A Comprehensive Guide to Metal 3D Printing: Opportunities and Limitations

White Paper

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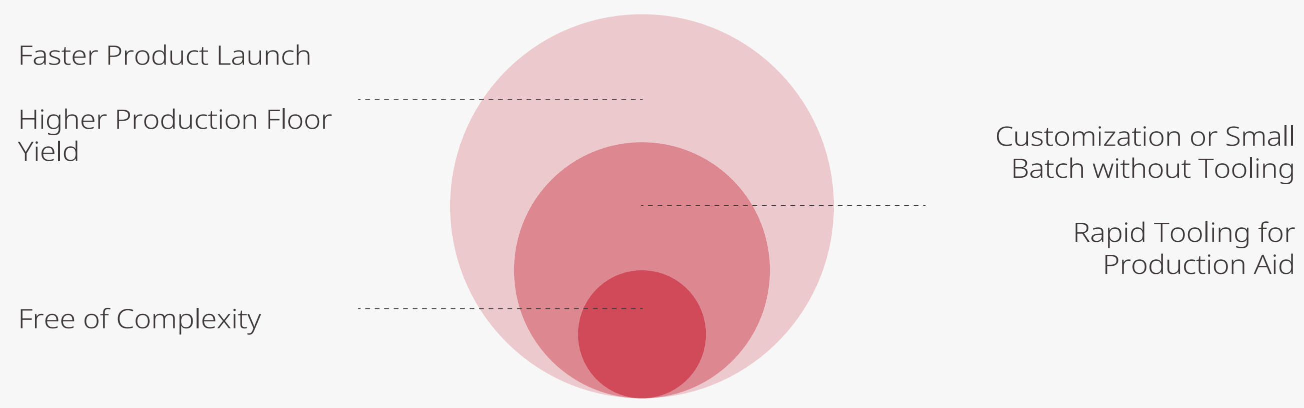
1 Positioning for Metal AM Technology

A variety of industrial segments have applied metal 3D printing to produce complex metal parts on demand, such as aerospace, defense and armory, medical, oil and gas, industrial and automotive. Unlike casting and CNC milling, metal 3D printing produces small batches of complex metal parts that are far more cost-efficient. Such an advantage can lead to higher-level benefits, such as production floor efficiency and the possibility of additional business models, depending on the scale and depth of the implementation of metal 3D printing.



Core Benefit

- **Free for Complexity**

  Complex features can be added at no extra investment cost. Only the necessary material is used where it is needed, instead of wasteful subtractive manufacturing. Objects originally constituted by multiple or complex parts with different manufacturing steps can be produced in a single step and even allow for more design adaptations optimized for the application that would otherwise be unfeasible or even not possible.

Production Benefits

- **Customization or Small Batch without Tooling**

  Metal 3D printing does not require extra tooling, such as molds, when fabricating different structures. For small batch production, the tooling in conventional manufacturing process probably causes longer lead times, greater costs and put a limit on feasibility.

- **Rapid Tooling for Production Aid**

  Metal 3D printing can also help production indirectly. Metal spare parts, jigs and fixture are a common demand on the production floor. An ability to supply these tools rapidly and in-house can lead production line maintenance and organization to be seamless.

Commercial Benefits

- **Faster Product Launch**

  When tooling becomes unnecessary, less time spent on design iterations makes production development quicker. In further stages, the rapid organization of a small batch production line can allow products to be ready for launch earlier than they would otherwise be.

- **Higher Production Floor Yield**

  When focusing on the impact metal 3D printing can have on the production floor, the lower need for organization and time spent on maintenance means more cycle time becomes available and gives a greater range of choices of production. Thus, greater capacity grants owners more business opportunities, especially for service providers.

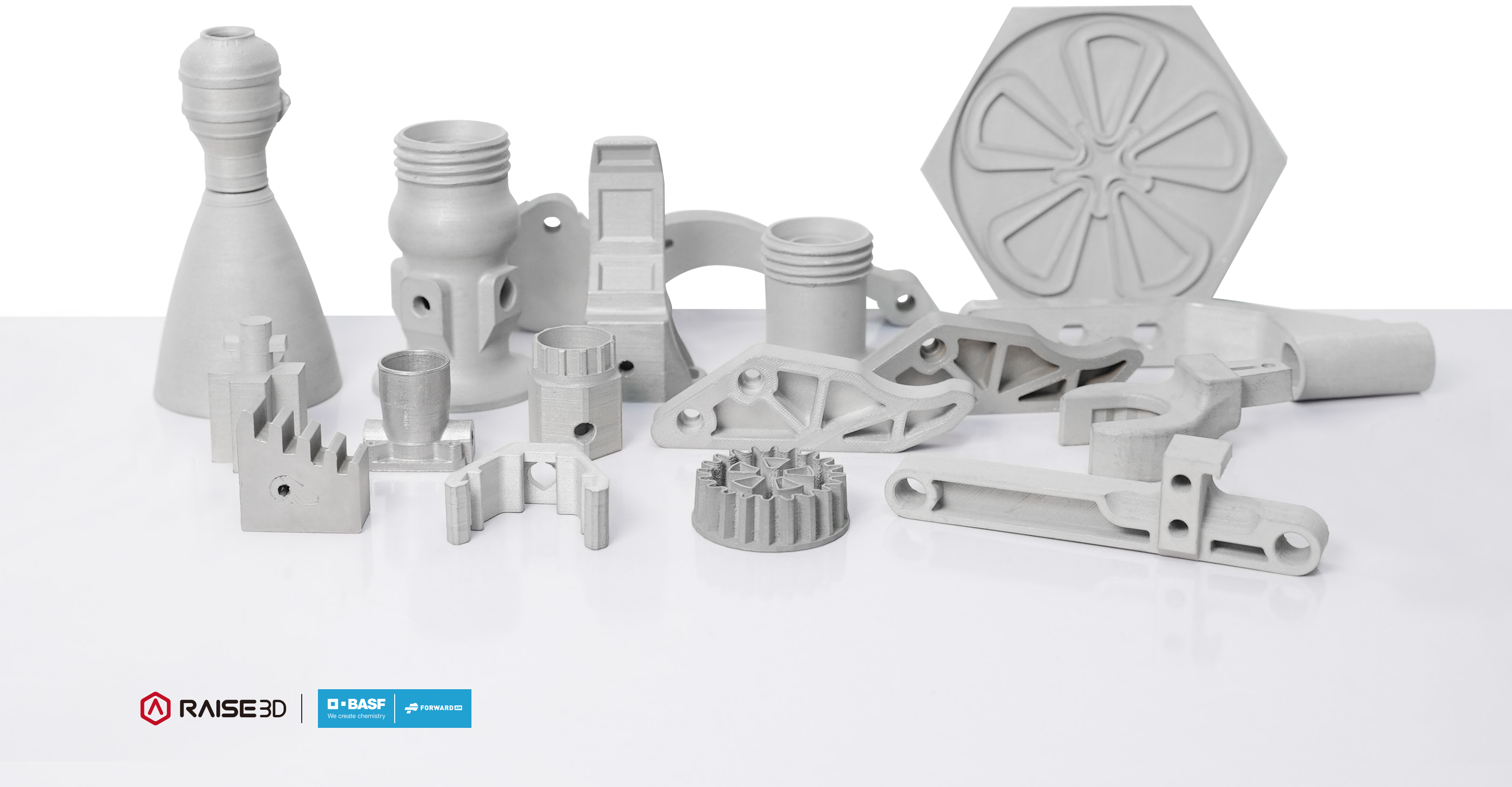
Early Adoption Segments	Typical Application	Benefit Identified
Automotive, especially in high-end applications like racing	• Transmission Plate • Engine Housing • Turbocharger • Heat Exchanger • Housing and Bracket of Front-Axis-Differential	• More time to iterate on and optimize designs, leading to improvements in fuel efficiency, performance benefits and overall cost savings. • Quick production of custom fixtures and tooling that makes it easy for manufacturers to optimize production lines. • More flexible production lines that simply print the new parts and keep manufacturing lines running smoothly. • Aftermarket parts – especially those that were once cast – can be easily supported by metal 3D printing.
Aerospace	• Thrust Chamber • Injector • Bracket • Rocket Nozzle • Turbopumps • Cylinder Block	• Complex parts can be simplified into one precisely printed component, rather than put together from multiple individual components. • Produce lightweight structures that meet the design requirements of the part, saving on the total weight of the aircraft but also having the secondary benefit of reducing waste material. • Spare parts can easily be produced on-demand, reducing inventory requirements, and enabling the manufacturing of parts closer to end users.
Defense and Armory	• Rocket Thruster • Microturbines • Heat Exchanger • Turbopumps • Choke Valve	• Increased vehicle performance with complex hypersonic components and can improve fuel burn, emissions, part lifecycles, and better material properties than casting. • Create distributed supply chains that reduce the reliance on foreign manufacturing and without the need for specialist knowledge to operate. • Agile manufacturing of replacement, legacy parts in order to maintain existing equipment in the field.

2 Common Technologies Available for Metal 3D Printing

Of the different metal 3D printing processes, there are two that are the most popular: sintering-based AM technology and binder shaping AM technology. The binder-based method makes use of the core mechanism from the traditional powder metallurgy process, which usually adopts pressing metal powder against molds or dies as a shaping procedure. Both processes are distinct and have their advantages and disadvantages.

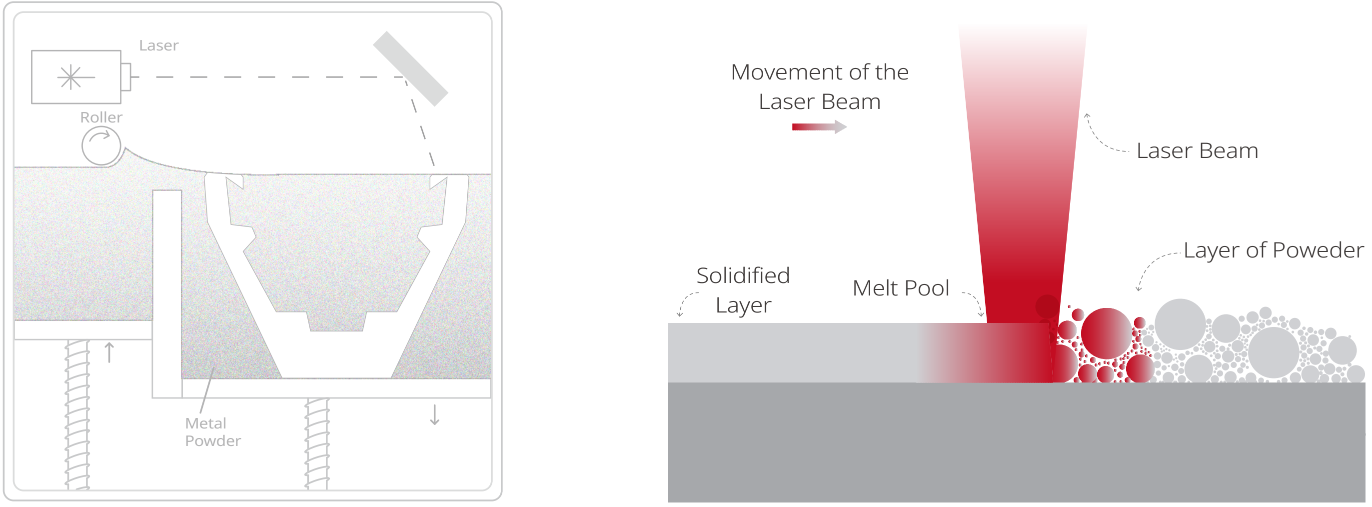
Metal AM Technology

- Sintering-based AM Technology
  - **L-PBF**
    Laser Powder Bed Fusion
    Metal powder is fused with a high-power energy beam
- Binder Shaping AM Technology
  - **Metal FFF**
    Metal Fused Filament Fabrication
    Metal powder is dispersed in an extrudable binder matrix
  - **BJ**
    Binder Jetting
    Metal powder is bond together with a jetted binder



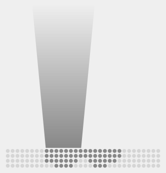
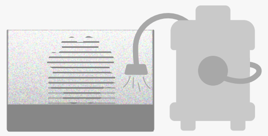
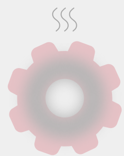
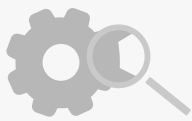
Sintering-based AM Technology

The sintering approach is one of the earliest adopted metal printing processes and consists of the distribution of an even and flat metal powder layer over the print bed. The metal powder layer has a thickness of between 15 and 100 microns. An energy beam scans over the top layer and melts the powder. Currently, L-PBF is the most widespread industrialized solution, adopting laser as energy source, with other mechanisms existing, such as E-Beam.



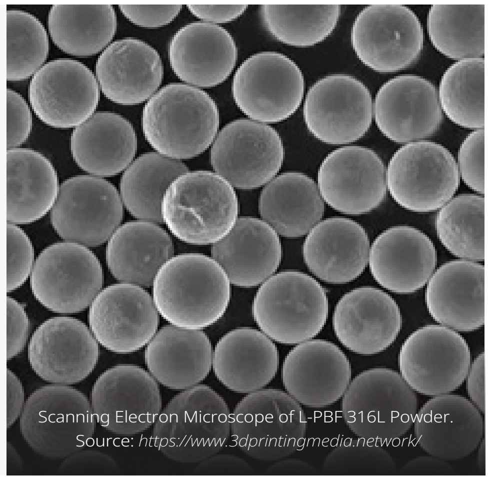
The mechanism of sintering-based AM technology

General Process of Implementing Sintering-based AM	
Model Optimizing	• Screening and modifying design constraints for metal sintering include: • Overhangs • Thin Features • Support Strategy has to take into account positioning and substrative post processing
Model	• Planning support structure for overhanging surface. • Converting 3D model into 2D layers, • Generating Gcode files.
Loading Feedstock	• Filling metal powder into the powder tank. • Extra caution when handling potentially toxic and pyrophoric metal dusts. • Personal protection is required, such as a mask, to prevent inhaling metal powder.

Printing 	• The metal part is gradually formed by repeat powder spreading and sintering. • This procedure is conducted in an inert atmosphere (argon,nitrogen or vacuum). • The fast heating and cooling rates create an atypical anisotropic crystal structure. • Additionally, the process of laser melting of metals creates vaporized soot, some of which deposits in the processing chamber and in the extraction module and filter. The smoke particles can be even finer than the powder itself and need to be cleaned out with care on a regular basis.
De-powdering 	• After a metal print is complete, it's covered in vat of metal powder. The powder must be emptied to reveal the part and recycled for future use. • The part needs to have remaining residual powder cleaned off further.
Stress Relief 	• Annealing in an argon atmosphere up to 1100 °C of the component to set the required crystal structure and to relieve internal stresses.
Removing Support 	• Removing the part from the build plate with a band saw or by wire cutting. • Supports are removed with tools or with conventional CNC operations like milling and drilling.
Support Surface Finishing 	• Since the support structure was sintered into the main body surface, rough surfaces will remain as a result. Specialized grinding tools and other equipment are needed to clean the residual metal and give a better surface finish.
Refine Assembly Surface Precision 	• Metal 3D printing is relatively less accurate for high tolerance level assembly. Thus, it is generally required to locate and machine essential areas for further assembly. This requires extra professionals to operate the machining equipment.

Material

The sintering-based approach adopts pure metal powder. Its processing quality depends highly on powder flowability. Therefore, it has a narrow range regarding the particle size (the most common being 20-60 μm), as well as a strict standard of particle size distribution, smoothness, roundness and regularity, resulting in a relatively higher manufacturing cost. For instance, the -LPBF steel powders are supplied on average at $20-$50/kg, and with a low volume of suppliers, with its total value being estimated at around 80 million dollars.



Scanning Electron Microscope of L-PBF 316L Powder.
Source: *https://www.3dprintingmedia.network/*

Advantages

- Mature technology with software and machinery.
- Process delivers the metal part directly.
- Provides the highest density among all metal printing technologies.
- Valued for its ability to print large-sized, heavy-load end-use parts, commonly used in the aerospace industry.

Disadvantages

- Workflows and process development is resource-intensive with specialized personnel.
- Lower yield rate due to thermal stress.
- Parts are welded to the build plate and must be removed with EDM or bandsaw. Support material must also be cut or milled off.
- Loose metal powder can be dangerous and requires significant training to handle. Swapping materials requires hours of labor and have high risk of contaminations.

Binder Shaping AM Technology

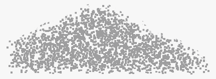
Origin: MIM and Feedstock

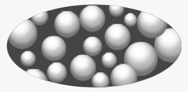
MIM (Metal Injection Molding) is one of the most adopted processes for complex metal manufacturing, and consists of pressing metal powder and injection-molding it into a desired shape, called the "green part" then sintering it into the final metal part. In MIM, a feedstock is used which provides the advantages of conventional injection molding: stable process conditions and high throughput with complex designs. This is achieved by mixing/compounding selected metal powders and a polymeric matrix, which makes the feedstock flowable under injection-molding conditions.

The "green" part will be post-processed by being debound then sintered using other equipment. In the debinding step, most of the binder matrix is removed and only small amounts of binder remain to hold the metal powder object in shape.

The subsequent sintering process is divided into two phases: residual thermal debinding and the final sintering step. In the first phase, the last binder components are thermally decomposed and removed. During this process, the metal powders already form bonds and keep the component in shape. In the final step, the powders are compacted to form the final metal part, driven by diffusion processes.

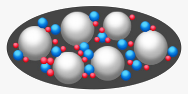
1 Metal Feedstock





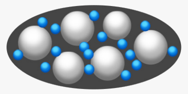
The applied feedstock is a mixture of metal powder and binder polymer which acts as a temporary glue to shape the metal powder.

2 Shaping



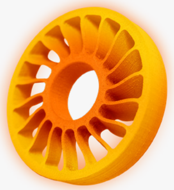
A mold is used to shape feedstock into the designed geometry and form the"green" part, which is composed by metal powders that are fully bound with a binder agent. The "green" part will be post-processed with debinding and sintering using other equipment.

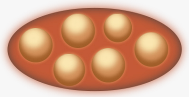
3 Debinding



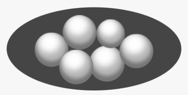
Most of the organic binder agent is extracted by catalytic depolymerization, for example, or dissolved in a solvent.

4 Sintering





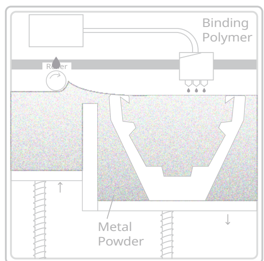
5 Finished Part



The sintering process consists of the use of a furnace, heated to up to 1,400°C, which is used to vaporize all remaining binders and leaves a dense metal part.

Liquid Binder AM: Binder Jetting

As an AM technology, binder jetting (BJ) inherits debinding and sintering workflow from the MIM process. Instead of molding technology, the 3D printer is used to shape and form the desired object. Its shaping relies on selectively depositing a liquid binding agent onto a thin layer of metal powder.



General Process of BJ

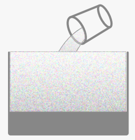
Model Optimizing

- Screening and modifying design constraints for PM-approach 3D printing including:
  - Maximum Size
  - Minimum Wall Thickness
  - Overhangs need to be avoided

Model Slicing

- Planning separate support structures for overhanging surfaces.
- Converting 3D model into 2D layers,
- Generating Gcode files.

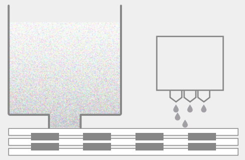
Loading Metal Powder into Printer



- Filling metal powder into powder tank.
- Extra caution when handling potentially toxic and pyrophoric metal dusts.
- Personal protection is required, such as mask, to prevent inhaling metal powder.
- Binder jetting uses pure metal powder as its material.

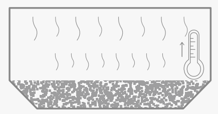
  Ventilators and a clean room are necessary, as metals may be potentially dangerous.

Printing



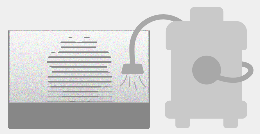
- Special metal powder formulations are subsequently layered on top of each other in a manner similar to LPBF. For each layer, a binder material is jetted into the powder bed to form the green part. Afterwards, the green parts, which are usually fragile, have to be removed from the powder cake.
- BJ conducts printing in enclose binder jetting chamber, which is similar for powder spreading but does not involve high temperatures or an inert atmosphere.

Curing



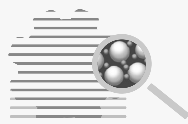
- Load the whole powder box with green burred to further dry and solidify the binder.

De-powdering



- De-powdering is a manual process thanks to the fragile and sensitive nature of the green parts.

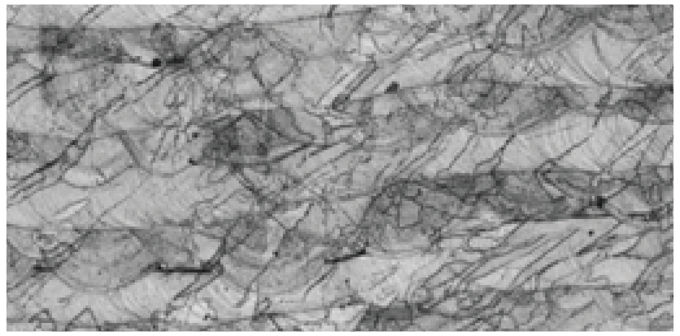
Debinding

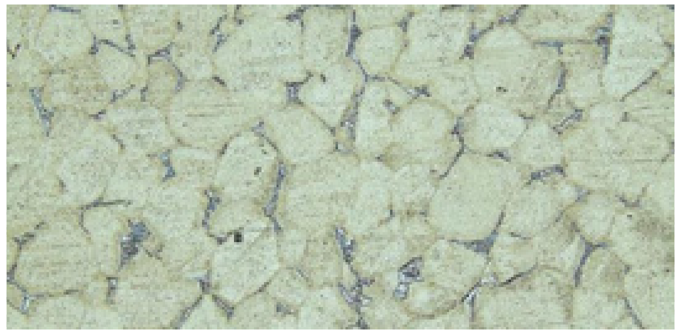


- Debinding refers to placing green part into a specialized debinding furnace. This purpose of this procedure is to extract the binder agent from the green part.
- Usually performed in the sintering furnace as a thermal debinding step

Sintering	• Sintering refers to placing the debound part into a specialized sintering furnace. The purpose of this procedure is to burn out binder residual and fuse metal particles into a solid mass using high temperatures.
Removing Support	• Supports are removed with tools or with conventional CNC operations like milling and drilling.
Support Surface Finishing	• Since the support structure was sintered into the main body surface, any rough surface will remain as a result. Specialized grinding tools and equipment is needed to clean the residual metal and give a better surface finish.
Refine Assembly Surface Precision	• Metal 3D printing is relatively less accurate for high tolerance level assembly. Thus, it is generally required to locate and machine essential areas for further assembly. This requires extra professionals to operate the machining equipment.

Another critical difference between L-PBF and BJ printing is the microstructure. L-PBF printed metal parts show heterogeneous microstructures where there are obvious tool paths under the microscope along the X, Y, and Z axes. In contrast, the dense BJ metal parts show a homogeneous microstructure along the same X, Y, and Z axes. But this doesn't mean BJ printing parts always perform higher mechanical values than L-PBF ones under all conditions. For example, under certain circumstances, BJ printing parts show higher elongation at break (60+% vs. 30+%) when compared to LPBF, while also maintaining similar tensile strength as a wrought metal part. While in other conditions, L-PBF metal parts feature higher tensile strength than both BJ and wrought parts.





Left: Microstructure of the LPBF 316 L steel, optical micrograph, vertical cross section. "Microstructure, Solidification Texture, and Thermal Stability of 316 L Stainless Steel Manufactured by Laser Powder Bed Fusion"

Right: Optical microscopy of Ultrafuse stainless steel 316L microstructure after sintering, vertical cross section. "Material Properties and Shrinkage of 3D Printing Parts using Ultrafuse Stainless Steel 316LX Filament"

	Wrought	ASTM 8883 as Sintered	MetalFuse
Density (%)	100%	99%	> 97%
Ultimate Strength（MPa）	424 MPa	450 MPa	499-528 MPa
Yield Strength（MPa）	170 MPa	140 MPa	172-205 MPa
Elongation at Break (%)	40%	40%	64-69%
Hardness (HV)	100 HV	121 HV	121 HV

Challenges of Powders for BJ

Since BJ relies on recoating procedure like sintering-base technology, BJ also has very narrow and specific powder characteristics due to the important flowability and powder bed quality. The green part density is defined by the powder bed density, as after the binder jetting, the particles are "glued" in this state. Besides the common condition used by sintering-based technology, BJ has the extra condition of wettability and surface chemistry. The higher of these two gives a greater depth to binder penetration, therefore less binder is needed for the green part and results in a higher green part strength. Overall requirements of BJ powder currently usually result in a cost 1.5-2 times higher than that L-PBF powder. This number is still to be confirmed as BJ is said to be the technology for high throughput on an industrial scale but is still missing the proof of this approach.

Advantages

- Printed metal parts are more cost-effective than sintering-based approach on a larger scale.
- Wider material availability than sintering-based AM technology.
- Valued for producing batches of parts.

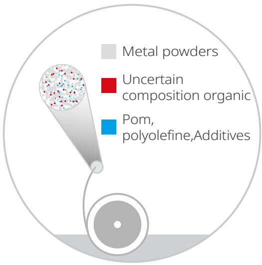
Disadvantages

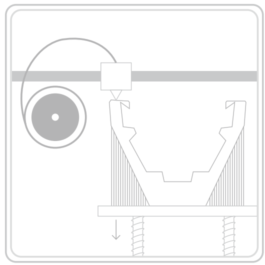
- The process generates metal parts with slightly lower density and lower tensile strength than those made using a sintering-based approach.
- Green parts made using BJ are very fragile before sintering.
- Poorer mechanical properties if the green part density is low. Powder optimization is critical.
- BJ is a multistep process requiring post-processing steps, which, in some cases, involves additional equipment.

Feedstock Approach: Metal FFF

The feedstock approach in binder-based AM technology has been emerging in recent years. Besides debinding and sintering, the process applies MIM feedstock as a material which is converted into an easy-to-handle filament. While the shaping procedure adopts FFF (Fused Filament Fabrication) 3D printing rather than injection molding.

FFF 3D printer heats and extrudes thermoplastic filament layer by layer in cross-sections on the printing bed. Thanks to the binder agent in feedstock, the metal filament also inherits high flowability at relatively low temperature (~240 °C). This type of binder-shaping AM technology with this metal filament strategy is also called Metal Fused filament Fabrication (Metal FFF).





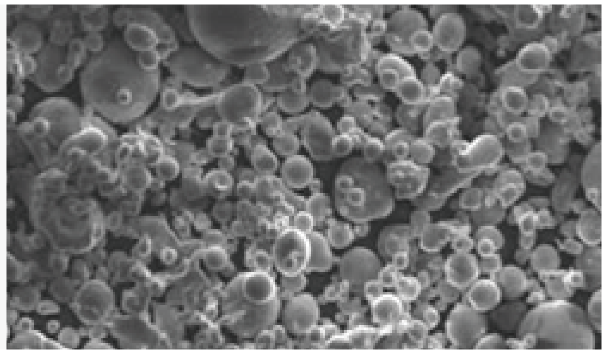
Since Metal FFF shares the same feedstock, debinding and sintering procedure, the final metal parts have the same kind of properties as MIM parts, as well as possible end-use applications.

General Process of Metal FFF	
Model Optimizing	• Screening and modifying design constraints for PM approach 3D printing including: • Maximum Size • Minimum Wall Thickness
Model Slicing	• Planning support structure for overhanging surface. • Converting 3D model into 2D layers, • Generating Gcode files.
Loading Filaments into Printer	• By comparison, loading filament feedstock is more simple and safer than powder feeding. It is basically same as loading plastic filament. No extra protection or caution is needed.
Printing	• Metal FFF solution prints the green part as simply as plastic filament printing. There are no special environment prerequisites for Metal FFF printer and printing.
Debinding	• Debinding refers to placing the green part into catalytic debinding furnace. The purpose of this procedure is to extract the binder from the green part. • Metal FFF solution can cure batch of green parts together. • This procedure can be close-looped or compatible with third-party debinding equipment, depending on the binder solvent adopted for the green part.
Sintering	• Sintering refers to placing the debound part into a specialized sintering furnace. The purpose of this procedure is to burn out binder residual and fuse metal particles into a solid mass using high temperature.
Removing Support	• The Metal FFF solution is able easily create a breakaway support structure for the metal part by printing less adhesive filament as a support interface using a second extruder. • As a result, both processes generate a relatively smoother overhang surface which doesn’t need a great amount of post processing.
Refine Assembly Surface Precision	• Metal 3D printing is a near net shape technology and less suited for high tolerance level assembly. Thus, it is generally required to locate and machine essential areas for further assembly. This requires extra professionals to operate the machining equipment.

Metal FFF Materials

Besides the shaping mechanism difference, Metal FFF material manufactures and costs are very different to those of BJ. MIM feedstock is compatible and has a wide tolerance for variance in powder properties. There is the potential to become a very cost efficient technology once the level of adaption and material throughput is reaching an industrial scale similar to the MIM industry.

Scanning Electron Micrograph of 316L Powder Used in MIM. John L. Johnson, Lye King Tan, Pavan Suri and Randall M. German. January 2004. Mechanical properties and corrosion resistance of MIM ni-based superalloys.



Generally, Metal FFF and BJ have different shaping procedures and materials, but have similar debinding and sintering procedures. Their differences result in distinct performance and application.

Binder Shaping AM Technology

Advantages

Binder Jetting	Metal FFF
• Uses tried-and-tested inkjet technology from the paper printing industry for the binder, • A high output of metal components can be expected due to a fast production of green parts. • The process is based on experience and solutions from powder metallurgy.	• Significantly more attractive total cost of ownership. • Very complex parts can be manufactured thanks to integrated support structures. • The printer is very easy to handle and can be used effectively with minimal training. • High yield — parts are usually successful on the first print. • Bound powder filament is safe — usage is similar to that of a standard FFF 3D printer. • Parts can be printed with an open cell infill, reducing the part's weight.

VS

Disadvantages

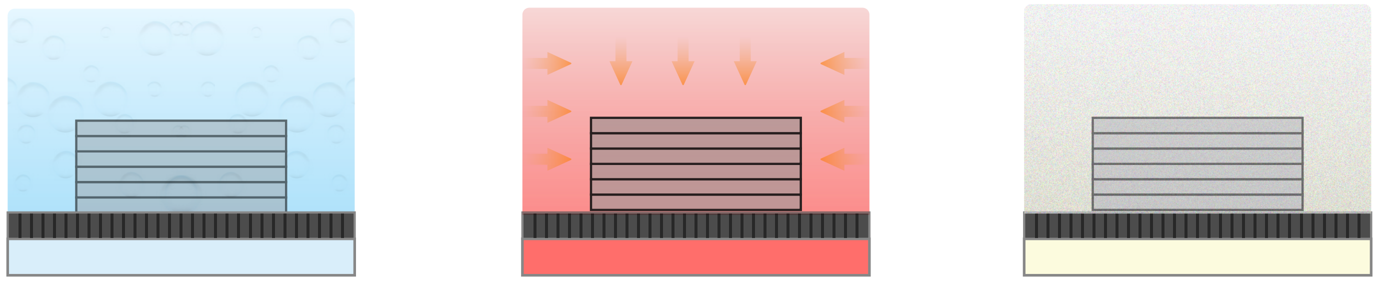
Binder Jetting	Metal FFF
• Expensive hardware investment, usually over 1 million dollars. • Green parts are fragile. This typically means a limit in terms of size, wall thicknesses, and post-processing. • Powder management requires significant resources. • De-powdering requires a high level of manual intervention because of the fragile and sensitive nature of the green parts. • Accuracy, density, and repeatability are still unproven. • Special powder formulations required for consistent process and part stability. • No automated and integrated support generation especially inside a design hole or cavity.	• High degree of machine automation required for high throughput. • Lower resolution due to limitation of the extruder nozzle diameter and layer by layer approach.

VS

Differences and Advantages of Feedstock Types

First of all, debinding of feedstock significantly affects the strength of green part. Polymer-based matrix binders, such as Catamold® technology from BASF, can yield green parts that can withstand a high impact, such as dropping on solid ground and long-distance transportation. In comparison, other feedstock types with different matrix polymers such as wax-based binders suffer from much poorer green part toughness.

When looking at debinding, different feedstock options correspond to different processing technologies. The debinding process can be separated into 3 main types, according to the debinding method, such as thermal, solvent and catalytic.



Solvent extraction Thermal decomposition Catalytic degradation

The easiest and oldest method is thermal debinding. Thermal debinding uses melting, thermal decomposition and diffusion to remove the binder. Furthermore, thermal debinding is considered as "low and slow" as it leaves all the thermally decomposed materials in the furnaces making it dirty and very slow.

Solvent debinding can be divided into 2 types of state such as vapor and liquid immersion. In solvent debinding, organic solvent (acetone and hexane) is commonly applied. Usually, it is either acetone for polyamide-based binders or hexane for wax-based binders. All other suggested methods don't have much use on a commercial level. Both acetone and hexane are highly flammable and prone to explosion without a proper exhaust setup and certification.

Catalytic debinding is by far the most used technology for MIM. In the last few decades, the adoption percentage of catalytic debinding systems has grown over solvent and thermal ones in Europe and Asia. Catalytic debinding uses strong oxidative vapor, such as nitric acid and oxalic acid. Binder removal is done in a gaseous acid environment, at a temperature of approximately 120°C, which is below the softening temperature of the binder. The debinding process is fully gaseous and therefore the debinding speed and part penetration is naturally faster than a solvent based dissolving process or thermal decomposition.

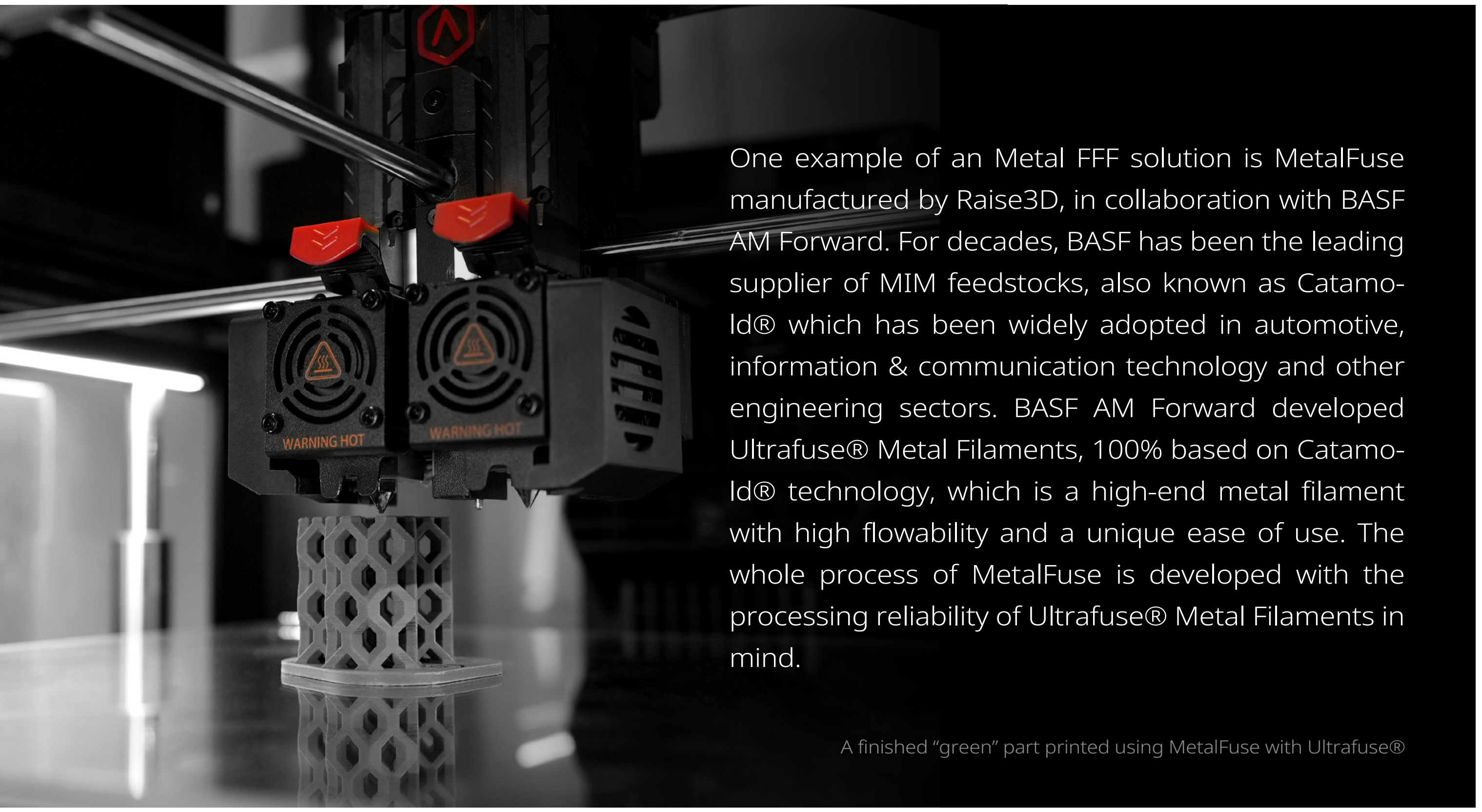
The acid acts as a catalyst in the decomposition of the polymer binder. Gaseous catalysts and its reactions with the binder matrix enable a very stable and constant debinding speed, even for thicker areas inside the green part. The acid used for debinding also gives a different performance. For example, oxalic acid is not a hazardous material, environmentally friendly, has lower part corrosion, is safer to use and has lower installation regulation requirements.

Compared to the solvent debinding system, catalytic debinding removes debinder agents 10 times faster while maintaining great shape retention after sintering. Catalytic debinding shows nearly linear behavior in debinding speed up to a penetration depth of 25 mm, while solvent debinding speed drops exponentially with penetration depth, making debinding of thicker parts with 100% infill nearly impossible. Thermal debinding is even considered slower with design restrictions when it comes to maximum wall thicknesses.

	Catalytic Debinding	Solvent Debinding
Cycle Time (hr) Based on 10 mm wall thickness	4-5	24-72
Debinding Speed per Hour	0.8-1.5	0.05-0.2
Maximum Thickness (mm)	Linear Up to 50mm	<10mm
Residual Amount	Low	Medium
Possible Flaws	N/A	Burst & Deformation

3 Metal FFF Workflow by MetalFuse Solution

Workflow Overview



One example of an Metal FFF solution is MetalFuse manufactured by Raise3D, in collaboration with BASF AM Forward. For decades, BASF has been the leading supplier of MIM feedstocks, also known as Catamold® which has been widely adopted in automotive, information & communication technology and other engineering sectors. BASF AM Forward developed Ultrafuse® Metal Filaments, 100% based on Catamold® technology, which is a high-end metal filament with high flowability and a unique ease of use. The whole process of MetalFuse is developed with the processing reliability of Ultrafuse® Metal Filaments in mind.

A finished "green" part printed using MetalFuse with Ultrafuse®

MetalFuse consists of a slicing program (ideaMaker for Metal), the Forge1 printer, the D200-E catalytic debinding furnace and the S200-C sintering furnace, as well as a previously configured processing profile for Ultrafuse® Metal Filaments. ideaMaker generates a machine code that can be read by the Forge1, D200-E and S200-C. The Forge1 prints green parts with mixture of ~ 10w% binder and 90w% metal, much like FFF 3D printers that create objects using thermoplastics. Once these green parts are created, they are transferred to debinding in the D200-E and yield brown parts with most of the binder already extracted from the part. Finally, the brown parts are directly transferred to and sintered in the S200-C. Out of this process in the furnace come the final metal parts, with a density of over 97%, in a manner similar to the MIM process. With such capabilities, MetalFuse offers a full in-house FFF metal printing process for manufacturers who require the internal production of metal parts for various uses.

Workflow	Time of Best Practice	Activities
Slicing	5-10 Minutes	• Choose and apply printing template • Plan layout
Printer Setup	5 Minutes	• Load filament • Insert USB and import .Gcode
Printing	Decided by Task usually below 12h	• Automated Processing
Debinding Preparation	1-2 Hours	• Soak green part in water to release the glue between print bed and green part • Refurbish the green part • Transfer green part to debinding furnace
Debinding	Approximately 6 Hours	• Automated Processing
Sintering Preparation	30 Minutes	• Inspect debinding rate • Transfer brown part to sintering furnace
Sintering	Approximately 10-24 Hours	• Automated Processing
Support Remove	Less than 30 Minutes	• Remove support structure
Post-Processing	Decided by Demand	• Apply any traditional surface finishing process for metal

The whole process generates a straightforward workflow with little manual activities. It starts with slicing using ideaMaker which has been installed with ready-to-use templates for all Metalfuse procedures for various Ultrafuse® Metal Filaments. To print the Gcode with the Forge1, the user only needs to ensure the loading of filaments and clearing of print bed, while still having the ability to customize all process parameters to suit the requirements of the desired part and application. There is no specific need for a special room environment, nor personal protection or special care for handling the material. Printed green parts can be easily detached from the print bed by applying water and can then be directly loaded into debinding furnace. Green parts are so tough that they can be surface finished to the desired quality with sandpaper, milling or drilling. Due to dual extrusion capability of the Forge1, the user can print a green part with detachable support structure which will prevent hangover structures from collapsing during debinding, meaning no additional support solution is needed for this procedure. Such readiness also applies for sintering where the user can directly transfer the brown part to the sintering furnace, except when a ceramic setter is needed.

Cost-Effectiveness and Implementation Strategy

Each product of Raise3D MetalFuse has unique processing mechanism and thus can be coped with certain strategies.

Printing

Cost-Efficiency

The Forge1 prints green parts using Ultrafuse® Metal Filaments via an FFF mechanism. During printing, the POM binder in filament melts and the metal particles carried within it are deposited in a structure according to a given command within the Gcode. In a single print job, thanks to the dual extrusion system, the user is free to print designs with overhanging structures. Thanks to Catamold® technology, green parts using Ultrafuse® are also compatible with existing MIM industries.

The Forge1 is more user-friendly, extremely affordable and robustly built. The filament used to print is safer and easier to handle than the powder feedstock of binder jetting or L-PBF. It is also easy and safe to deploy several FFF printers in an office environment, unlike other metal printing solutions, and they can be operated by non-professional staff, making it highly accessible for on-demand scalable production.

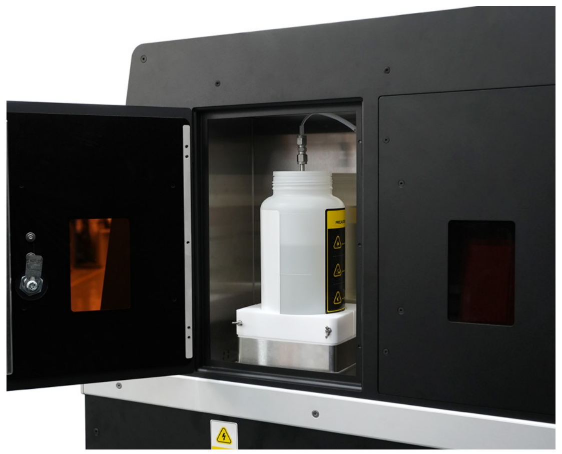
Strategies

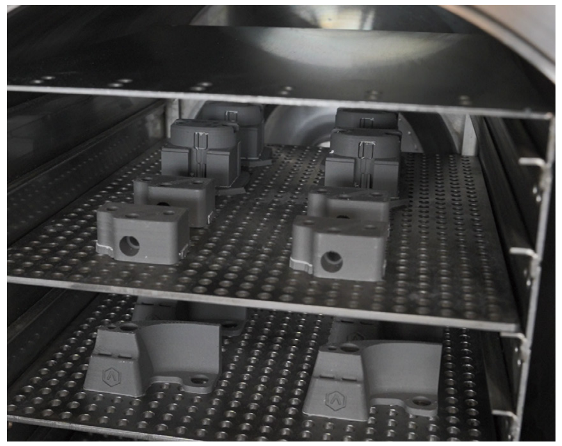
- The Forge1 can print numerous green parts of different designs on the print bed. Therefore, for prototyping tasks, the user can collect multiple orders and print them in the same machine at the same time.
- The flexible deposition method allows the Forge1 to print hollow structures with a controlled infill rate. Therefore, it is extremely easy to create lightweight metal parts without having to go through a design optimization process.
- Green parts printed with Ultrafuse® are very tough and can be blasted or even CNC machined. Compared to a full metal part, the processing tools for green parts are more accessible.
- Another advantage is that it is possible to print green parts in-house only and outsource them to traditional MIM service vendors for debinding and sintering. The strength of green part using Ultrafuse® reaches 70 Mpa and can withstand common long-trip transportation.
- For small and medium corporate and workshop users with demands for large orders of customized metal parts but with a limited budget for investment, a set of Forge1 printers is affordable and can yield the needed green parts. Debinding and sintering can be achieved by outsourced service rather than having to invest in furnaces.
- For corporate users who own the Metalfuse system and have growing potential demand, the Forge1 gives a cost-efficient scalability for future expansion in terms of investment and deployment space.

Debinding

Cost-Efficiency

The Raise3D D200-E is a catalytic debinding machine used to decompose the binder in green parts based on Catamold®. In the presence of oxalic acid in the high-temperature acidic environment created by the machine, the catalyst gas penetrates the green parts and the POM is decomposed and vaporized. A brown part is yielded after this process. It can simultaneously process up to 7 trays (70 green parts of smal size) in just 15 hours.





Sintering

Cost-Efficiency

During the sintering process, the debound brown parts will shrink into dense solid sintered parts. In the end, the sintered part's density after sintering reaches 97% of that of wrought metal.

The Raise3D S200-C adopts partial-pressure sintering. In terms of cost-saving, the S200-C uses much less inert gas, which makes it very cost-effective while maintaining an excellent level of sintered part quality.
S200-C can simultaneously process up to 6 trays at once while using the same amount of energy.

Strategies

- The catalyst, oxalic acid gas, is a naturally-occurring acid that is biodegradable and has low toxicity, and the formaldehyde and acidic gas produced during the debinding process in the D200-E will be extracted along with the protective gas (nitrogen.) through the exhaust gas filtration system. In this way, the D200-E is eco-friendly and suitable for a lab environment.
- Thanks to large capacities, the owner of a D200-E and S200-C can process orders from multiple Forge1 units simultaneously. This enables a possible market community with third-party debinding and sintering services to centrally provide for a dispersed Forge1 user group.

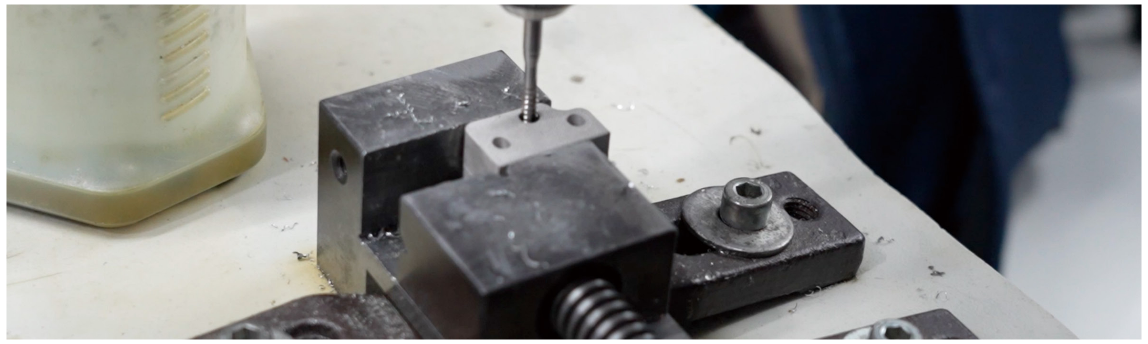
Post Processing

Cost-Efficiency

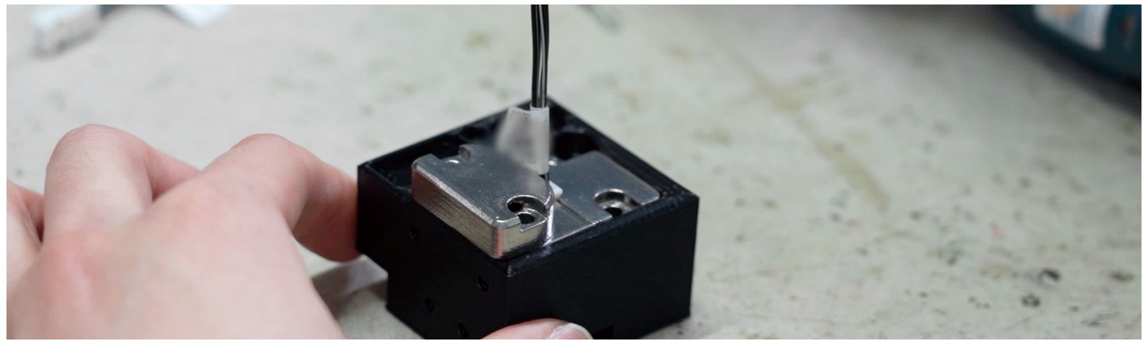
After going through the printing, debinding, and sintering processes, the final metal parts can be put directly into use. The sintered part density reaches >97% of that of wrought metal, therefore sintered parts can be subject to machining and finishing. The standard deviation of precision can meet a design tolerance requirement of ±0.2mm.

Strategies

- With design planning, the user can adopt light machining to achieve customized assembly metal parts with MetalFuse. In the case illustrated below, a connector insertor is designed with an assembly tolerance standard of ±0.2 mm, as well as holes for tapping. Yielded by MetalFuse, the outline of sintered part reaches targeted assembly tolerance and can be finalized. The diameter of the hole meets applicable standards and tapping is successfully carried out to allow screw fixing. The drilled sintered parts are used directly in a client's wiring testing line.

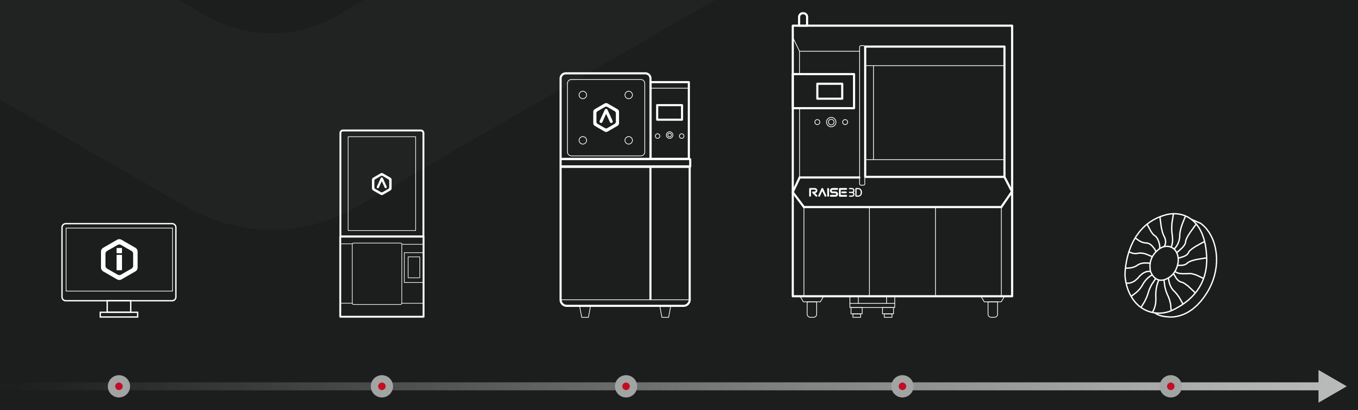


- Finishing methods, such as magnetic abrasive finishing, electroplating, polishing, are also appliable to fulfill manufacturer requirements. In same example illustrated above, magnetic abrasive finishing is adopted to make the surface of the connector inserts smoother, making it safer and easier to handle.



4 Conclusion

- Raise3D's MetalFuse brings high productivity, reasonable investment, and short lead times to metal fabrication. Factories can boost their on-demand metal fabrication capacity with fewer investments in labor training, labor hours, setup, process integration and overall costs. MetalFuse enables metal 3D printing accessible to more manufacturers with various types of demands and stages of development.



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