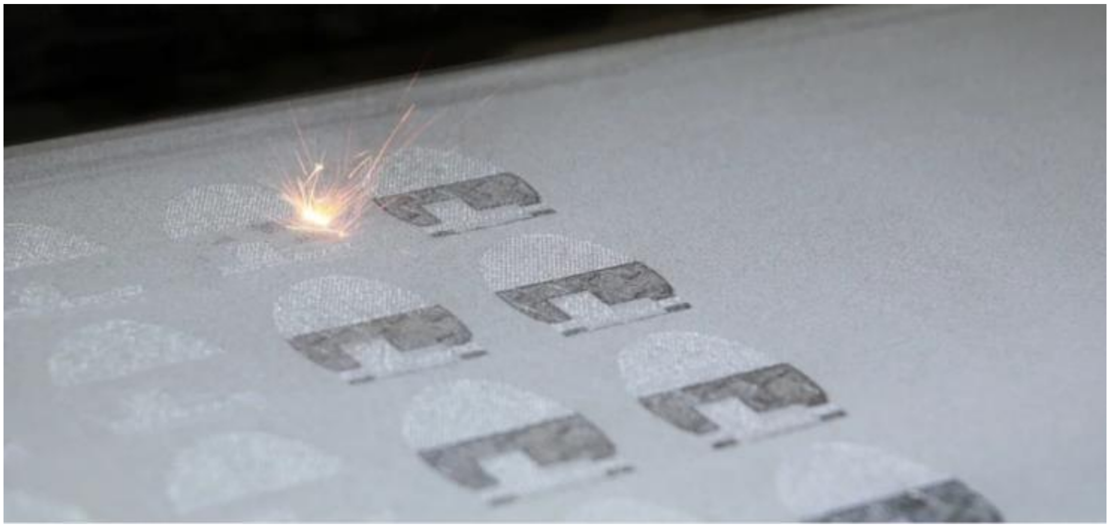


Figure 10 Powder Bed Fusion: laser scattering cause rough surface finish and partially unfused metal particles (Image credit: EOS)

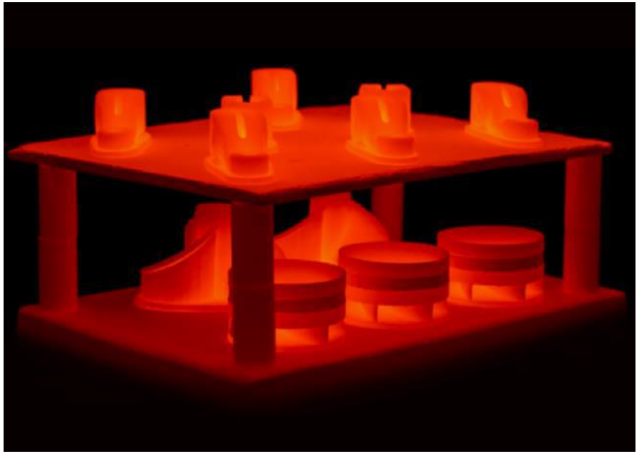


Figure 11 Binder Jetting: metal particles are fully fused together in the sintering process (Image credit: Digital Alloy)

COST AND LEAD TIME

In most cases, cost and lead time are the deciding parameters for setting up any part design and manufacturing process.

Generally, the most direct cost is from part volume, since it directly reflects the material usage, while the equipment capital investment is directly reflected on the final part based on overall part dimensions. Many other factors need to be taken into consideration, such as the engineering skillset required for Additive Manufacturing.

For prototype and very low volume production, cost is similar between metal binder jetting and laser powder bed fusion, with the latter being slightly higher due to the higher equipment complexity.

When compared to traditional manufacturing methods, both metal binder jetting and laser powder bed fusion can be cost competitive. What usually makes additive manufacturing extremely advantageous is prototype or low volume applications, with lead time of just a few days in most cases. Generally, metal binder jetting is faster since there is no post processing required.

	Metal Binder Jetting (Azoth)	Laser Powder Bed Fusion (Typical)
*Prototype cost per part**	1x	1.5-5x
*Prototype process speed**	1x	1-1.5x
*Production cost per part**	1x	10-100x
*Production process speed**	1x	10-100x
Applications	Prototype and production	Prototype, small volume production
Volume	Any, low to high	Low only
Resolution	35 µm	50 µm
*Tolerance - at best***	± 0.75%	± 0.50%
Tolerance - typical	± 1.5% of outer dimension	± 1.0% of outer dimension
Minimum feature size	0.1mm	0.35mm
Material properties	Isotropic	Anisotropic, residual stresses
Surface finish	3 µm Ra standard <1Ra polished	10 µm Ra
Post processing step	n/a	Supports machining

*On small parts below 50mm in largest dimension

**On adequately designed parts

ECONOMIES OF SCALE

In considering cost, one must also consider the number and volume of parts being built.

The more parts that are added, the more advantageous metal binder jetting becomes. That is simply because laser powder bed fusion must draw out each parts 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 dozens or hundreds of units. This difference becomes extreme on small parts below 50mm in largest dimension.

While metal binder jetting is regarded as the fastest and cheapest metal printing strategy, laser powder bed fusion may, at times, outperform binder jetting for the printing of a single unit, or for the printing of larger parts. However, laser-based powder bed fusion methods are often the slowest when considering quantities above very low volumes. 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, contributing to the final part cost. Even then, with several points drawing out parts at the same time, the system's overall speed remains relatively slow.