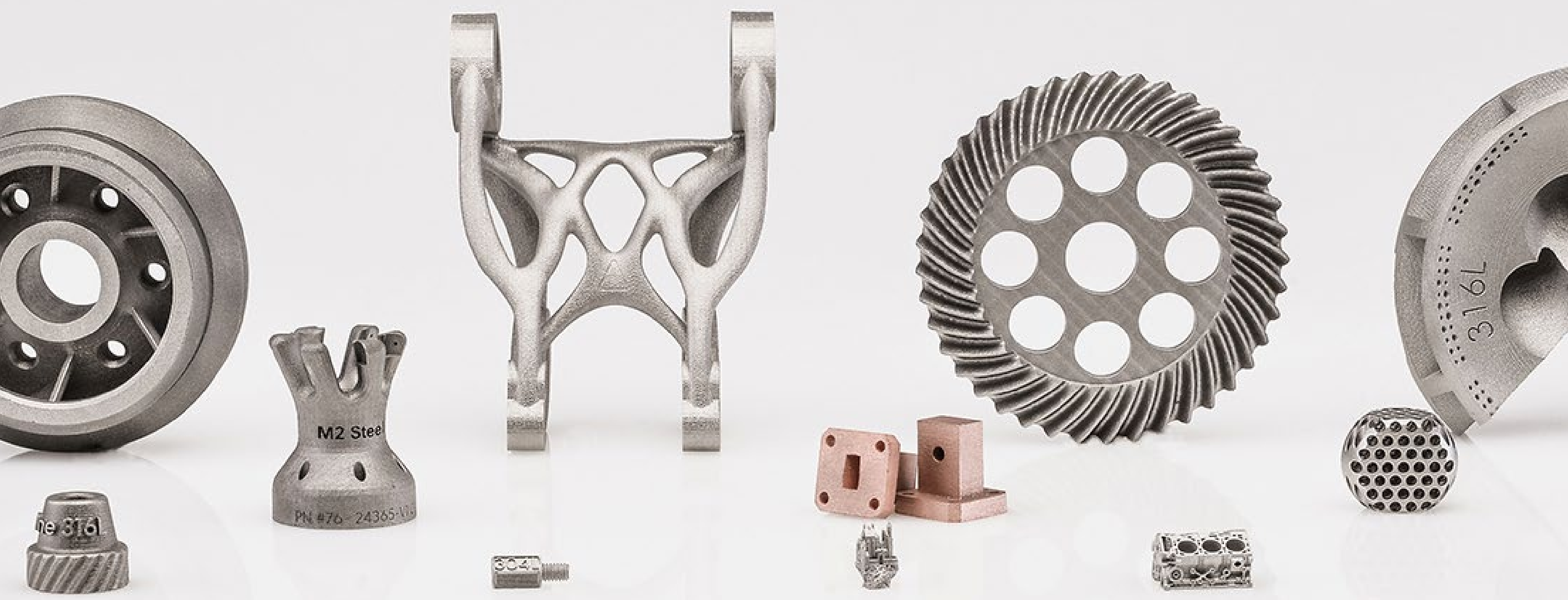
THE ULTIMATE GUIDE to

Laser-Free Metal 3D Printing with Binder Jetting Technology



Desktop Metal®

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About this Guide

This 40-page guide is the most authoritative introduction to date on metal binder jetting — the most promising ASTM-recognized 3D printing technology for the mass production of metal parts and products.

Written by Desktop Metal, the global leaders in binder jetting technology, this guide contains a comprehensive overview of high-speed 3D printing of metals without a laser. In binder jetting, an inkjet printhead — similar to those used in a paper printer — applies a liquid binder to powdered metal one layer at a time to create a desired object. Similar to parts created with Metal Injection Molding (MIM), the printed object is then sintered to high density in a furnace.

Desktop Metal was co-founded by Prof. Ely Sachs of the Massachusetts Institute of Technology, the inventor of binder jet 3D printing, and is home to a team of experts that has commercialized more than a dozen metal binder jetting systems since 1996 as the technology has matured.

Inside this guide, you'll take a deep dive into what makes binder jetting a truly special and advantageous approach in the metal 3D printing marketplace — one that is drawing new entrants into the field, such as HP and GE.

We'll cover these topics:

- Binder jetting's unique benefits in metal manufacturing
- Ideal applications for metal binder jetting
- Inkjet printheads as an industrial power tool
- Printer system design approaches and considerations
- An overview of powder, binder, and printing recipes
- The future of binder jetting aluminum and titanium
- How binder jetting compares to laser powder bed fusion
- The rapid evolution of binder jetting in the marketplace

Explore why binder jetting holds the keys to enabling the next era of Additive Manufacturing 2.0, which can unlock the innovation, agility and sustainability benefits of 3D printing in meaningful high volumes.

Introduction

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

Teams of designers and engineers must design parts that can be produced with existing manufacturing technologies – all that equipment you see on a factory floor that transforms raw materials into finished parts.

When it comes to making metal parts, most of the world still starts with a billet, rod, or plate of material. Then, skilled workers use subtractive machine tools to mill, drill, or otherwise sculpt unnecessary material away, until the final part is shaped. Finally, these metal pieces must be shipped around the world and assembled into their final products.

This traditional metal manufacturing ecosystem is full of complex challenges and compromises. That's because virtually every traditional manufacturing technology has limitations in the geometry of parts it can produce, how long it takes to make them, and how expensive it is to transform the raw materials into a desired object. Oftentimes, these limitations require engineers to craft many parts separately, so they can be welded, fastened, or assembled together into a final part. This is done simply because traditional techniques do not enable many modern designs to be manufactured as a single unit.

There are serious downsides to this traditional approach. For one, 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 about 90% of the material purchased to create a metal component is cut, shaved, and grinded away to create the final part[1].

By weight, the amount of metal material that makes it onto the aircraft is about 10% of what was purchased, with the majority carved away. While most manufacturers work to recycle and minimize this inefficiency, this waste has been a necessary part of the traditional manufacturing approach.

Buy-to-Fly Waste

Use the QR code or link below to see an example of typical subtractive part waste.

TeamDM.com/BuyToFly

1. Buy-to-fly ratios of 10-to-1 are common in aerospace applications – meaning that only 10 percent of the original material that is acquired remains in the final part – when parts are produced by traditional subtractive manufacturing processes (Kobryn et al., 2006).

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

Unfortunately, these manufacturing limitations hold everyone back. Designers, engineers, manufacturers, and society, deal with these limitations every day. By producing traditional design assemblies with smaller manufactured pieces, we often compromise on the final performance of a product by adding unnecessary weight and features. This traditional method of producing end-use metal parts has been preventing the world from delivering more innovative and sustainable products.

What's more, this approach to manufacturing often prevents the simple practicality of having goods manufactured closer to where they'll be used, as traditional manufacturing technologies require high investments in hard tooling and centralized locations, causing supply chain challenges that can break down. As the COVID-19 pandemic demonstrated, that can leave us without the things we need when we need them most.

But the time is right to modernize the world's metal manufacturing ecosystem with Additive Manufacturing. Sometimes used interchangeably with the more common term

"3D printing," Additive Manufacturing or "AM" is the official industry term (ASTM F2792).

The roots of this new approach stretch back to the 1980s, and after decades of development, AM is finally ready to deliver breakout change with binder jetting technology.

Many companies have already begun their journey. From contract manufacturers like Azoth 3D in Ann Arbor, Michigan, to oil and gas manufacturer PGV in Karnes City, Texas, or leading global tooling company Kennametal, companies big and small around the world and across industries are already reaping the benefits of metal binder jet 3D printing. It's even being used to fabricate subtractive tools and process tooling more efficiently.

The Potential of Binder Jetting

A specialized form of Additive Manufacturing called Binder Jetting Technology (BJT) holds the key to a better way of metal manufacturing. Binder jetting produces metal parts quickly **without lasers or tooling**, which can be expensive and often have long lead times. Instead, binder jetting uses an industrial inkjet printhead to quickly deposit a bonding agent onto a thin layer of powdered particles, either metal, sand, ceramics, or composites. This high-speed process is repeated, layer-by-layer, using instructions from a digital design file, until the object form is complete.

The binder jetting process is highly similar to the simplicity of printing ink on paper, with each "sheet" representing an extremely thin layer of powder, usually 30 to 200 micron (µm) high, and the "ink" representing a binder, usually a chemistry developed to work specifically with the printhead and metal powder being used.

For metals, this process creates "green" parts made of bonded metal powder that are then cured, or dried, in an oven. The printed part is then removed from the powder bed — a process called "depowdering" — and cleaned before final sintering in a high-temperature furnace, where the particles fuse together into a final metal object that is dense, accurate, and can be machined.

VIDEO: Metal Binder Jet in Action

Use the QR code or link below to see the process.

TeamDM.com/BJTSuccess

How Binder Jet Densities Compare

Use the QR code or link see how final part density stacks up to MIM, PM, and gravity or pressure castings.

TeamDM.com/MetalDensity

Binder Jet Leverages Existing Manufacturing Approaches

This final sintering step is nothing new in the world of metal manufacturing. In fact, it's nearly identical to how metal parts have been made with metal powder and binder in the Metal Injection Molding (MIM) or press-and-sinter (PM) markets for more than four decades. In those processes, metal powders with binders are injected into a mold, or stamped into a mold by a press, and then removed for final sintering. These processes have been used throughout the electronics, medical, and automotive industry for more than 40 years with great reliability.

The main difference between binder jetting and MIM or PM is that bound metal parts produced with a 3D printer do not require a mold, enabling more design flexibility.

Today, metal parts made with binder jetting deliver a final part density that is better than press-and-sinter and as-good or better than parts produced with MIM, depending on the specific material. Additionally, parts made with binder

Binder Jetting Process: Simple and Flexible

Digital File Prep

Machine & Material Prep

3D Printing

Powder layer

The recoater applies the first thin layers of metal powder in the print area or job box.

Liquid binder

A gantry of inkjet industrial printheads selectively applies binder to the powder to bind particles together where desired. Different binders work with different materials to achieve desired results.

Lower & recoat

After each layer, the bed lowers for the next layer to be applied. Recoating is a critical step in binder jetting, as the consecutive powder layers must be precisely and compactly applied to deliver a high-quality precision part. Whether using coarse or fine particles, powder handling is a critical element of successful binder jetting.

Repeat steps

Once the next powder layer has been applied to the print area, the stage has been set for the next layer of binder to be selectively deposited. This recoating-and-binding sequence is repeated until the part is complete.

Fast layer speed

With a full sweep of printheads, a binder jet 3D printer can complete a full layer very quickly. This is one of the core benefits of binderjetting compared to other additive manufacturing methods.

Next steps depend on application and specific materials

Printing complete

Once the print job has finished, parts can be removed from the print area o job box. Depending on the material ar binder used, additional curing and post-processing steps may be necessary. Metal parts typically require curing and sintering.

Metals

- Curing
- Depowder
- Debind & sinter

The German automaker BMW Group uses sand binder jet systems from Desktop Metal's ExOne brand with sustainable inorganic binder for production 3D printing of the sand cores needed to metalcast water core jackets for automotive engines. The use case of sand binder jetting is a blueprint for the future of metal binder jetting technology for production.

jetting routinely deliver improved density as compared to gravity or low-pressure metalcastings, enabling binder jetted parts to be CNC'd or processed like traditional metal pieces.

Binder Jetting Unlocks 3D Benefits at Scale

Binder jetting enables the production of complex part geometries and consolidated designs that can reduce weight and solve other engineering problems. It's also extremely efficient, using only the material needed to shape the part.

In binder jetting, any unbound powder leftover from the printing process can be reused following a straightforward mixing and reconditioning process. A 2020 research paper in The Minerals, Metals & Material Society, "Metal Powder Recyclability in Binder Jet Additive Manufacturing," concluded one could recycle powder in the binder jetting process up to 16 times — delivering an overall efficiency of material consumption of up to 96%.

Binder jetting offers one key benefit that other 3D printing approaches struggle to deliver – the ability to enable mass manufacturing at speeds and costs that compete with traditional manufacturing technologies.

Consequently, binder jetting is one of the few 3D printing technologies that holds the key to enabling a decentralized metal manufacturing ecosystem. Once deployed at scale, binder jetting would enable goods to easily be manufactured closer to where they'll be used at high speeds that deliver low costs and allow for consolidated designs that reduce part weight and improve performance — all while also eliminating waste. What's more, it enables manufacturers to shift to a more efficient digital inventory model.

There are a growing number of examples of metal binder jetting being deployed in the marketplace. Importantly, the use of binder jetting at high, production scale volumes has already been proven out by a German automaker for binder jetting of sandcastings. For more than 20 years, the foundry industry has been using binder jetting to produce sand molds and cores at high volumes — proving that this method is reliable for serial production.

Customers Using Metal Binder Jetting

- Nate Higgins, above, President of FreeFORM Technologies of St. Marys, Pennsylvania, which owns a fleet of Desktop Metal binder jetting systems, including the Production System™ P-1 shown here.
- Applications Engineer Ronnie Sherrer uses the Shop System™ at Azoth in Ann Arbor, Michigan to produce metal components for industrial customers.
- Christian Tse, bottom left, of Christian Tse Designs & Manufacturing Inc. in California uses a Production System P-1 to print 925 sterling silver, a popular precious metal for luxury jewelry applications.
- TriTech owner Robert Swenson, bottom right, pictured here with his Production System P-1 in Detroit, 3D prints titanium alloy Ti64.

Binder Jetting in the Metal AM Ecosystem

Understanding how binder jetting can deliver on the vision of mass production – and why other metal 3D printing techniques struggle to do so – requires a deeper look inside the metal 3D printing ecosystem.

Generally speaking, Additive Manufacturing is the process of creating an object by building it one layer at a time, usually from direct 3D model data. AM is the exact opposite of subtractive manufacturing, where a part is sculpted or carved from more material than is ultimately needed.

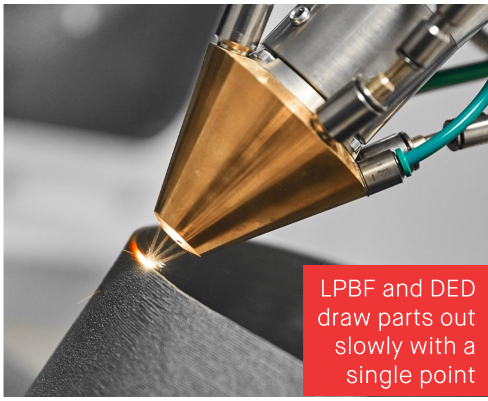
But there are many ways of 3D printing metal parts layer-by-layer, each with its own pros and cons.

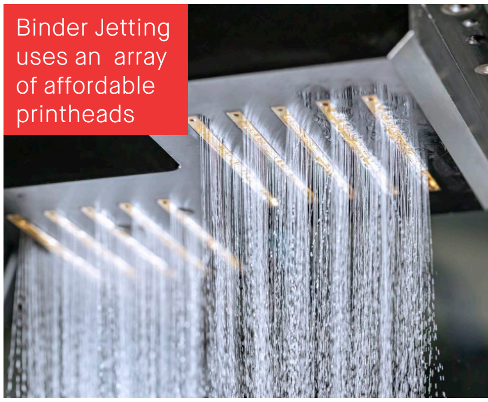
ASTM recognizes six categories of AM processes for metals, a type of 3D printing that got its start in the mid-1990s. The most mature methods on the market today are material extrusion, laser powder bed fusion, binder jetting, and directed energy deposition. But new methods of metal AM are continually being developed within the recognized categories, by combining categories, and even creating all-new approaches.

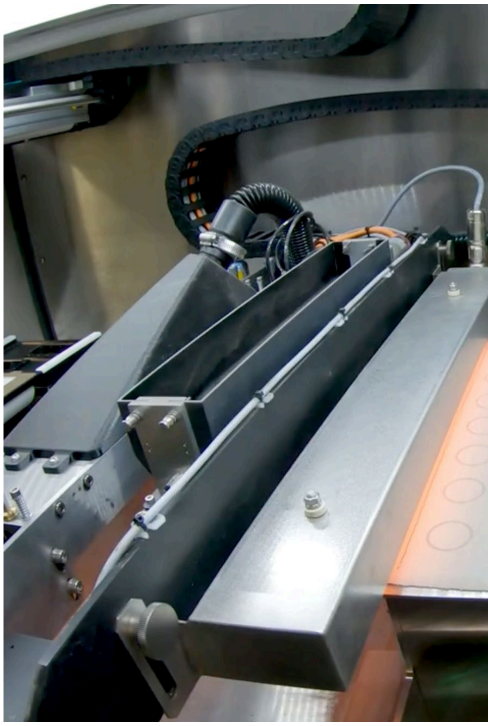
Today, most of the more mature 3D printing methods are great for one-off production of prototypes and even batch production. Generally, though, most of them are too slow – and therefore too expensive – to be considered for mass production of thousands or millions of parts quickly and cost effectively. That's largely because most of those methods use a 3D printing approach that draws out parts layer-by-layer with a single point, usually a nozzle or laser. Even when multi-laser systems are used, they are no match for the sweeping strategy of binder jetting.

Area-Wide Metal 3D Printing

By using a relatively affordable industrial inkjet printer, which builds a full layer of parts swiftly at one time, binder jetting can simply build parts faster. What's more, it does this process







Metal 3D Printing

Binder Jetting
Mid-1990s, RTS-300 Printer
Print head deposits binder in large sweeps onto metal powder bed

Late 1980s
Material Extrusion (ME)
Nozzle
SINGLE POINT

Early 1990s
Powder Bed Fusion (SLM, DMLS, EBM)
Laser
SINGLE POINT(S)

Mid-1990s
Directed Energy Deposition
Laser
SINGLE POINT

2011
Sheet Lamination
Ultrasonic welding of metal sheets

2017
Material Jetting
Prints metal suspended in nanoparticles

Area-Wide AM Enables Serial AM Production

Most metal 3D printing technologies use a single point, such as a nozzle or laser, or even a series of single points (which adds cost). But binder jetting, which uses a gantry of printheads, is one of the few metal AM methods that can form an entire layer rapidly with an area-wide printing approach. This enables faster print speeds and lower costs — which are essential for shifting AM from prototyping and low-volume tooling applications into higher volumes.

Area-wide binder Jetting on the Desktop Metal X-Series

at a low temperature, often room temperature, until the final sintering process. This delivers benefits over laser processes where parts are, essentially, melted and cooled throughout the build, requiring additional post-processing steps and microstructure considerations that will be discussed later in this paper.

While many 3D printer technologies can deliver a monolithic complex part that solves a complex problem – say lightweighting an automotive component – binder jetting is one of the few technologies that can deliver that solution in affordable mass volumes that can make a big impact.

Consequently, binder jetting holds the potential to solve complex engineering challenges and deliver more sustainable products in high volumes that can deliver a bigger benefit to society.

Binder Jetting technology can easily produce complex metal parts and systems — especially in high volumes

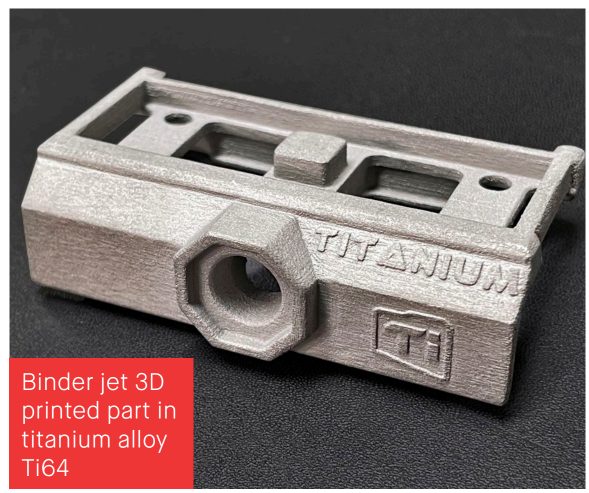
Ideal Binder Jetting Applications

While every 3D printing process has a sweet spot, binder jetting is also one of the few solutions that can be used for one-off prototypes and parts, batch production, or high-volume production.

Binder jetting technology is also incredibly flexible when it comes to materials. Essentially, it has the potential to process just about any powder with the right binder and process parameters. Today, binder jetting can produce parts in a wide range of metals, as well as ceramics, including sands and ceramic-metals or cermets.

Desktop Metal binder jet systems are capable of processing more than 20 metals in the following categories:

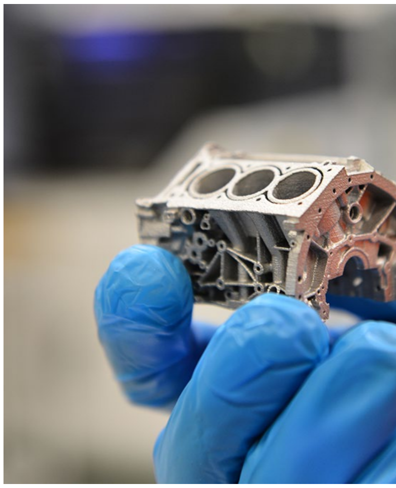
- Aluminum Alloys
- Carbides
- Copper + Cu Alloys
- Nickel Alloys
- Nitrides
- Oxides
- Precision Metal Alloys
- Refractory Metals
- Stainless Steels
- Titanium Alloys
- Tool Steels



Binder jet 3D printed part in titanium alloy Ti64

As will be discussed in this paper, specific types of binder jet systems may be required for specific types of materials. This is based on several factors such as the approach to powder management and printhead types that can process certain binder chemistries that may not work with all materials. Some materials, such as aluminum and titanium alloys, may also require an inert or controlled atmosphere system.

So, what types of parts are best for binder jetting?



Binder jet 3D printed part in aluminum alloy Al6061

AM Parts Ready for Higher Production Volumes

While virtually any metal part can be made with binder jetting, from extra small to basketball sized, the technology has sweet spots. For its current maturity level, it tends to favor higher volume production, complexity, and parts that are fist-sized or smaller. Thus, areas that often benefit most include:

- **In-Production AM Parts.** Parts that are already being 3D printed with other metal printing process, such as laser powder bed fusion or material extrusion, and now want to graduate to more affordable or higher volume production

- **Complex Parts.** Parts with channels that transfer air, liquids, or semi-solids, such as those managing oil, gas, or food products. Any part with an intricate internal or trapped feature

- **Thermal/Electrical Components.** Parts carrying heat or electrical current that are limited or restricted by classical design possibilities. Applications in heat exchangers or electric car components

- **Complex Assemblies.** Parts made up of multiple assembled segments could be consolidated into a single or monolithic part for performance or weight benefits, as well as reduced process steps

- **Lightweighting.** Heavy parts that would benefit from lightweighting design strategies while preserving other characteristics, such as load handling

- **Mass Customized Parts.** Parts such as medical tools where design iterations can be easily adopted without cost penalty or adopted for specific patient use cases

- **Fast Product Cycle Parts.** Metal parts that benefit from rapid iteration possibilities, such as fashion hardware on luxury goods, belts, and handbag hardware

- **MIM-Extension Parts.** Binder jetting can enable standard MIM-size parts at affordable lower volumes. It can also enable MIM-style parts at larger sizes, even exceeding 100 grams. Binder jetting is even capable of delivering complex parts as big as a basketball with optimization

Binder jet 3D printed part in copper alloy C18150

Overview: The Binder Jetting Process

Within any commercial binder jetting system, the printing process contains several steps, which may be executed differently depending on the brand and model of the system.

1. Print

Binder jet systems typically perform the printing process with the following steps:

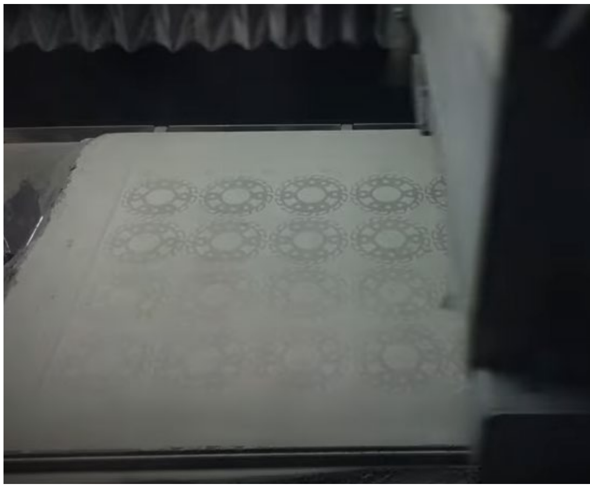
- Deposit powder
- Spread powder
- Compact powder
- Selectively deposit binder
- Heat or dry the binder (Optional)
- Repeat the process

These steps are usually executed in the order above, or in combination with one another, and some machine manufacturers may include other steps not mentioned here during the process. Printers from different manufacturers often exhibit differences in the way powder is deposited or spread, or even the software approach they use to deposit the binder.

After each layer is created, the build plate or platform shifts down, and a new layer of powder is spread on top of the previous layer. This process is repeated until the job is complete.

2. Dry, Cure, Crosslink

After printing, the build box containing the printed parts – which are called "green" at this stage, similar to the MIM industry – are placed into an oven where the binder is dried and the part essentially cures, building strength in the part – a process sometimes referred to as "crosslink." This curing step gives the green parts strength to be removed from the print bed. Otherwise, they'd simply be a fragile sandcastle of powder.



The binder jetting process is relatively simple. 3D printing, above, is followed by curing. Below, the strength of green parts after curing but before final sintering is shown.

Typically, a higher green part strength will deliver a higher yield from the print, with low or no breakage of green parts.

Some binder jet systems perform this curing step inside the printer. While this may seem convenient, it may also be expensive. Printers are often a higher capex or capital expenditure component of a print system and it should be utilized for printing, while lower cost ovens should perform drying, curing, and crosslinking. In most systems, you remove the box of parts and start another print job while the box is curing in a less expensive oven.

After curing, parts are depowdered, as shown above. Finally, parts are sintered in a furnace where powder particles fuse into a high-density part that typically exceeds a gravity casting and meets or exceeds standard MIM parts.

3. Depowder

The process of removing or excavating green parts from the loose powder contained in the build box and preparing those parts for sintering is called "depowdering."

During the depowdering process, parts are removed and the unused loose powder that surrounds the parts gets recycled for use in future builds. The degree of recyclability may vary between different binder jetting system offerings.

Often, parts are cleaned with a simple air gun. A variety of fully- and semi-automated depowdering solutions are in development throughout the binder jetting field to simplify the removal and cleaning of green parts.

The green parts produced by binder jetting are similar to the those produced by MIM, with some key advantages. Crucially, parts from the MIM process contain far more binder and wax than parts from the binder jet process. This enables faster debinding of binder jetted parts, with decreased load effects, and often with fewer adjustments to part chemistry.

4. Sinter

After parts are removed and cleaned, they are ready for sintering, where the metal powder particles are fused together and the part is densified. During sintering, the green state parts are heated to temperatures approaching the melting point of the powder. Depending on the powder alloy, the method for densification can be either solid state sintering or liquid phase sintering.

Solid state sintering works by diffusion of the alloy at temperatures below the solidus point of the material. Typically, for most solid state sintering processes to minimize porosity in final parts, the sintering temperature approaches the solidus point. Liquid phase sintering can be implemented by picking a temperature range between solidus and liquidus point of the alloy. During both sintering mechanisms the particles begin to "neck" or attach to one another and the void spaces collapse, creating a dense part.

Parts typically undergo shrinkage during the sintering process and, potentially, distortion if not designed and supported properly. Parts processed within a furnace are placed on a plate and may require the use of setters, similar to MIM.

Desktop Metal's Live Sinter™ software makes sintering easy by predicting and correcting for shrinkage and distortion in part designs in as little as 20 minutes, delivering sinter-ready, printable geometries. This powerful, best-in-class, multi-physics sintering simulation software is now trusted by users at more than a hundred companies globally.

VIDEO: See Bulk Depowdering Action

While depowdering is typically a manual process, automation solutions can be developed for serial production. This DM approach, shown below, is currently in R&D.

TeamDM.com/Depowdering

5. Recycle or Reuse

While powder recycling and reuse steps may vary by brand and model of binder jet system, generally, most powder reclaimed in the printing and depowdering processes can be sieved and blended with virgin powder in preparation for the next print.

When considering a binder jet system, it's important to consider the process for preparing, reclaiming, and reusing powder in order to get the most efficiency out of the binder jet process. As previously mentioned, binder jetting has the potential to deliver an overall efficiency of material consumption of up to 96%.

Binder Jet Material Efficiency Study

2. Mirzababaei, S., Paul, B.K. & Pasebani, S. Metal Powder Recyclability in Binder Jet Additive Manufacturing. JOM 72, 3070–3079 (2020). https://doi.org/10.1007/s11837-020-04258-6al., 2006).

TeamDM.com/BJTefficiency

The Six Essential Elements of Binder Jet 3D Printing

Within the seemingly simple binder jet process, there is actually a complex interplay of six key elements.

To truly be an expert on binder jetting, it's essential to develop a deeper understanding of these elements, which is where most differentiation occurs in binder jetting systems between brands and models. These distinctions can help inform the best system fit for a specific application, desired volumes, as well as costs.

The six elements of binder jetting, to be covered in this section, are:

- Powder
- Binder
- Inkjet Printheads
- Machine Design
- Controls
- Recipe

Powder

Like other trusted additive and subtractive manufacturing methods, powdered metal is the central medium of binder jetting.

Over the years, binder jetting has evolved from printing coarser grain powders like sand, which flows and spreads easily, to ultra-fine MIM-standard powders that are highly cohesive and difficult to manipulate. For many binder jet systems, these finer powders are essential for high-quality printing of metals.

The easiest way to think of the difference between these grain sizes is that the bigger grain powders flow like standard table sugar or salt and the MIM-sized powders are more like baking

Image of binder jetted parts from Global Tungsten & Powders Corp.

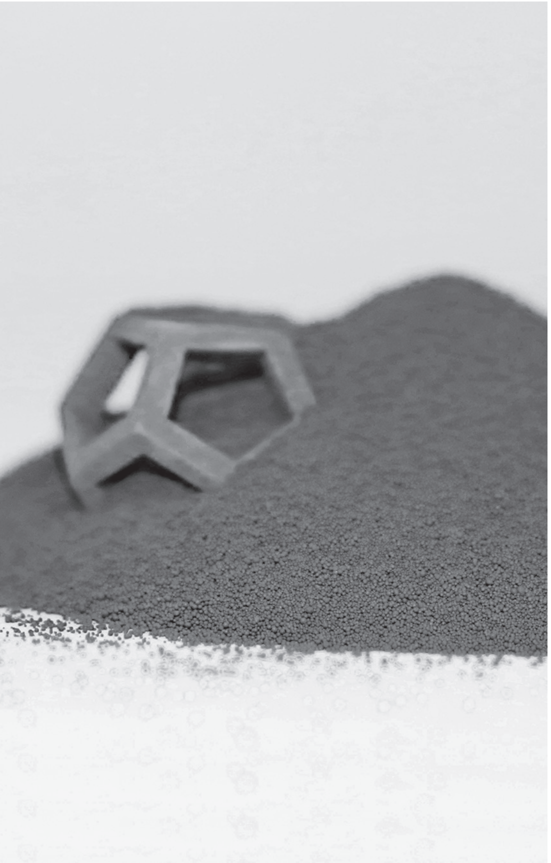
Rheology is a branch of physics, and it is the science that deals with the deformation and flow of materials, both solids and liquids. Learn more about working with powders here.

TeamDM.com/Rheology

powder or flour, prone to caking, clumping, and irregular flow. To print the highest-density metal parts using certain binder jetting systems, your 3D printer must print powders on this finer, more challenging side of the spectrum. Most commercial binder jet printing systems process MIM powders with a median particle size of 9 μm or a range of 9-25 μm. Using ultra-fine powders such as these helps to ensure the particles can sinter together to form a dense, uniform microstructure that delivers reliable functionality and performance. Although some binder jet systems can process even smaller particle sizes, there is a cost benefit to tapping into the MIM industry's existing powder supply chain.

Ultra-fine powders can be challenging to deposit and spread. Once the powder is deposited, it can be disturbed and displaced by drops of jetted binder. What's more, the larger the surface area you're trying to cover, the more challenging it is to create a uniform printing environment.

So, to successfully 3D print a metal part using binder jetting technology, your binder jet system must tightly control your powder recoating process as well as how the powder responds to the deposition of binder.



Fortunately, there are many strategies and techniques to manage these conditions, such as environmental controls, and these approaches tend to be differentiated among make and model of binder jet systems.

Ultimately, the final test of your 3D printer's powder management quality will be revealed after sintering, where any flaws in the structural binding of the powders may ultimately be exposed.

Desktop Metal's binder jetting systems use three different approaches to depositing and managing powder that will be covered in the machine design and controls section. Each approach offers different pros and cons, from cost of implementation to the variability of powder they can process.

It's also important to keep in mind that some binder jet systems and manufacturers allow for open or closed powder systems. Closed systems offer tight control over the quality of the powder, and therefore the quality of the printing process and its repeatability. Generally, open powder systems are more expensive than closed powder systems but allow for the use of lower cost powers and are designed for more experienced enterprises. Closed powder systems tend to be lower cost but require the use of more expensive powders for an easier experience.

Binder

While the metal powder used in binder jetting is off the shelf and standardized across the industry, the liquid binder deposited from the printhead is typically a special sauce.

In today's marketplace, the liquid binder tends to be proprietary to each manufacturer of binder jetting systems. As each liquid binder is different, each liquid binder meets different requirements and can exhibit different performance.

For starters, binder must be compatible with the printheads that are being used – for example, you don't want a binder that clogs the printhead nozzles. Also, the binder must be compatible with the metal powder. Not all binder chemistries are truly universal, compatible with all metal powders, although some binders are compatible with a very wide range of metal powders.

Desktop Metal has identified six main categories that are managed and optimized in a binder to deliver outstanding printability, sintering, safety, and cost:

1. Jettability. The combination of the binder and printhead must produce drops of the desired size and speed, repeatedly. Considerations such as viscosity, surface tension, and more are considered and optimized in a binder, along with waveforms and velocities for being jetted by the printhead for each specific metal material.

2. Wettability. Binder must deliver controlled wetting of the metal powder to which it is applied, with limited or no bleeding. Different materials may require different wetting strategies to deliver the highest part quality. Further, while the binder must wet the powder, the wetting should arrest to prevent smearing and other ill effects when the next layer of powder is deposited.

3. Strength Building. The binder must cure with each metal powder in a way that delivers a strong green part for depowdering. Different binder-material combinations may require different cure cycles.

4. Thermal Burnout. Binder must debind easily and burn out during sintering, producing little or no carbon residue.

5. Safety, Health, and Environment. The binder must be safe to ship, store, and use. Ideally, any binder used should have a long shelf life and be green.

6. Cost. Binder should be highly affordable to enable mass production with binder jetting.

Additionally, the strategies with which a binder is applied may also be highly important.

For example, droplets of binder impacting the powder bed can generate ejected powder particles. Without controls to manage this ballistic effect, the ejected powder can damage instrumentation within the print chamber and reduce the quality of powder deposited and spread within the powder bed. Management of this problem is particularly important when printing at high speed.

DM Live Build | Patent-Pending Dithering Strategies

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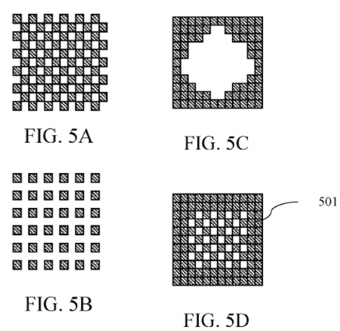
Our patent-pending DM dithering strategy is **just one of many** proprietary print strategies we use to deposit binder, delivering exceptional speed and performance

- **Desktop Metal "Live Build" software has used dithering since the launch of our metal binder jetting systems.** Formerly known as Fabricate MFG, Live Build contains micro- and macro-dithering print strategies for interior, exterior/shell, top and bottom features that are also proprietary to DM. Sophisticated logic built into our dithering and related strategies.
- **Pending patent on dithering in binder jetting. Barbati, A., et al. (2021)** *Methods and Devices for Three-Dimensional Printing*
- **An IFAM team recently investigated benefits of dithering** in binder jetting and found a positive effect. "The results prove the effectiveness of this approach and outline a field of research not identified previously." Materials 2022, 15, 3798. https://doi.org/10.3390/ma15113798



[0015] FIGS. 5A-D show example micro-dithering and example macro-dithering patterns for creating negatively printed features, such as features with differing saturation levels.

What is dithering?

Instead of applying a complete voxel full of binder where powder binding is desired for each layer, we create deliberate and strategically specific voids in the print pattern, as well as other binder deposition strategies, which allow gas to escape more quickly during printing as the particle bed is wetted. This enhances both speed of saturation and also improves surface finish, in addition to other binder jetting benefits.

Desktop Metal has developed and deployed countermeasures on select systems to overcome this problem. For example, this is the case in the Production System P-50, which uses ultrafine droplet sizes and ultrahigh resolution DPI printheads with anti-ballistic strategies, including a combination of steam and humidity control in the print bed.

What's more, Desktop Metal uses a patent-pending process called dithering. Instead of depositing binder everywhere powder binding is desired for each layer, Desktop Metal's Live Build™ software creates deliberate and strategically specific voids in the print pattern, as well as other binder deposition strategies, which allow gas to escape more quickly during printing as the particle bed is wetted. This enhances both speed of saturation and also improves surface finish, in addition to other binder jetting benefits.

Proprietary Live Build software contains both micro- and macro-dithering print strategies for interior, exterior/shell, top, and bottom features.

A team at Fraunhofer IFAM, one of the most important independent research institutes in Europe, has investigated the benefits of dithering in binder jetting and found a positive effect. "The results prove the effectiveness of this approach and outline a field of research not identified previously."[1]

So, it's not just the binder itself that's extremely relevant in binder jetting – but also how it's applied in waveform and location.

Inkjet Printheads

The industrial printhead is the engine of a binder jetting system. Similar to a car, there are different kinds of engines with different pros and cons, such as performance and cost.

The two most predominant printhead types used in binder jetting are thermal and piezoelectric (often called "piezo"). Both types of printheads are capable of delivering high-quality binder jetting results, though each type has its own advantages and disadvantages.

The requirement of a printhead in the binder jet process is

Know Your Printheads

The Desktop Metal Production System P-1 and P-50 use the Fujifilm Samba G3L, shown above, which offers:

- **Advanced Silicon Micro-Electro-Mechanical Systems with 2048 nozzles per module**
- **1200 native dpi / 600 dpi in redundant mode**
- **2.4 picoliter native drop size**
- **RediJet® continuous ink recirculation**
- **VersaDrop™ multi-level grayscale plus multi-drop and fixed drop sizes in binary mode**
- **Scalable, narrow to wide printbars possible**
- **Robust design and high speed operation**
- **Multi-ink compatibility**

The Desktop Metal Shop System and X-Series use other printheads — the Memjet Versapass and Fujifilm StarFire® SG1024, respectively — to deliver different benefits in terms of cost and material.

[1] https://doi.org/10.3390/ma15113798

	Thermal Inkjet Printheads	Piezoelectric Printheads
Operating Mechanism	Ink chamber is heated to create a vapor bubble that expands and forces a precise drop of ink out of the nozzle	Electric charge is applied to piezoelectric elements (i.e., crystals) to deform the surface, creating pressure that forces a precise drop of ink out of the nozzle
Printhead Life	Shorter. Typically used as a consumable, but category offers a wide range of printhead life	Longer. Typically not a consumable but may need replacement every several years. Also may be repaired.
Cost	Lower	Higher
Binder Compatibility	Only works with water-based (aqueous) binders	Works with a wide variety of binders, including water-based (aqueous), and solvent based, as well as higher viscosity binders. Including those that may contain particulates or non-liquid additives
Droplet Size	Single; binary on or off	Variable; enables grayscaling and varying wave or droplet formations
Maintenance	Consumable; designed to be easily replace in printer	More involved; designed to be maintained over time
OEMs	HP, Canon, Memjet	Epson, Fujifilm, Xaar

to deposit binder precisely in the X and Y directions with controlled levels of bleeding and saturation in the Z direction (although Z saturation may be more directly tied to the binder chemistry and powder, the interplay of all these factors remains important).

A good printhead must deliver the binder in a droplet or jetted stream and at a velocity that works well with the given powder material. The printhead must also work well with the binder liquid, jetting material with ease without clogging.

Even within the thermal and piezo categories, there are many makes and models of printheads, each offering their own advantages and disadvantages.

Thermal and piezo printheads use different strategies to deposit ink or other liquids, such as binder.

Thermal printheads work by heating a resistor, causing a small volume of water-based ink to vaporize, creating a bubble. As the bubble expands, it pushes a droplet of ink out of the printhead and onto the print media. Thermal printheads are known for their high resolution and are commonly used in desktop printers and some industrial printing applications.

Virtually all thermal printheads require a water-based binder to create a bubble; therefore, most thermal printheads are limited to water-based binder chemistries. This may limit the number of metals they can print.

Emanuel “Ely” Sachs, above, a pioneer of 3D printing, is the inventor of binder jet printing. Sachs is a co-founder of Desktop Metal and professor of mechanical engineering at MIT.

Thermal printheads are typically less expensive and easier to produce, but they may, at times, have lower resolution and can be less durable.

Piezo printheads, on the other hand, create droplets mechanically via displacement from the expansion and contraction of a piezoelectric crystal. Piezo printheads are known for their high speed and are commonly used in industrial printing applications such as wide-format printing and high-speed inkjet printing.

Piezo printheads are typically more expensive and more complex to produce, but they may have higher resolution, better durability, and more performance options. For example, they can process a wider range of viscosities, including binders with particles in them, and deliver droplets or jet streams, enabling more sophisticated binder deposition strategies.

Desktop Metal’s Shop System uses a thermal printhead, which keeps the cost of the system highly affordable, whereas the company’s X-Series and Production System printers use piezo printheads.

Machine Design and Controls

Binder jetting was initially developed and patented at the Massachusetts Institute of Technology by Ely Sachs, a Co-Founder of Desktop Metal, in the early 1990s. ExOne, now a subsidiary of Desktop Metal, obtained the exclusive license to this inkjet-in-powder-bed approach in 1996 and launched the market's first commercial metal binder jet 3D printer, the RTS-300, in 1998.

Desktop Metal's team of binder jetting experts has launched more than dozen binder jetting systems, delivering virtually all of the technology's most significant breakthroughs and different machine design approaches. That includes processing MIM-standard powders and developing two distinct approaches to binder jetting — one focused on speed, Single Pass Jetting (SPJ), the other focused on compaction, Triple Advanced Compaction Technology (ACT).

These various machine design approaches resolve different challenges and offer different benefits.

Within our portfolio, we offer these overarching binder jet approaches:

Bed-to-Bed Jetting

Bed-to-bed powder deposition is one of the earliest and least expensive forms of powder spreading. This approach, offered in the Shop System with a thermal printhead, is highly affordable and very reliable; binder jet systems first produced in 2003 using this approach are still printing commercial parts today.

The ExOne R2 , shown below, was one of the first commercial binder jet systems on the market after ExOne licensed the MIT patent for metal binder jetting from MIT in 1996. It employed bed-to-bed powder deposition and the systems are still in use today.

Triple Advanced Compaction Technology

Also known as Triple ACT, this approach is used in the X-Series lineup, which includes the InnoventX, X25Pro, and X160Pro, with a piezo printhead system. This approach uses different methods of dispensing, spreading, and compacting ultra-fine powders for the highest density green parts. The hallmark of this approach is tight individual parameter control of particle dispensing, spreading, and compacting. This allows processing for a wide range of metals and ceramics.

Single Pass Jetting for Production

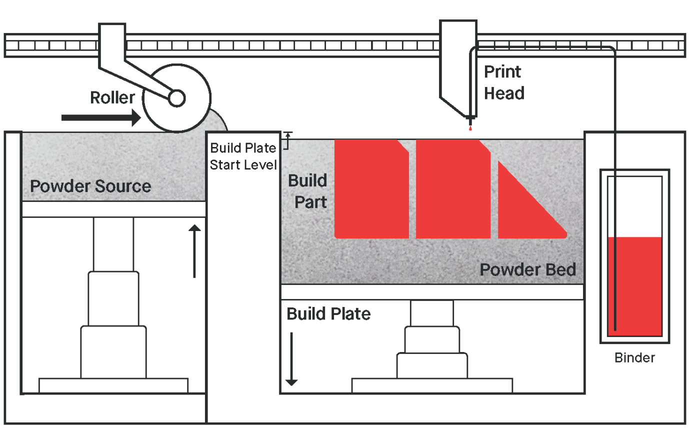
Single Pass Jetting, or SPJ™, is the top-of-the-line high-speed system designed for mass production. Used for maximum speed on the Desktop Metal Production System P-1 and P-50, SPJ arises from the interplay of several technology approaches joined together to maximize speed in binder jetting.

This is where Single Pass Jetting sets itself apart. SPJ takes all of those binder jetting process steps and combines them into a single, unified step. With a single pass of the integrated carriage, a full layer is completed. By performing these steps concurrently, each layer is completed in as little as 3 seconds, dramatically accelerating the printing process and delivering the unprecedented speeds of the Desktop Metal Production System.

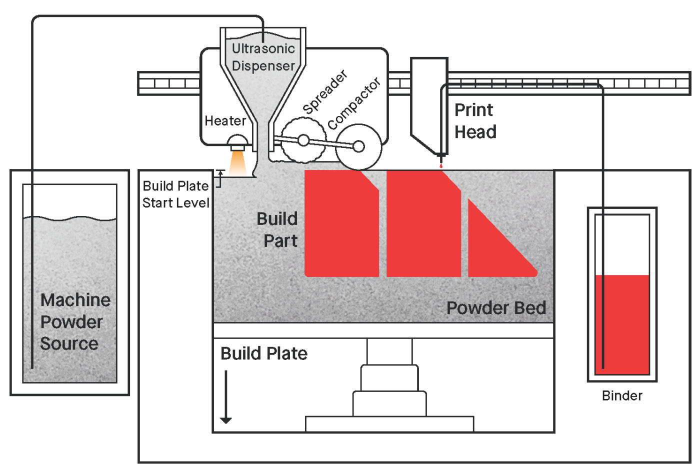
A. The process starts with powder dispensing. The Desktop Metal Production System™ P-50 printer includes two hoppers to hold fresh powder. This powder is automatically conveyed to the hoppers through the Powder Process Unit (PPU).

B. The powder is controllably metered from the hoppers onto the bed through a precise gap between two counter-rotating rollers. Our SPJ Technology uses an approach called Constant Wave Spreading to produce a consistent supply of powder in front of the compaction roller, resulting in consistent bed density (a key requirement to deliver tight

Box-to-Box Binder Jet Design



Triple Advanced
Compaction Technology (ACT)



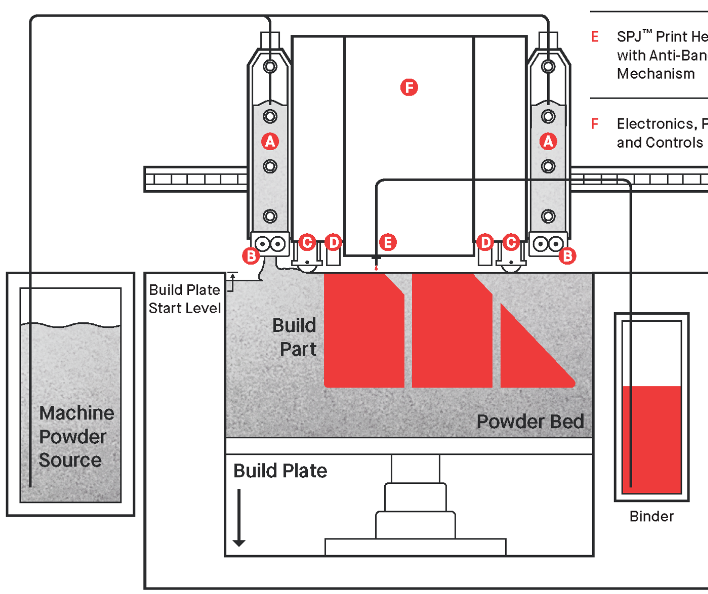
geometrical tolerances and consistency).

C. A technology unique to the Desktop Metal Production System, the anti-ballistics module treats the freshly compacted powder bed to control particles during the printing process. Drops from the inkjet printheads are expelled at up to eight meters per second. When they hit the powder bed, some of that momentum is transferred to the particles within the bed. Left uncontrolled, the particles can fly back toward the inkjet printheads and, over time, clog the nozzles. Anti-ballistics technology eliminates this ejecta, greatly improving jetting reliability.

D. The printing module carries the inkjet print array, which is capable of addressing each 1200 x 1200 dpi pixel location on the bed in a single pass. Desktop Metal intentionally chose the highest performing industrial inkjet printhead in order to deliver high resolution and high throughput in a single pass. By addressing the powder bed through an array of nozzles, the Production System realizes a 100x speed improvement over vector-based methods like powder bed fusion. Additionally, the entire array employs anti-banding technology, meaning it can be shuttled between every layer. By moving the array slightly in the direction orthogonal to the schematic below, ensuring consistent binder coverage in the case of an occasional nozzle drop out.

Within seconds, this process produces a completed layer. The symmetrical design of the carriage means the same steps can be reproduced if the carriage traverses the bed in the opposite direction. That bidirectional printing capability ensures maximum productivity with no wasted motion. As soon as a layer is complete, the build platform drops according to the layer height and immediately begins printing the next layer.

Single Pass Jetting (SPJ)



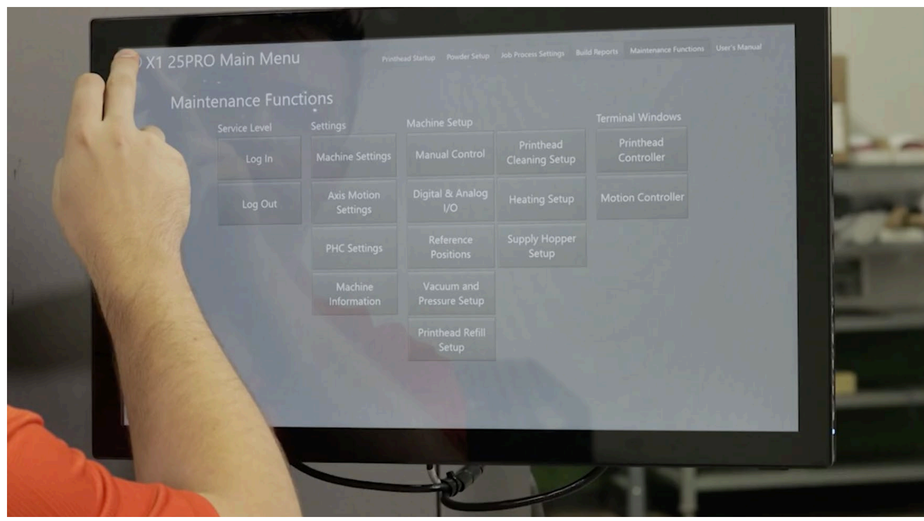
- A Powder Hopper
- B Powder Metering Module
- C Constant Wave Spreading System
- D Anti-Ballistics Module
- E SPJ™ Print Head Module with Anti-Banding Mechanism
- F Electronics, Pneumatics, and Controls

Other Machine Design Considerations

Beyond powder deposition, there are many other important machine design considerations. Including, for example, the environment of the system.

The Desktop Metal Production System P-1 and P-50 both offer controlled atmospheres, including inert environments, that tightly manage attributes such as humidity that may interfere with powder dynamics and also allow for the safe printing of reactive materials, such as aluminum and titanium.

Desktop Metal has customers that can 3D print both of these reactive materials today, though the company has not yet announced a turnkey commercial solution for printing these materials.



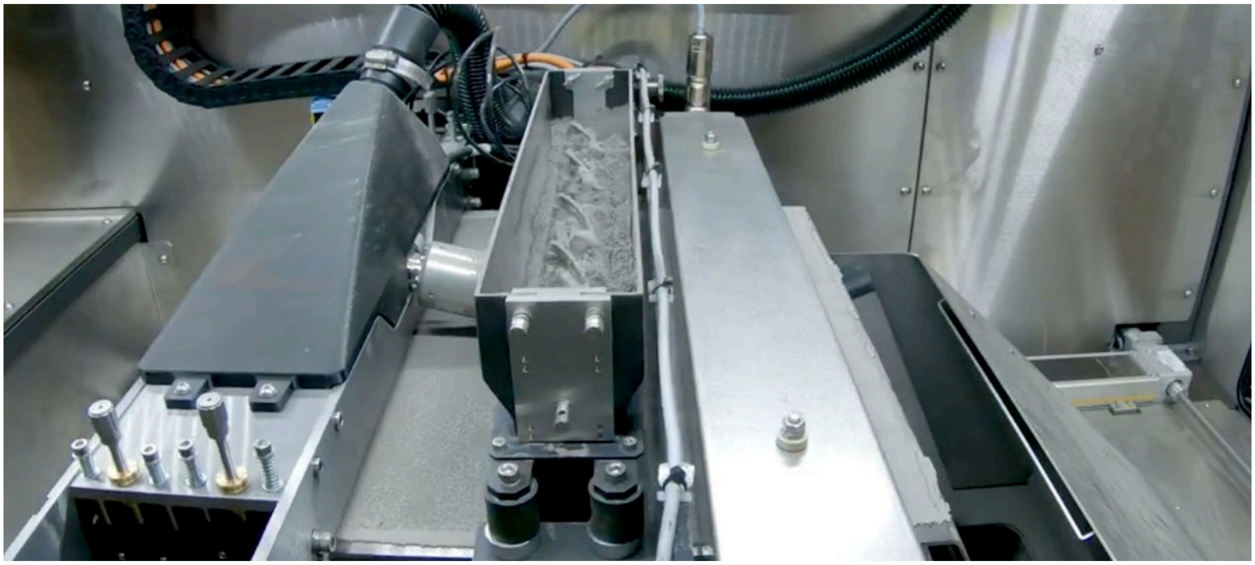
Recipe

What is a recipe in binder jetting?

Essentially, it's the specific blend of process parameters for every type of material, and even the cut of material or the layer thickness, that is unique to every binder jet printing system.

At Desktop Metal, all materials are qualified to meet or exceed MPIF, or MIM industry standards, where they are available, and these recipe process parameters are established for every unique printing system.

Customers can also develop their own recipes for their own materials, though it usually takes an experienced engineer or operator to develop these parameters in an efficient way.



Powder Rheology

To become a next-level binder jet expert, it may also be advised to dig a bit deeper into powder rheology – the study of the flow behavior of powders and granular materials.

Rheological properties of powders play a critical role in 3D printing. Powder properties affect the flowability, packing density, and resolution of the printed parts, among other factors. Rheological properties are determined by a number of factors, including particle size, shape, and surface properties, as well as the physical and chemical attributes of the surrounding fluid or gas.

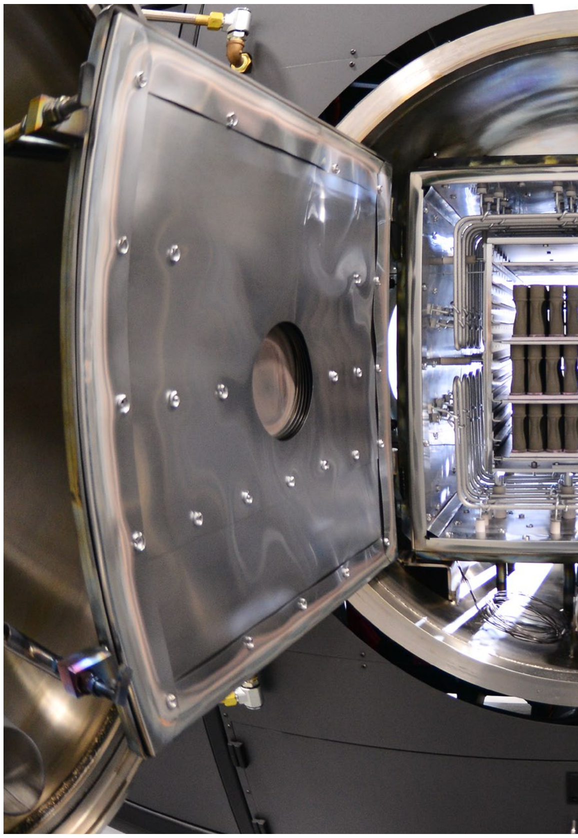
Measurement is central to powder rheology.The response of powders to external forces, such as shear, compression, and impact are important characteristics in 3D printing.

Powders behave neither as simple liquids or solids. This makes it difficult to predict their behavior, as they can exhibit different properties depending on the shear rate or stress applied to a collection of powder particles.

Common techniques for measuring powder rheology include shear cell, hall flow, tap density, and bulk compression tests. The results from these tests and others are often used to calculate rheological parameters such as the flow indices, the unconfined and confined yield strength, and the angle of repose.

Powder rheology is also important in many other industrial applications beyond binder jetting, such as powder metallurgy, food processing, and pharmaceuticals. Depending on where you are in your binder jetting journey, it may be important to understand the behavior of powders during handling, storage, and transport.

Binder Jetting versus Laser Powder Bed Fusion

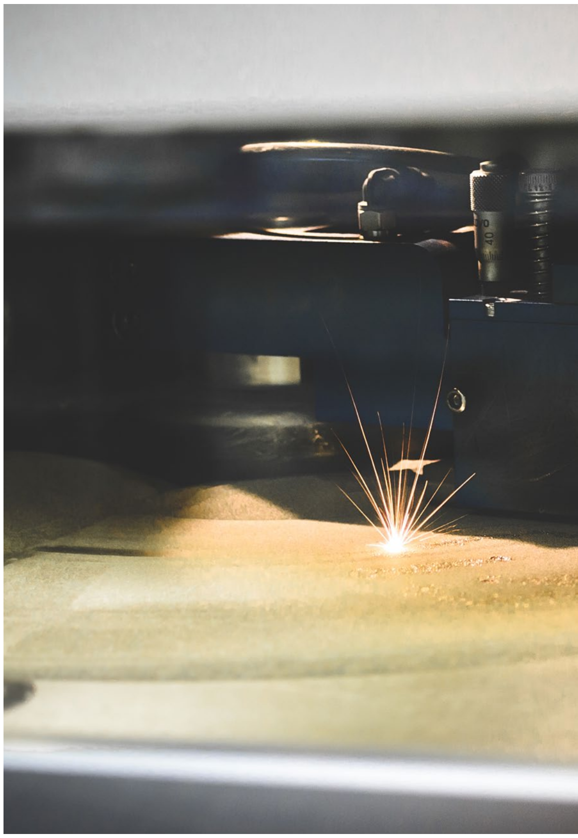


This chapter will compare binder jet technology (BJT) to the other most commonly deployed metal AM processes in the market, both of which are powder bed fusion (PBF) processes: electron beam melting (EBM) and laser powder bed fusion (L-PBF), also commonly referred to as selective laser melting (SLM) or direct metal laser sintering (DMLS).

In the PBF techniques, thermal energy — applied by a laser in L-PBF and an electron beam in EBM — is used to fuse metal powder particles in a bed. In binder jetting, a liquid binding agent is selectively deposited through an inkjet head onto powder particles in a bed. Each process builds the part one thin layer at a time. However, there are important distinctions:

Binder jetting is distinct from these powder bed fusion processes for several critical reasons:

- BJT does not rely on a single or a small number of directed energy beams to draw out a part in material. Binder jetting delivers superior volumetric output because it uses a gantry covered in printheads to join material quickly.
- BJT forms a part in metal powder separately from densification. This has important consequences for the final part's microstructure, which is critical to delivering reliable functionality and performance.



So, how do the details of binder jetting compare to laser powder-bed fusion, one of most common methods of 3D printing high-value metal parts today?

Thermal Considerations. When printing each part element with L-PBF and EBM, the part undergoes rapid heating and cooling. In addition to leading to anisotropic material properties, this gives rise to thermal stress, and the printed objects must be stress relieved before the part is used. BJT is the only process where the shaping of the part is executed at a consistent, low temperature. It is only after this green part is sintered that it becomes a final part with isotropic mechanical properties.

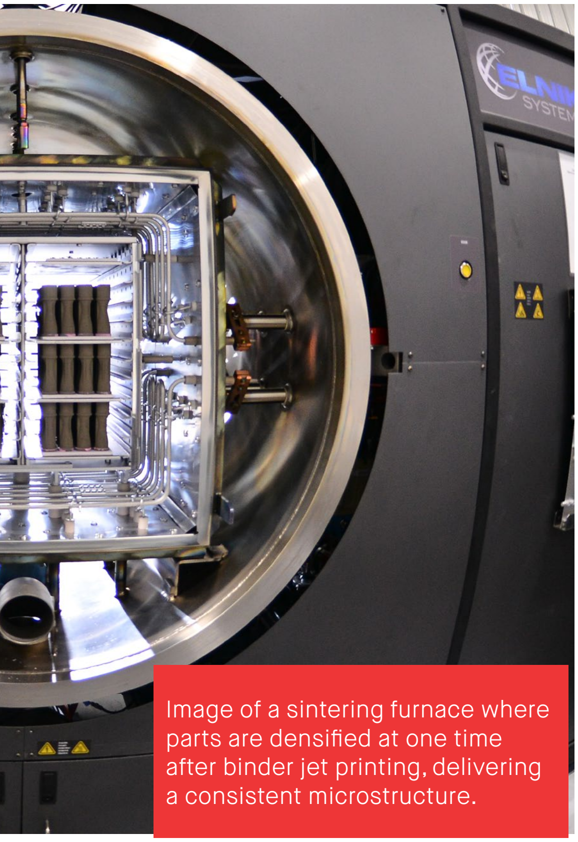


Image of a sintering furnace where parts are densified at one time after binder jet printing, delivering a consistent microstructure.

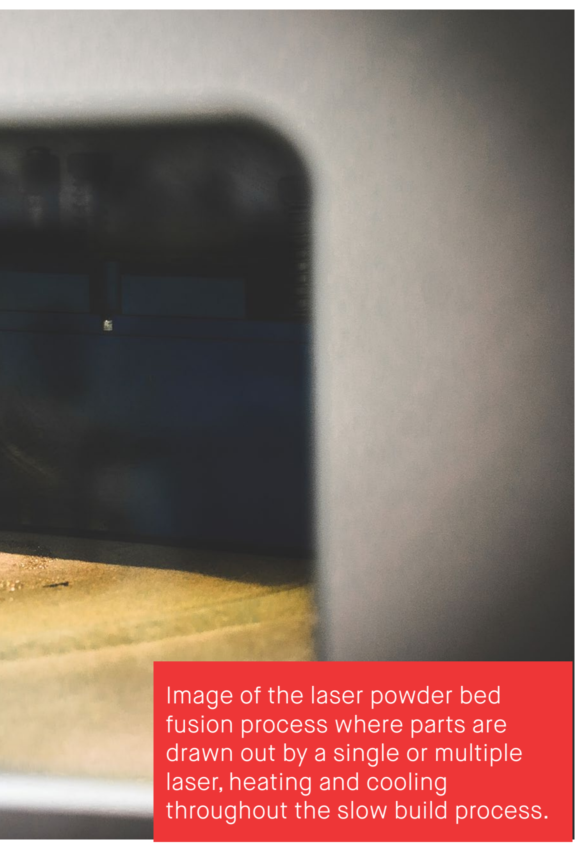


Image of the laser powder bed fusion process where parts are drawn out by a single or multiple laser, heating and cooling throughout the slow build process.

File Preparation and Support. SLM requires that both thermal and structural supports be designed and fabricated with the 3D build. With EBM, the powder surrounding the part is partially sintered during the build process, enabling it to act as a mechanical support. Despite this apparent advantage, EBM still requires the design of thermal supports. BJT requires no printing supports. In BJT, parts are supported by unbound powder during the low-temperature build. However, similar to parts produced using metal injection molding (MIM), BJT parts made without simulation aid from software like Live Sinter often require ceramic or metal supports in the sintering furnace.

Speed Considerations. There are several ways to look at binder jetting speed: time to build a layer, time to print a complete part, and total start-to-finish time from loading powder into a printer to having a final end-use part. In many cases, 3D printing is the fastest and easiest part of the process. Setup and post-print steps have their own burden in time and complexity. In printing time alone, one must also consider the number and volume of parts being built. For example, while BJT is regarded as the fastest printing strategy, EBM may, at times, outperform BJT for the printing of a single unit when one considers other necessary BJT process steps such as curing and sintering. However, L-PBF is often the slowest when considering total end-to-end process time.

The more parts printed in each production run, the more advantageous BJT becomes. That's simply because L-PBF and EBM must raster 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 L-PBF systems now contain multiple lasers, the build speed is still significantly slower than BJT and it is unknown whether the additional lasers cause additional thermal stress in the part. Thus, the added 3D printing time to produce four units in L-PBF and EBM is typically several times the time it takes for one unit. In BJT, it depends on how many units can fit in the printer's build area, and if the four units all fit in one bed, the added time may simply be 5-10% of the time it takes to build one.

Necessary Processing Steps. L-PBF, EBM, and BJT all have unique processing steps and tasks that are required before, during, and after the 3D printing is complete. All of these steps

Comparing Metal 3D Printing Processes

LASER POWDER BED FUSION (L-PBF, SLM, DMLS)

2 Weeks + 30 Hours Hands-on	Design Thermal Supports	Design Structural Supports	Vacuum and Inert Procedure	Monitor 3D Printing for Curling/ Swelling
Machine Training Required	File Preparation		Core 3D Process	

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

BINDER JET 3D PRINTING (BJP)

3 Days 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
Machine Training Required	File Preparation	Core 3D Process		

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.

vary in terms of time required, complexity, and operator skill requirements.

For BJT, depowdering a bed to remove green parts, curing, and sintering are all core to the process. Turnover time between print jobs is usually rapid, though it depends on the make and model.

Both L-PBF and EBM, meanwhile, require skilled machine preparation including cleaning and component changes, which takes significant time, usually about 2-3 hours. After printing, L-PBF 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 most PBF methods, with L-PBF often requiring machining such as wire EDM or milling.

Final Part Microstructure. Binder jetting is the only form of metal powder 3D printing where a part is fully formed before thermal processing and consolidation. This has important consequences for the final part's microstructure, which is critical to delivering reliable material properties, functionality, and performance.

In L-PBF, the thermal annealing required to relieve stress imparted by heating during fabrication also affects the microstructure. When drawing out each layer with a fine laser point or points, the part is hot where the build 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

Binder jetting is a faster, less complex process with a lower operator budget 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 26th Annual International Solid Freeform Fabrication Symposium. The 2016 study is available at **TeamDM/Metal3DOperation**

Skilled Labor Required

Thermal Destressing

Remove Build from Plate with EDM

Remove Supports by Hand

Reset Machine: 2-3 Hours

Average Number of Waste Products: 4

Required Post-Processing

Machine Preparation

Waste

- Start plates
- Maintenance of Lens + supplies needed
- Filters, multiple per build
- Maintenance of build plate + eventual replacement

Parts are Prepared for Sintering

Sintering in High-Temp Furnace Fuses Particles

Reset Machine: About 1 Hour

Average Number of Waste Products: 4

Machine Preparation

Waste

- Binder is recycled
- Cleaner
- Nozzle paper
- Some powder

inconsistent nature of the microstructure or the thermal gradients created during the printing process.

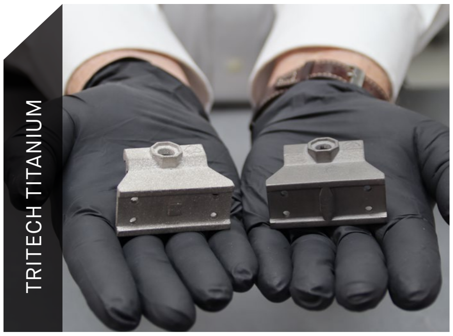
Research conducted by ExOne, and presented at the 28th Annual International Solid Freeform Fabrication Symposium, demonstrated important differences in the microstructures of metal parts 3D printed with binder jetting, L-PBF, and EBM. It showed that both EBM and L-PBF produce columnar grain structures with relatively large grains, while the BJT 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 BJT produces results in isotropic mechanical properties and good fatigue life.

Binder Jet Study on Microstructure

See a detailed comparison of the microstructures of binder jet 3D printed parts versus laser powder bed fusion and electron beam melting. Includes micrograph images.

TeamDM.com/BJTmicrostructure

Customer Case Studies

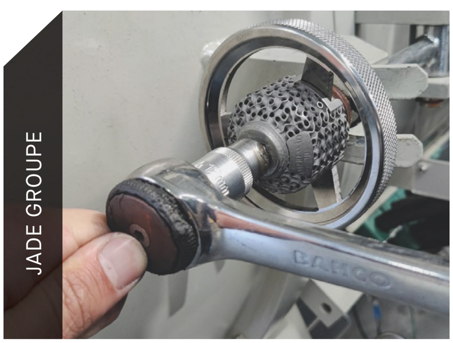


Binder jetting with reactive titanium powder

TriTech Titanium operates the first production titanium binder jet 3D printer. Building parts layer-by-layer in Ti64 powder on the **Production System P-1** delivers near net shape precision parts with a high strength-to-weight ratio without the cost or lead time of traditional tooling.

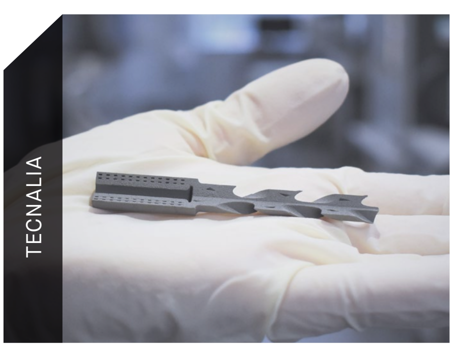
Capitalizing on opportunity with 3D

AmPd Labs recognized a demand for immediate solutions to minimize production down times, including for metal parts traditionally cast or machined. 3D printing stainless steel on the **Shop System** allows the company to offer new manufacturing solutions with metal binder jetting and Live Sinter software.



3D printing enables more efficient production

Jade Groupe requires jigs and fixtures in production with expensive tooling and long lead times that delay getting finished products to market. Binder jetting on the **Shop System** creates fixturing and tooling without disrupting CNC operations and improving manufacturing efficiency.



Hard metal and tool steels for cutting tools

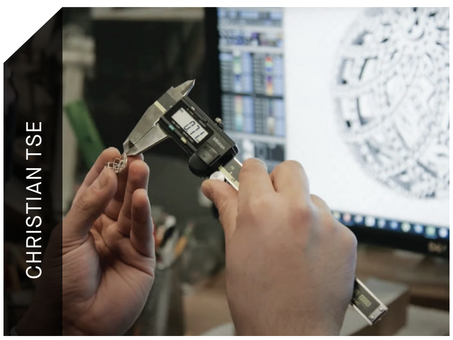
TECNALIA Research & Innovation uses specialty material binder jetting to create unique designs and shorten lead times of WC-Co and M2 tool steel advanced cutting tools. 3D printed parts from the **InnoventX** had densities comparable to traditionally manufactured commercial components.

Download the complete stories

TeamDM.com/MetalSuccess

Reducing costs and cutting lead times with digital production

FreeFORM Technologies provides engineering and manufacturing services for many customers familiar with metal injection molding (MIM). The **Production System P-1** delivers finished parts without the high investment cost and long lead times of traditional MIM molds.



Unlocking design potential and increased speed to market

Christian Tse is a private label jewelry manufacturer for global luxury brands known for precision and quality parts. Binder jetting on the **Production System P-1** enables the company to develop designs not possible with traditional methods that can be printed the same day.

Fast iterations for data-driven product optimization

Wall Colmonoy supports a variety of industries with manufacturing solutions and uses metal 3D printing to accelerate product improvements. Using the **Shop System**, the company prints and tests new design iterations in-house to quickly produce data validating performance improvements.

Take One Make One lean supply chain strategy

Azoth 3D uses the **Shop System** for the production of complex metal parts, empowering its customers to convert physical to digital inventory. Employing a Take One Make One (TOMO) strategy, supply chain disruptions are eliminated with qualified production of metal components on demand.

Benefits of Binder Jet at Scale

Excellent part quality

High-resolution 3D printing and a uniform print bed allow the Production Series to produce dense, high-quality parts capable of performing in the most demanding applications.

High-resolution printing

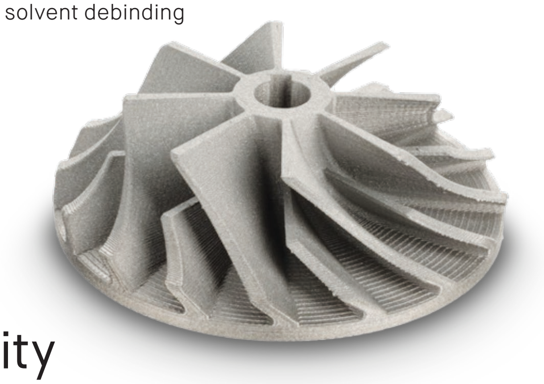
With a native resolution of 1,200x1,200 dpi and layer heights as small as 50 µm, the Production Series can 3D print parts with excellent surface finish and incredibly fine features.

Uniform print bed

Proprietary constant wave spreading technology enhances density uniformity across the powder bed, delivering greater part consistency in each build and from build to build.

Fully dense parts

Produces end-use parts with densities up to or exceeding 99% with properties similar to castings, suitable for demanding applications. No infill or solvent debinding step needed.



Best-in-class repeatability

The Production Series offers robust repeatability through anti-ballistics technology, print bar redundancy, and live optical print bed inspection, so you can print with confidence.

Print reliability

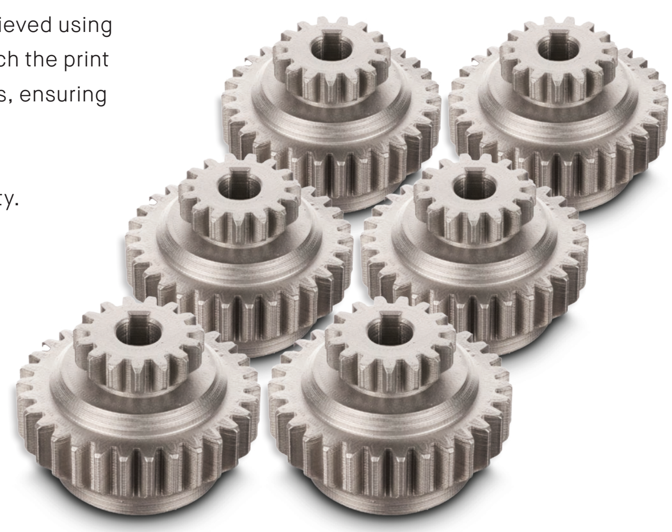
Patented anti-ballistics technology, engineered to reduce powder bed disturbance, reduces variability in the 3D printing process while increasing the longevity of the print bar.

Print bar redundancy

Full print bar redundancy is achieved using an anti-banding strategy in which the print bar is re-aligned between layers, ensuring reliable binder deposition and suppressing defects that would otherwise affect final part quality.

Real-time print bed inspection

An overhead camera monitors each layer using multi-angle lighting and imaging to detect print defects and nozzle performance during printing, facilitating part inspection and build audits critical to deploying AM in production environments.



Wide material compatibility

The Production Series' inert environment, open material platform, and selection of Desktop Metal-engineered binders enable 3D printing with a wide variety of metals, including everything from stainless steels to reactive metals and high-performance alloys.

Inert, closed-powder environment

A closed-powder environment, inerted to < 2% Oxygen, safely supports a range of non-reactive and reactive metals. Isolation from ambient conditions produces powder with consistent characteristics and quality, facilitating part uniformity and repeatability.

Open material platform

The P-50 features an open material platform that allows customers to source the same metal powders used in the MIM industry or custom alloys from their supplier of choice, keeping costs low and ensuring compatibility with bulk sintering processes.

Desktop Metal engineered binders

Our proprietary binders are formulated to support an array of alloys and maximize success through every stage of the binder jetting process, ensuring jettability during printing, green part strength during depowdering, and clean burn off prior to sintering.

Competitive cost per part

Within the Production Series, the P-50 delivers part costs competitive with traditional manufacturing technologies through the use of low-cost metal injection molding (MIM) powders, high-speed printing, and the ability to densely nest many parts in a single build.

Low cost MIM powders

Both the P-1 and P-50 use low-cost MIM industry powders, a trusted powder supply chain that can scale to volume production. Up to 99% or more of the powder recovered during the process can also be recycled, driving further cost efficiencies while reducing waste.

High-speed printing

Up to tens of thousands of parts per day† can be 3D printed with the P-50's SPJ technology, delivering print speeds of up to 100x those of laser powder bed fusion systems.‡

Dense 3D nesting

By densely nesting parts in the build box, customers can efficiently deliver high-throughput builds. What's more, tooling-free binder jetting means parts are supported by loose powder and don't require welding to a build plate — or removal.

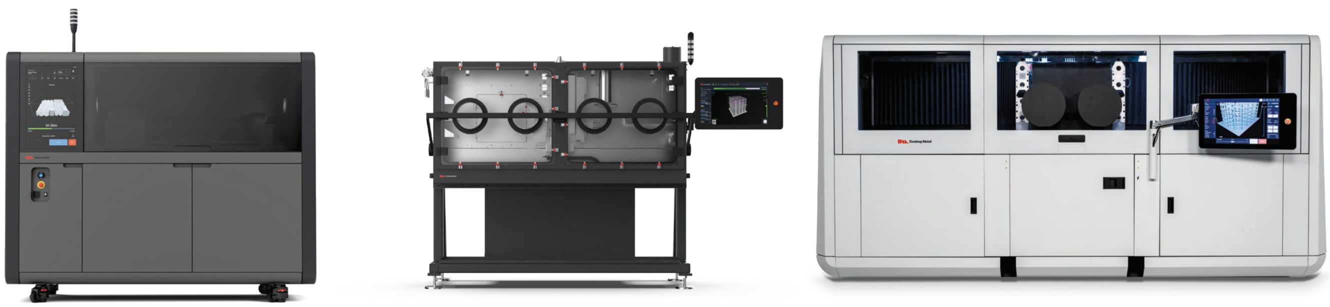
† Management estimates as of December 7, 2020.
‡ Based on published speeds of single-laser, mid-range laser powder bed fusion systems as of August 25, 2020.

Leaders in Binder Jet Technology

At Desktop Metal and our family of brands, we are passionate about the benefits that binder jetting technology can deliver to manufacturing and the world at large.

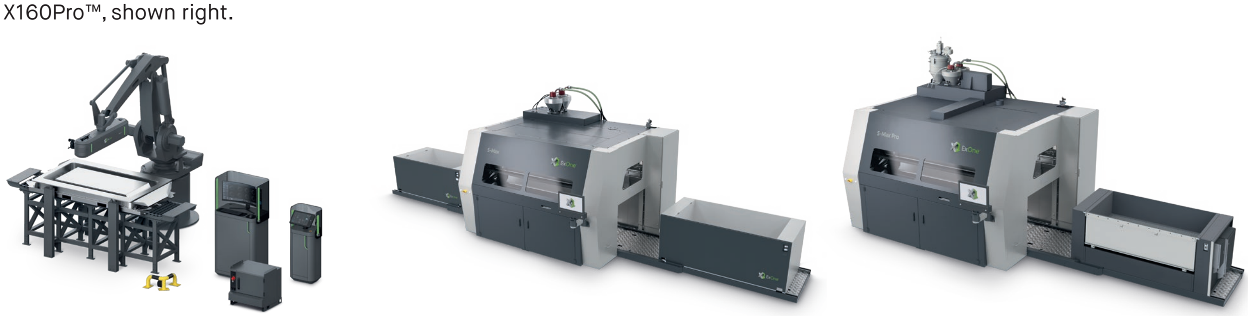
We offer a complete portfolio of binder jet systems for sand, metal, ceramics, and even upcycled material such as wood.

Our portfolio of solutions, and our expertise in this technology, is unmatched.



The Desktop Metal Shop System™, left, is a turnkey binder jet system that can proccess metal and wood. The Production System™ P-1, center, and P-50, right, feature Single Pass Jetting (SPJ) technology. SPJ is designed for the highest speeds and lowest costs needed for serial production. The P-1 is an R&D tool leading to higher volume AM on the P-50.

The Desktop Metal X-Series features Triple Advanced Compaction Technology, which ideal for specialty materials such as ceramics and can also process ultra-fine metal powders. The family includes the InnoventX™, left, X25Pro™, center, and the X160Pro™, shown right.



The S-Max line of sand 3D printing systems for foundries is among the most popular production binder jet systems in the world. Shown from left to right here, the S-Max® Flex robotic sand 3D printer, the S-Max®, and the S-Max® Pro with a box-in-box efficient footprint design. While these systems were designed for sand printing, they can also process coarser grain ceramics.

Conclusion

Binder jetting is one of the fastest, most flexible, and promising additive manufacturing technologies in the world.

By leveraging a relatively straightforward inkjet printhead, this process builds upon 30 years of development to transform a wide range of powders – metals, ceramics, sawdust, and other waste – into end-use parts. When working with metal powders, these parts can be sintered to high accuracy and density, similar to the long-trusted MIM process.

The freedoms that binder jetting metals unlocks are significant for innovation, design, new business models, supply chains, and sustainability. Complex, once-impossible geometries are now easy to produce directly from a design file, allowing for new lightweight designs, part consolidation, and optimized designs that can improve product performance and solve complex engineering challenges. Final parts can be further machined or processed if desired.

Binder jetting eliminates the long wait times and expense of hard tooling and enables economical, on-demand production across small, medium, and mass production volumes. This simple process also enables decentralized production where files, rather than physical parts, can be shipped to far-away locations for printing closer to where they'll be used, reducing or eliminating shipping of goods.

Ultimately, binder jetting can help to transform our world's complex metal ecosystem from one full of challenges, limitations, and waste to one that is convenient and offers new design freedoms – all while generating little to no waste.

While many 3D printing methods can deliver some of these benefits, **only binder jetting has the potential to deliver these benefits at high speeds, low costs, and mass volumes** that compete with traditional manufacturing technologies. Binder jetting can bring the benefits of 3D printing to a production environment at scale, delivering sweeping improvements that truly make a difference in the world.

At DM, our entire global team is proud to offer a green, progressive manufacturing technology — because we believe technology has a vital role to play in solving the world's toughest problems.

Additive Manufacturing 2.0

Metal | Polymer | Ceramic | Composite | Wood

Printer platforms

Desktop Metal

Desktop Health

ETEC

ExOne

FIGUR

Materials

ADAPTIVE3D

FORUST

Applications and more

aidro
Desktop Metal Company

aerosint

Desktop Labs

About Us

Desktop Metal (NYSE:DM) is driving Additive Manufacturing 2.0, a new era of on-demand, digital mass production of industrial, medical, and consumer products. Our innovative 3D printers, materials, and software deliver the speed, cost, and part quality required for this transformation. We're the original inventors and world leaders of the 3D printing methods we believe will empower this shift, binder jetting and digital light processing. Today, our systems print metal, polymer, sand and other ceramics, as well as foam and recycled wood. Manufacturers use our technology worldwide to save time and money, reduce waste, increase flexibility, and produce designs that solve the world's toughest problems and enable once-impossible innovations. Learn more about Desktop Metal and our #TeamDM brands at www.desktopmetal.com.

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