

HP Metal Jet technology

HP's digital printing technology for metals



Three-dimensional printing of useful objects and machine components is a reality. 3D printing offers the ability to produce rapidly and at low cost both industrial-scale runs of high-value parts and one-of-a-kind parts. Now, with a new technology for metal parts, HP continues to reinvent the design, production, and distribution of 3D-printed parts to drive the digital transformation of manufacturing with the most advanced 3D metals printing technology for mass production: HP Metal Jet. HP Metal Jet extends the breakthroughs in speed, quality, reliability, and cost made possible for plastics by HP Multi Jet Fusion technology.



HP Metal Jet printer¹

The KISTERS logo, featuring a stylized 'K' symbol followed by the word 'KISTERS' in a bold, sans-serif font.

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¹ Image shown may differ from actual product.

Introduction

For more than 30 years, HP inkjet technologies have disrupted and led a broad range of printing markets. In 2014, HP introduced a revolutionary 3D printing technology for plastics: HP Multi Jet Fusion.² HP Multi Jet Fusion places drops of functional liquid agents onto a powder bed to control the physical properties and features of plastic parts point-by-point. It leverages HP's deep assets in imaging and printing to take the digital transformation of printing off the page and into a three-dimensional world of highly-functional, high-value manufactured items.

HP Multi Jet Fusion offers high build quality, speed, and at the lowest cost relative to competitive 3D printing solutions in the marketplace today.² These breakthroughs in quality and speed will accelerate the adoption of 3D printing to create a digital transformation of manufacturing as widespread and profound as the way HP Thermal Inkjet changed the landscape of conventional printing markets and applications. As with other HP products, HP Jet Fusion 3D printers offer users HP's key values of reliability, ease of use, versatility, and an end-to-end digital workflow.

HP Metal Jet leverages and extends the workflows and technologies that HP developed for printing 3D plastics into metals with new functional agents, processes, and printing hardware.

HP Metal Jet solutions break through the economic, design, and time constraints of traditional methods for metal part production while delivering quality, productivity, and cost beyond the capabilities of existing 3D printing technologies for metals.³

Using HP Thermal Inkjet to precisely deliver *HP Binding Agent* to a powder metal bed and industry-standard metal injection molding (MIM) metal powders for low cost, HP Metal Jet is a binder jet technology that features:

- Multiple parts produced at the same time, or large parts, in a powder bed 430 x 320 x 200 mm (16.9 x 12.6 x 7.9 in).
- Parts can be arranged freely in multiple levels in the powder bed to optimize packing density, productivity, and cost.
- No build plate required, compared with selective laser melting (SLM).
- Low-cost, high-quality final parts for serial production up to 100,000 parts.⁴
- Best-in-class price-productivity.^{3,4}
- 1200 x 1200 dpi addressability in a layer 50 to 100 microns thick.
- Finished parts with isotropic properties that meet or exceed ASTM and MPIF Standards.⁵
- High reusability of materials can reduce materials cost and waste without compromising part quality.⁶
- Density after sintering > 93%, similar to MIM.

With a design and technology foundation proven in generations of HP's commercial and industrial printing solutions, HP Multi Jet Fusion and HP Metal Jet printers deliver industrial productivity with reliable, consistent, and repeatable results.

Figure 1 shows sample metal parts made from 316L stainless steel MIM powder produced by an HP Metal Jet printer after sintering and before post-processing (e.g., surface polishing, etc.).

Figure 1. Sample 316L stainless steel parts made using HP Metal Jet technology

(L-R top row, designs courtesy of McMaster-Carr, GKN (2); L-R bottom row: Autodesk Netfabb, HP)



² For more information and detailed claims, see the HP Technical White Paper "HP Multi Jet Fusion Technology", 4AA5-5472EEW, March 2018 and current specifications for HP Jet Fusion 3D Printers at hp.com/go/3Dprinting.

³ Productivity based on print speed for serial production up to 100,000 parts compared to competitive binder jetting and selective laser melting (SLM) metals 3D printing solutions available as of July 31, 2018.

⁴ Low cost based on comparable competitive binder jetting and selective laser melting (SLM) metals 3D printing solutions available as of July 31, 2018.

⁵ Specifically, ASTM/MPIF standards for tensile strength, yield strength, and elongation.

⁶ Compared to selective laser melting (SLM) and based on internal testing of HP Metal Jet technology as of September 2018.

3D printing

Whereas manufacturing by milling, grinding, and cutting *removes* material from a workpiece, additive manufacturing—“3D printing”—is a digital technology that creates objects by selective material *addition*. This allows each 3D-printed part to be unique in the same way that each page printed by an inkjet or laser printer can have unique content. 100% variable content page to page and part to part is a capability that digital technologies bring to 2D and 3D printing.

Prime applications for 3D-printed metal parts include the functional and aesthetic components for automotive, medical, industrial, and 3Cs (computers, cellphones, and consumer electronics). These parts—with complex internal and external geometries—can be produced in runs of 1000s or can be customized, high-value one-of-a-kind products. 3D metal printing is targeted to compete with metal injection molding, investment casting, and press and sinter processes.

Before 3D printing, parts with complex surfaces, moving elements,⁷ and internal fluid passages were assembled from subcomponents that were aligned and assembled with fasteners and/or adhesives. In conventional parts—especially those designed to handle air and liquids—joints and sealing surfaces may be points where mechanical failure and leakage occurs. Because 3D printing builds objects from a stack of thin cross-sections, complex parts can be produced either as a monolithic structure or from fewer subcomponents. 3D printing has the potential to simplify design and manufacturing processes and to reduce processing time and costs. Parts can be made by 3D printing that cannot be made by other methods, and this creates many new possibilities for innovations in design, form, and function.

To meet the needs of a broad range of applications, a 3D printing solution should offer the desirable attributes of high productivity, low cost of hardware, low cost per part, high build quality, and choices in materials and material properties for strength, elasticity, and other properties. While commercial 3D printers have been available for more than 30 years, adoption of 3D printing has been limited to niche markets and applications because all of these attributes have not been available together from a single technology or 3D printing solution. HP innovation is changing this.

HP Multi Jet Fusion and HP Metal Jet were conceived to overcome the tradeoffs and constraints limiting current 3D technologies. Offering speed, quality, strength, and novel functionalities, HP products will accelerate the adoption of 3D manufacturing across a wide range of industries and applications where plastic and metal parts are required by the application.

HP’s vision is to reinvent part design and manufacturing with streamlined workflows and new capabilities for 3D printing. The supply chain for finished, high-value items will be fundamentally changed by the ability to manufacture parts on-demand and where they are needed. HP’s Open Platform approach will break down barriers to the adoption of 3D printing through collaborative innovations in materials, printing hardware, sintering solutions, and design and production software.

HP Metal Jet technology

HP Metal Jet printers can precisely place up to 630 million nanogram-sized drops per second of a *liquid binding agent* onto a powder bed to define a part’s cross-section layer by layer.

HP Binding Agent is a water-based liquid agent delivered by HP Thermal Inkjet Printheads. HP Binding Agent is formulated with a polymer that binds the metal particles together wherever HP Binding Agent is printed.

Capillary forces pull HP Binding Agent into the smallest interstices between the metal particles to produce a uniform binder distribution.

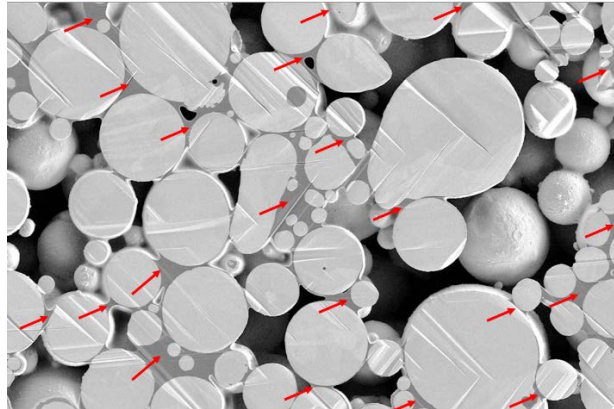
Curing the bed (see Figure 4) evaporates liquid components and cures the polymer to produce a **high-strength green part**.⁸ The red arrows in Figure 2 show how the binder flows to act like a hot-melt adhesive holding the metal particles together in preparation for sintering.

The polymer decomposes during sintering.

⁷ For example: gears, sliders, rotating joints, and other kinematic elements.

⁸ “Green” refers to a part made of metal powder and stabilized by binders before sintering.

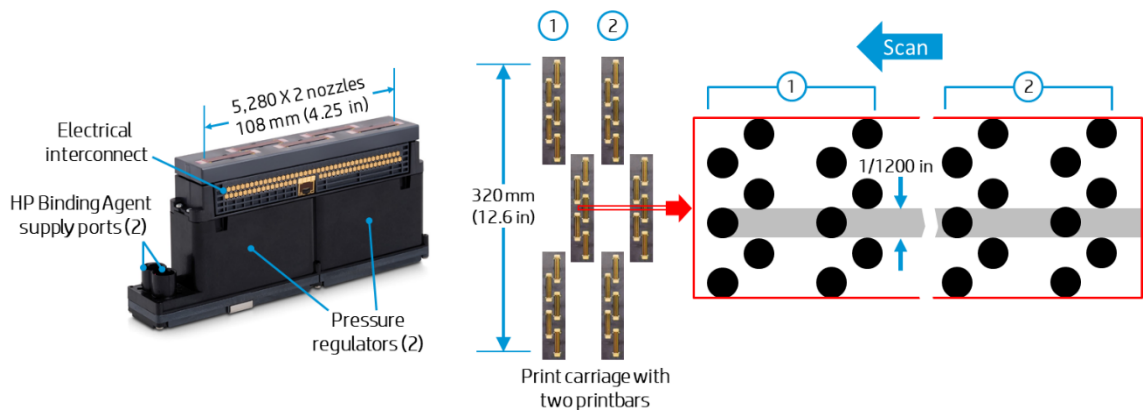
Figure 2. Micrograph of cross-section of an HP Metal Jet green part showing metal particles and cured binder (red arrows)



HP Thermal Inkjet printheads provide precise placement of drops of HP Binding Agent in the powder bed. The printhead for HP Metal Jet printers is based on a design that has been proven in-service in HP’s PageWide Web Presses and HP Latex printers. Each printhead produces a 108-mm (4.25-inch) print swath with *two independent columns of 5,280 nozzles* that are spaced 1200/inch in each column. The printhead is shown on the left in Figure 3. There are two independent supply ports for HP Binding Agent and two built-in pressure regulators.

A key feature of HP printheads is quick and easy replacement by the operator. No tools, handling fluid or electrical connections, or manual alignment is required.

Figure 3. HP Thermal Inkjet printhead for HP Metal Jet printers, printbars, and details of nozzle arrangement



HP Metal Jet printers employ multiple *printbars* for high productivity and nozzle redundancy. As shown schematically in Figure 3, two printbars (1 and 2) on the print carriage, each with three 108-mm (4.25-inch) printheads in a staggered and overlapping configuration, produce a print swath 320-mm (12.6-in) wide.

Voxel resolution

A *voxel*—“*volume element*”—is the 3D equivalent of a 2D *pixel* in digital printing. Voxel resolution is a planar grid in the powder bed with a depth corresponding to the thickness of each printed layer. HP Metal Jet printers address a **1200 x 1200 dpi grid** with a layer typically between **50 and 100 microns thick**. HP Metal Jet’s high voxel resolution produces fine details and precision definition of edges and surfaces both inside and outside the part.

Redundant nozzles

A group of nozzles across printbars 1 and 2 is shown on the right in Figure 3. The two columns of nozzles on each printhead are shown as well. The nozzles are aligned so that **four nozzles print in the same 1/1200-inch dot row** (gray highlight) in the powder bed. This means that up to four different nozzles can print HP Binding Agent in the same 1200 dpi grid point. This is called **4-times nozzle redundancy**, and it suppresses defects by reliably printing HP Binding Agent.

Printhead service station

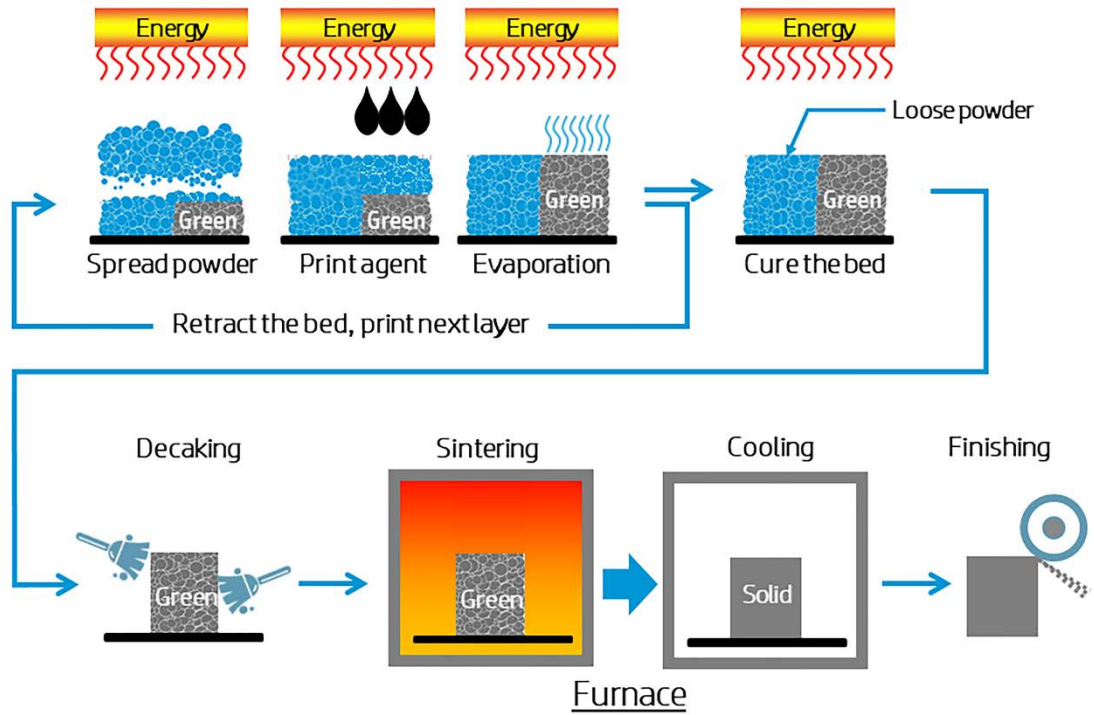
A printhead service station uses HP’s optical drop detector technology to quickly determine the health of each nozzle before, during, and after printing. This process identifies nozzles that are not performing within specifications. An automatic service cycle can recover nozzle function.

HP Metal Jet process

The process of building a metal part by HP Metal Jet is described schematically in Figure 4. A detachable *build unit*, containing the powder bed and powder supplies, is rolled into the HP Metal Jet printer for part production.

Note that throughout the printing process, the powder bed may be heated—shown by the “Energy” element—to evaporate volatile components of HP Binding Agent.

Figure 4. Schematic of HP Metal Jet printing process



Spread powder

The build begins with a scanning recoater laying down a uniform, thin layer of powdered metal across the working area. The recoater is refilled from supply bins of metal powder located at each end of the scan. This enables bi-directional recoating for increased productivity.

Print agent

HP printheads jet HP Binding Agent at precise locations onto the powder bed to define the geometry of single or multiple parts. At one end of the scan, a *printhead service station* tests, cleans, and services the printheads for reliable operation.

Evaporation

The liquid components of HP Binding Agent evaporate.

Retract the bed, print next layer

The powder bed is retracted the thickness of the printed layer, and the process repeats until the build is completed.

Cure the bed

The powder bed with its printed parts is heated to complete the evaporation of liquid components from HP Binding Agent and to cure the polymers to achieve high strength in the green part(s).

Decaking

The powder bed is now cooled, and parts can be removed. *Decaking* is the process of removing loose powder from the surfaces of the part. Once the parts have been decaked and removed, the remaining powder can be processed and reused for economical consumables management.

Sintering

The green parts are now moved into a furnace. At sintering temperatures, atomic diffusion at the surfaces of the metal particles binds them in a matrix that can exceed 93% solid density.⁹ The polymer from HP Binding Agent decomposes.

Finishing

The part(s) may now undergo machining and polishing to meet dimensional and surface finish requirements.

⁹ Solid densities greater than 93%, similar to MIM, can be achieved by HP Metal Jet.

Metals for HP Metal Jet

The first generation of HP Metal Jet printers will be based on an Open Platform for materials leveraging industry-standard stainless steel powders developed for metal injection molding (MIM). Extending HP Metal Jet technology to process additional metal powders commonly used in MIM is under investigation.

The grain structure in a test specimen produced by HP Metal Jet is visible in the photomicrograph of Figure 5. The section was processed by a 10% oxalic acid - electrolytic etch.¹⁰ The microstructure is typical of Type 316L stainless steel in the annealed condition, and consists of austenite grains and annealing twins.¹⁰ This sample shows superior grain isotropy compared to most competitive 3D metal printing technologies. For example, a cross-section of a part produced by selective laser melting (SLM) is shown for comparison in Figure 6. Notice the anisotropic grain structure, which will introduce orientation-dependence in physical properties (e.g., tensile strength may be different along X and Y axes in the powder bed and along the Z-axis).

Figure 5. SEM image of cross-section of a 316L stainless steel test specimen produced by an HP Metal Jet printer¹⁰

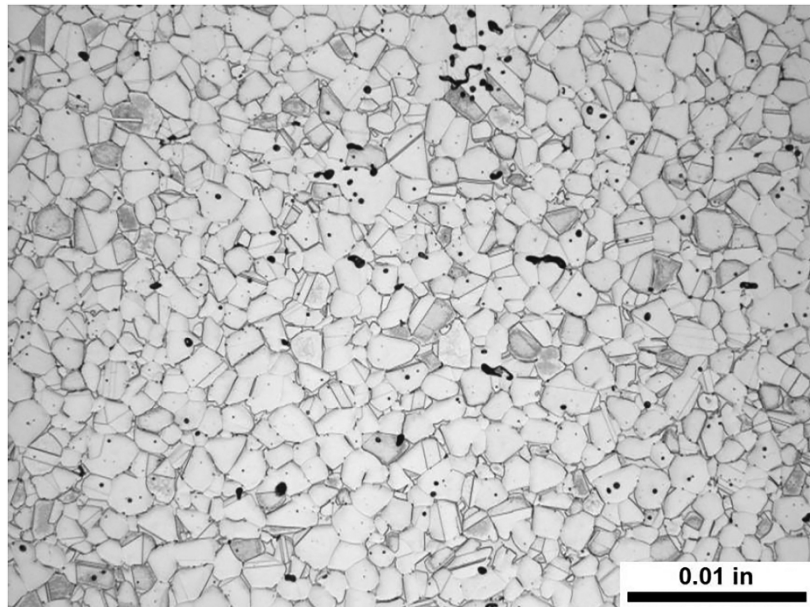
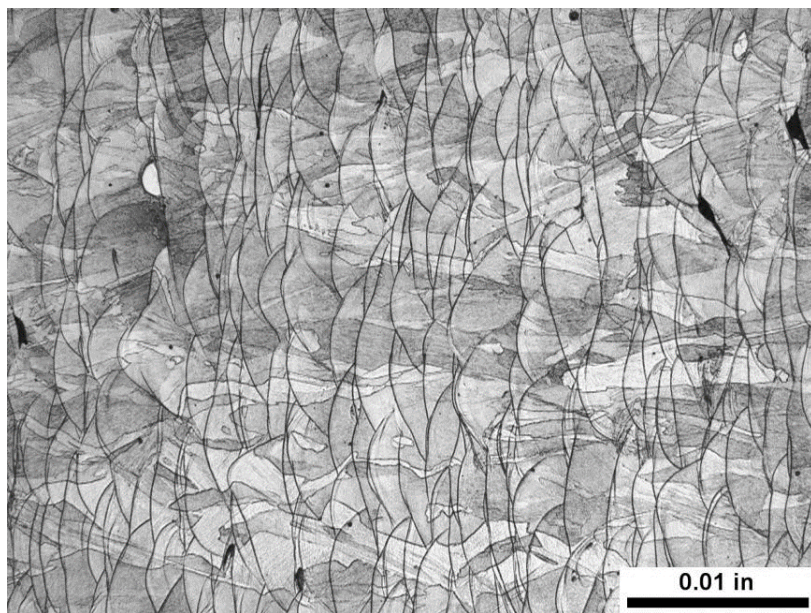


Figure 6. SEM image of a cross-section of a 316L stainless steel sample produced by selective laser melting (SLM)¹⁰



Clearly visible in Figure 6 are the microscopic pools of melt and the weld lines between them. Elongated grains—showing distinctive anisotropy—are visible as the gray shapes extending across weld lines.

¹⁰ Source: Element Materials Technology Report to HP Inc.: “Metallurgical Evaluation of Type 316L Stainless Steel Specimens.”

HP Metal Jet vs. metal injection molding

In MIM, a slurry of metal particles, wax, and polymers is injected under high pressure into a mold. MIM feedstocks are typically less than 93% metal powder by weight¹¹ versus up to 99% for HP Metal Jet printing.

MIM requires a *debinding process* to remove the wax, and this can add up to 20 hours to the MIM workflow. **Unlike MIM, a time-consuming debinding process is not part of the HP Metal Jet process.**

In both processes, the binding polymer decomposes under sintering. The polymer in HP Metal Jet is used at a lower weight fraction compared with MIM, and this facilitates the decomposition and evacuation of polymer residue during sintering. This is important to obtain high productivity of thick-walled parts.

Software for HP Metal Jet

HP Metal Jet printers will leverage the software and design workflows originally developed for plastics in HP Multi Jet Fusion printing. Specific workflow provisions for metals are currently under development.

HP's Open Platform

HP is developing an Open Platform for HP Metal Jet for industry-standard, low-cost materials and industry-standard sintering solution compatibility. More details will be announced as arrangements are finalized.

Availability

New customers can evaluate HP Metal Jet technology using the Metal Jet Production Service¹² with expected availability first half 2019.

Summary

HP's 3D printing technologies for plastics and metals are built on HP's core competencies in precision low-cost mechanics, precision metering and placement of liquid functional agents, high-volume manufacturing, material science, and imaging. Compared with other commercially available 3D printing technologies, HP Multi Jet Fusion and HP Metal Jet printers will define new levels of part quality, part functionality, productivity, and production economy.

The extension of HP Multi Jet Fusion technologies to metals—using stainless steels (17-4 PH and 316L) with industry-wide applications—opens new markets for high-quality, high-strength metal parts for automotive, medical, industrial, and 3Cs (computers, cellphones, and consumer electronics). Unique designs for one-of-a-kind applications as well as industrial-scale runs of high-value parts can be produced economically using the unique features of HP digital 3D printing workflows. This capability enables a host of new possibilities in the design and function of parts that are not well-suited to traditional manufacturing methods or other 3D printing solutions.

HP's 3D printing products will drive the digital transformation of manufacturing with a 3D printing ecosystem including advanced user interfaces, software for 3D part creation and production, and robust, industrial-grade 3D printers optimized to deliver end-to-end productivity and economy.



¹¹ See <http://www.pim-international.com/metal-injection-molding/sintering-in-the-metal-injection-moulding-process/>.

¹² HP does not provide manufacturing services. Customers work directly with and pay for manufacturing services provided by a trusted third-party manufacturing partner responsible for fulfilling the order. HP provides design compatibility check for HP Metal Jet printing. Metal Jet Production Service is expected to be available in Western Europe and the US.

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