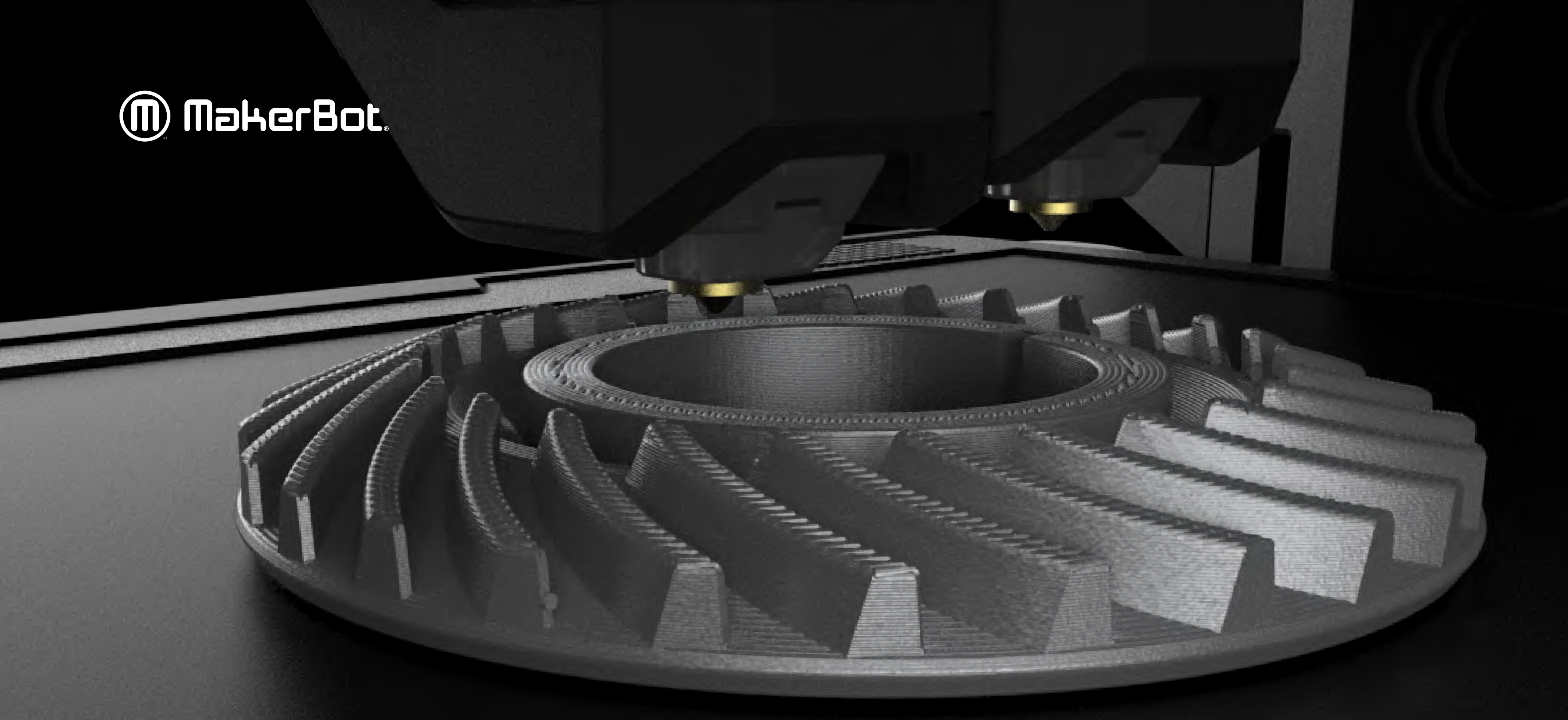
MakerBot



METAL 3D PRINTING

The definitive guide to metal 3D printing in your workshop

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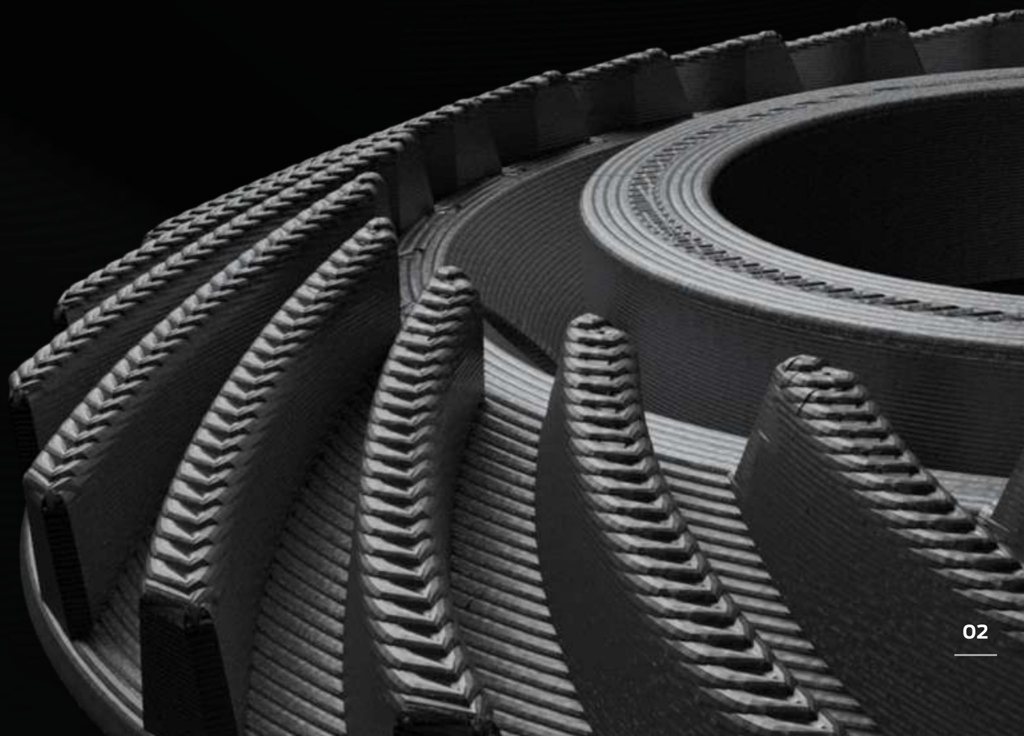
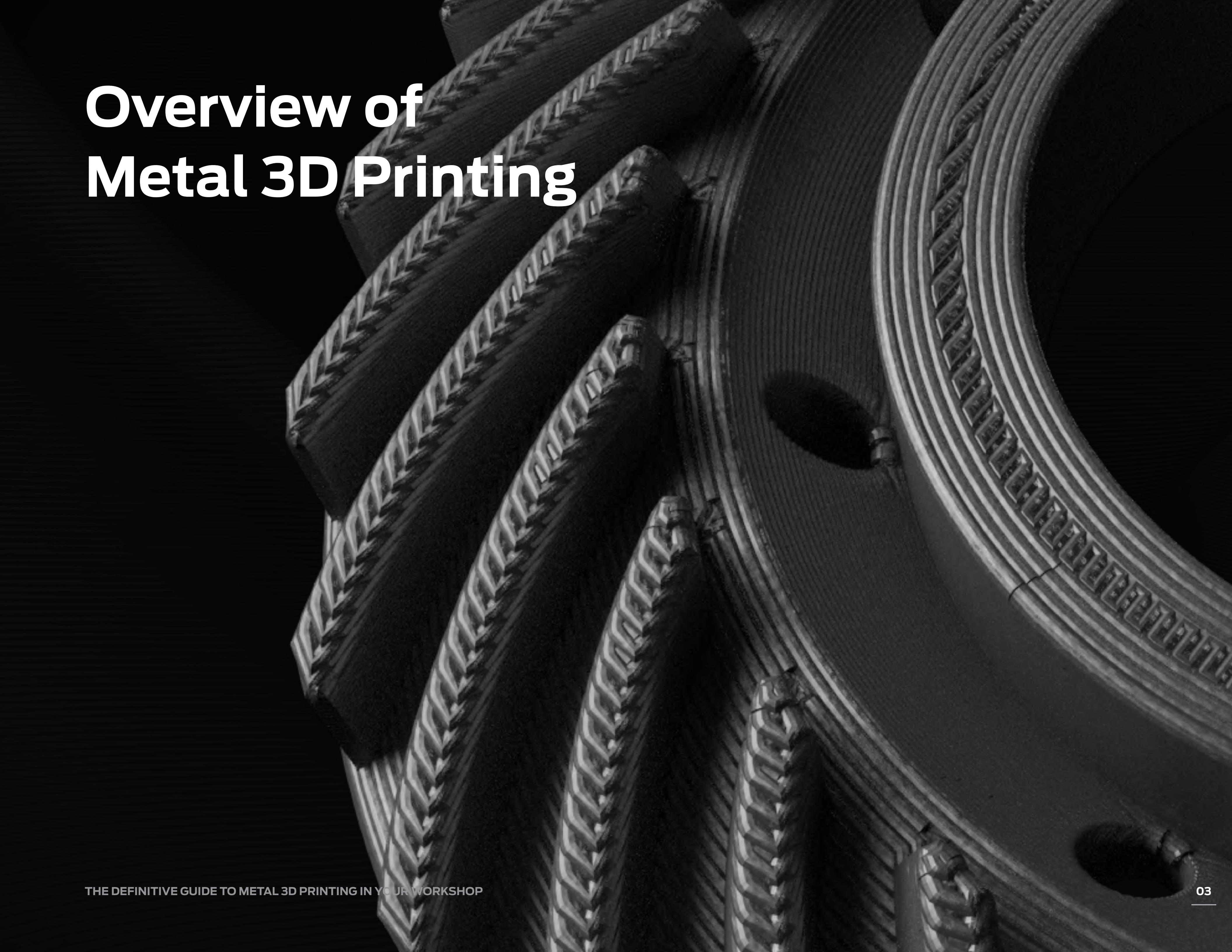
Introduction

3D printing has now been around for about 40 years, but the technology has only been available to over 90% of users for the last 10 years. Why?, you ask. The machines that were available for the first 30 years were simply not accessible to most people. They were incredibly expensive (hundreds of thousands of dollars) and incredibly complex to operate. Now you can buy a very simple 3D printer for hundreds of dollars - or spend a few thousand dollars for a more capable professional 3D printer.

3D printing materials have followed a similar trajectory. More companies than ever before are making polymers, composites, and (now) even metals available on more accessible platforms. In this guide, we will provide a landscape overview of metal 3D printing, then dive into the details of the new age of accessible and affordable metal 3D printing powered by material extrusion and bound metal filament.

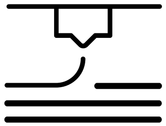
We will answer several frequently asked questions we get about metal 3D printing including: What types of metal 3D printing technologies are available? What are the PROs and CONs of metal 3D printing? What are the common industries and applications of metal 3D printing? And what design considerations go into successful metal 3D printing?





Overview of Metal 3D Printing

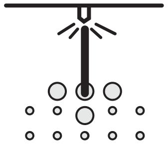
Types of Metal 3D Printing Technologies



Material Extrusion - FDM

Hardware Cost: $5K - $110K

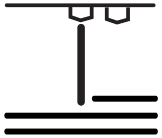
Material Extrusion metal 3D printers come in multiple varieties. FDM is one popular technology and it works by extruding a material that is around 80% metal powder and 20% polymer binder material by weight. Once printing is complete, the print requires debinding and sintering to achieve the desired solid metal part. Material Extrusion is by far the most affordable metal 3D printing technology, at about 10% the cost of the other three categories, making it the most accessible technology for individual users, small businesses, or at scale within larger businesses.



Powder Bed Fusion

Hardware Cost: $150K - $1MM

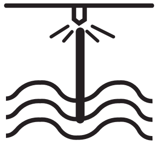
Powder Bed Fusion encompasses a variety of technologies, including Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Direct Metal Laser Melting (DMLM), Selective Laser Melting (SLM) and Electron Beam Melting (EBM). All these technologies use metal materials in a powdered form. A powerful beam of photons (laser) or electrons (EBM) is flashed onto the individual powder particles to sinter or melt them ultimately to form a strong bond with the adjacent particle. By flashing the beam on the required particles according to the geometry, the powder is melted together and the object is formed.



Binder Jetting

Hardware Cost: $150K - $1MM

Binder Jetting is similar to material jetting but it uses two materials instead of one. A powdered metal material sits in a tray and the binder material is sprayed onto it in a pattern to hold the powder together. A wiper brushes another layer of powder on top and the process is repeated - a feature also found in powder bed fusion. Once the “printing” is complete, post-processing is required which includes debinding and sintering to complete the part.



Direct Energy Deposition

Hardware Cost: $200K - $2MM

Directed Energy Deposition (DED) is kind of like 3D printing with a welder. A nozzle holds the material in a wire form, known as a feed, that moves across multiple axes. An electron beam projector or laser then melts the feed as it moves across while tracing the object geometry. This process is also called Laser Engineered Net Shaping, 3D Laser Cladding, Directed Light Fabrication or Direct Metal Deposition. This technology is much less precise but faster than other technologies, making it ideal for very large projects. Post-processing involves general shape refinement through grinding, sanding, polishing, etc.

Additional Configuration Considerations

Now that we've covered the landscape of 3D printing technologies, we'll narrow the focus to material extrusion / FDM solutions. Within this technology group, there are two subsets - the more expensive purpose-built material extrusion machines that include the full debinding and sintering solutions, and professional 3D printers that can print bound metal filament but require outsourcing of debinding and sintering.

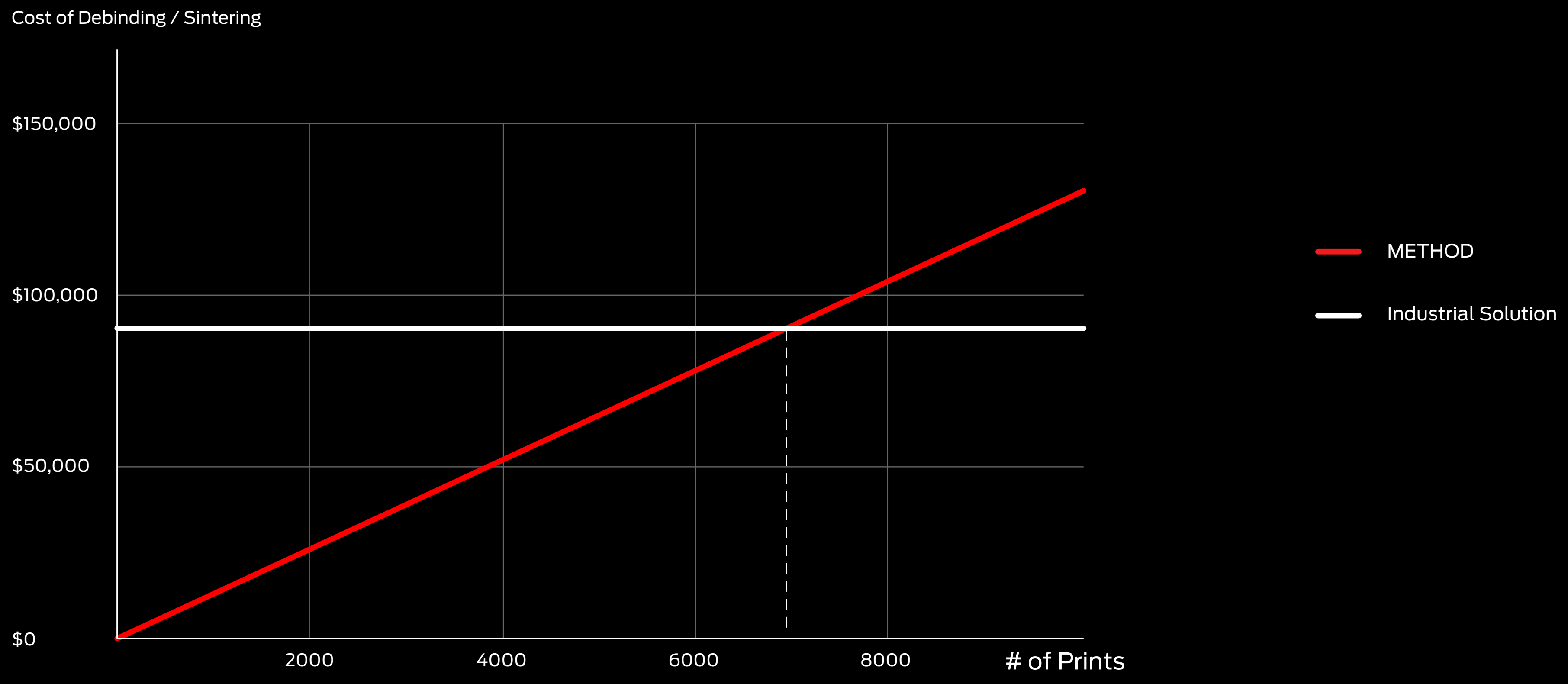
Metal-Only vs Multi-Material 3D Printers

There is only one technology that has the versatility to switch between metals, composites, and polymers, and that is material extrusion or FDM. While some of the most prominent metal 3D printing brands offer material extrusion 3D printers, they typically do not offer mixing. However, the more recent class of professional FDM 3D printers does offer this solution - most notably in collaboration with the global material manufacturer BASF Forward AM.

Cost and time comparisons of industrial vs desktop

Nearly all metal 3D printing requires some type of post-processing. Powder-based solutions require powder removal and recovery after each print - only a percentage of the powder is actually reusable. With FDM, material extrusion, or binder jetting solutions, you'll need to debind and sinter your part. Some companies actually sell post-processing solutions for debinding and sintering - such as large ovens. Alternatively, you can send your printed "green" part to a service provider who can do the debinding and sintering for you.

For the FDM options, you need to consider how many metal parts you will realistically need. The upfront cost of debinding and sintering solution can make up the bulk of the metal 3D printing cost with the pair costing $90,000. Outsourcing the debinding and sintering costs about $50/kg of parts (which amounts to 5-7 print jobs). Thus, you'll want to understand how much volume you'll be producing to make an educated decision.



From a pure cost standpoint, printing with a 3D printer like METHOD and outsourced debinding / sintering will be more affordable up to just under 7,000 parts.

3D printed Metals vs Composites

When it comes to absolute maximum temperatures and strengths, it is hard to beat metals. That said, many applications do not actually need the absolute maximums. The reason that many people use metals like steel and aluminum for common applications such as tools and fixtures is because traditional subtractive manufacturing technologies have made metal relatively easy to work with - at least compared with polymers and composites which may not be so easy to machine.

With FDM 3D printing, the opposite is true. Composite and polymer materials are more straightforward to print and can pretty much be used immediately after printing. In many cases, there will be a composite or polymer available that can perform the task at hand with less time and effort. Additionally these materials can provide a lightweight alternative when that is preferred.

At the end of the day it falls on the user to know what their requirements are. Manufacturers like MakerBot and BASF provide material properties on their website and the sales teams are able to help you identify easy alternatives.

F1 Wheel Nut

Material 316L Stainless Steel
Print time 25h 56m

Propeller

Material Nylon Carbon Fiber
Print time 23h 31 m

BASF Ultrafuse Metal and BASF Service Providers

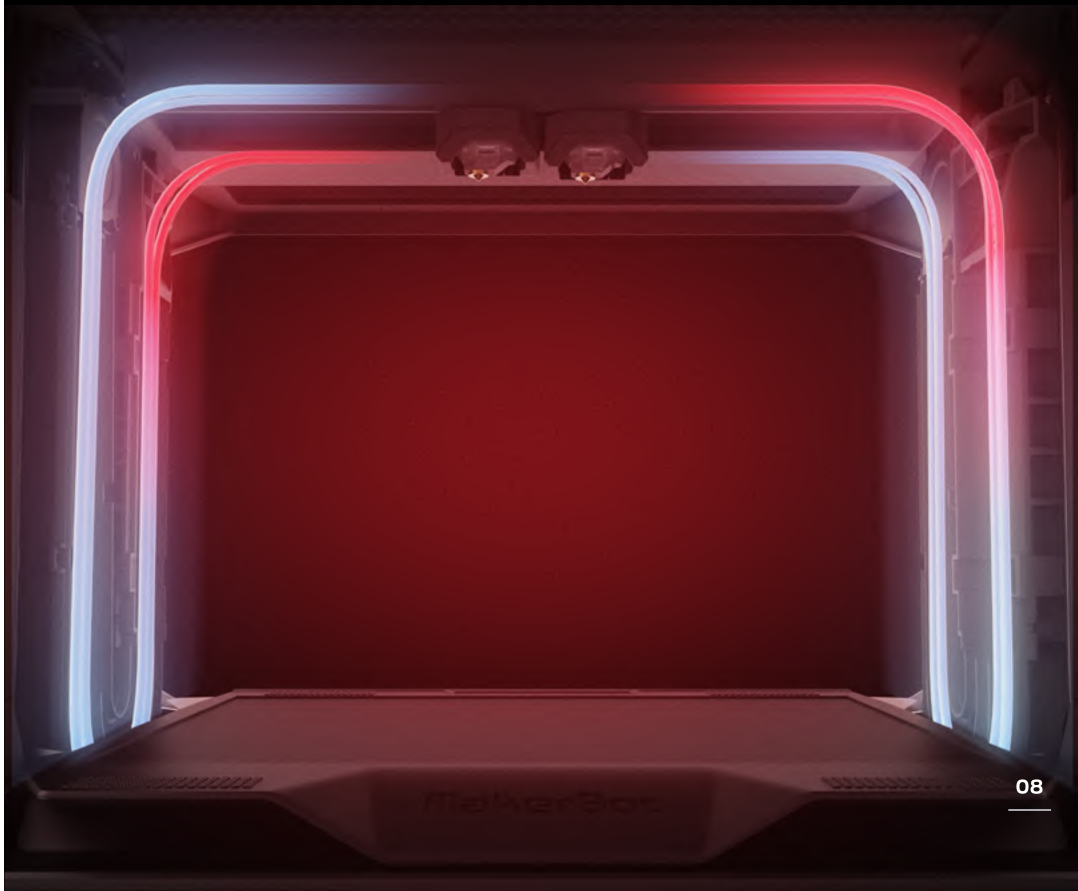
The fact that metal 3D printing at a desktop level is possible is primarily thanks to the development of bound metal powder filament by BASF in its Ultrafuse family of materials. Metal powders - such as 316L stainless steel and 17-4PH hardened steel - are mixed with a polymer known as the binder. The resulting filament is 80% metal and 20% binder, but has the raw filament properties of the polymer binder allowing it to be easily fed and extruded. Once the part is printed, the binder will be removed in the debind / sintering process yielding just the solid metal.

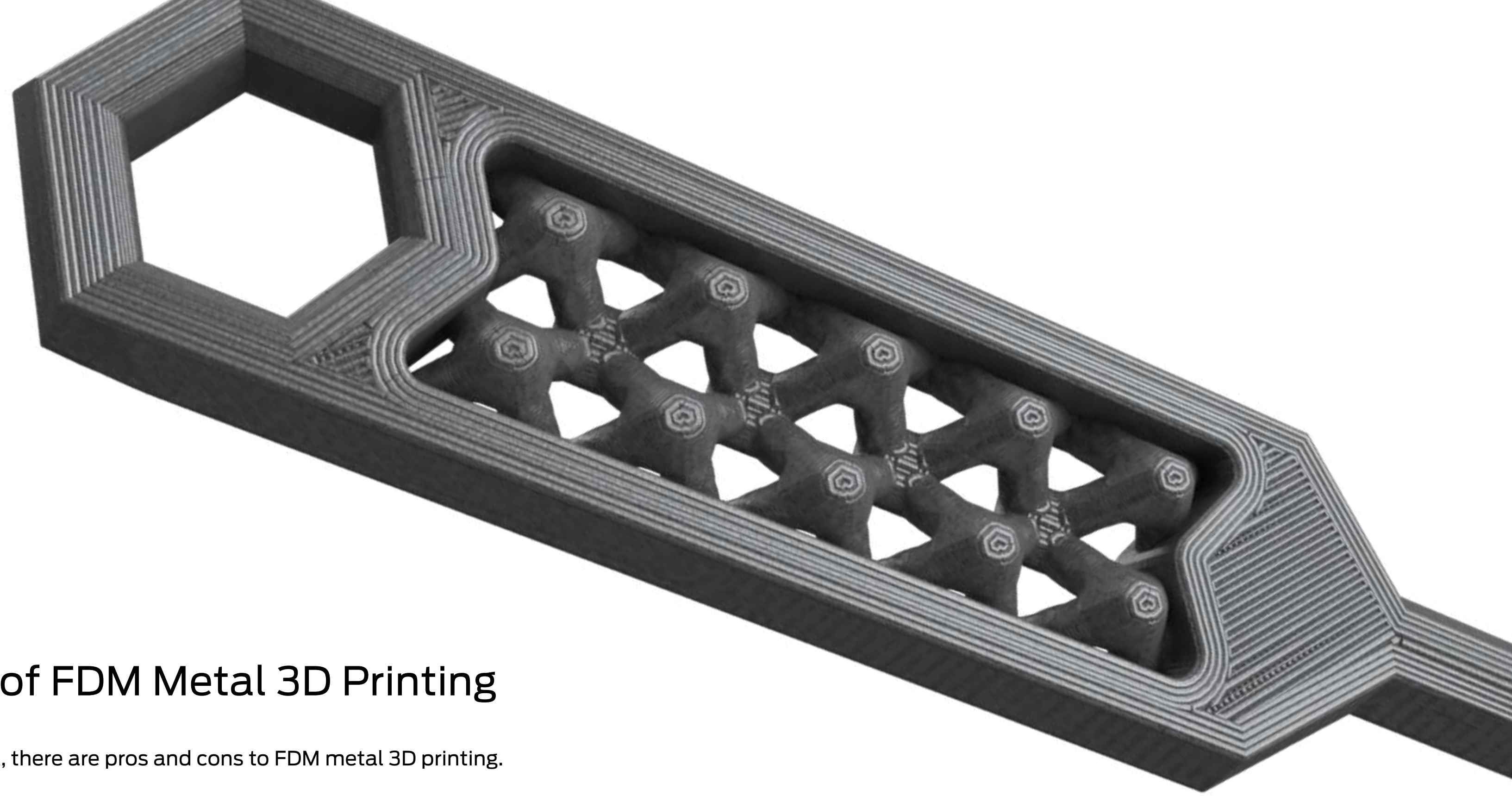
So you have your printed "green" part and need to send it in for debinding and sintering - where do you go next? BASF has partnered with two primary service providers for these services - DSH Technologies LLC in North America and Elnik Systems GmbH in Europe. Just buy a ticket (~$50 for 1kg worth of parts) and send it in along with your batch of parts. Depending on their schedule, you should get your parts back in a couple of weeks. These service providers are generally very knowledgeable - and it's worth reaching out with questions beforehand to ensure the parts have the best chance of succeeding.

What to Look for in a Professional 3D printer?

Along with the material - you're going to need a reliable 3D printer that can crank out parts in metals, composites, and polymers. There are of course low-cost hobby options available for hundreds of dollars, but if you are looking to take the next step into real professional 3D printing, you may want to consider a few features.

A heated build chamber is one notable feature that the experts at both BASF and DSH say will lead to more uniform printing which will result in a more accurate part and also provide additional strength thanks to better layer to layer adhesion. In the current landscape the MakerBot METHOD Series happens to be the only option within the professional category with a heated build chamber (or as we call it VECT Thermal Regulation). You'll find a number of additional feature considerations for 3D printers in the last section of this guide.





PROs and CONs of FDM Metal 3D Printing

As with every 3D printing material, there are pros and cons to FDM metal 3D printing.

PROs

- **Max material properties are superior to most polymers and composites**
  - Strength far exceeds max of printed polymers or composites
  - Heat Tolerance exceeds max of printed polymers or composites
  - Durability
  - Chemical resistance for 316L Stainless Steel
- **Weight (a pro if you are looking for a heavier part)**

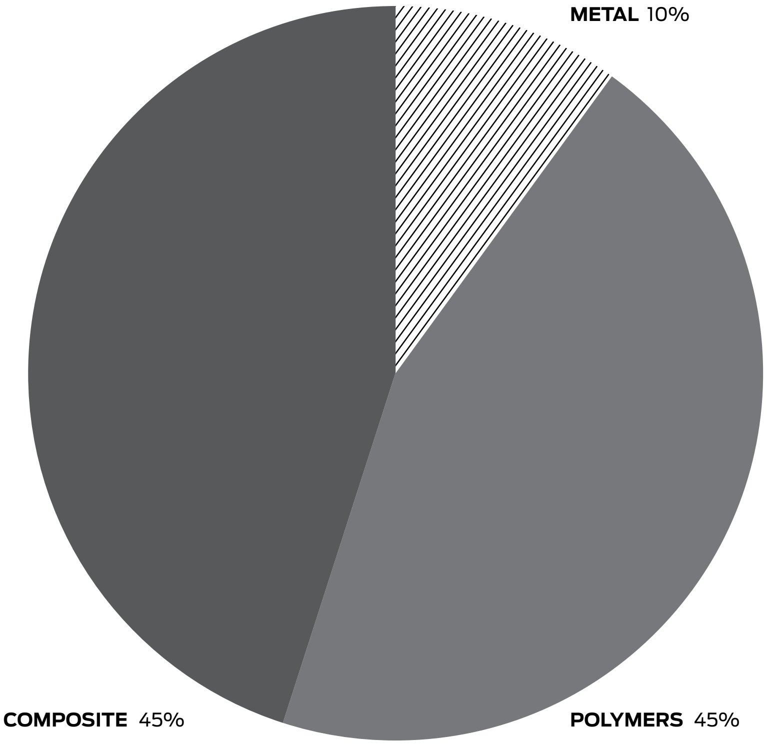
CONs

- **Longer post-processing time due to debinding and sintering**
- **Shrinking in post-processing can limit dimensional accuracy**
- **Limited in part geometry as overhangs can droop or collapse in sintering (supports are not easy to remove)**
- **Weight (a con if you are looking to reduce weight)**

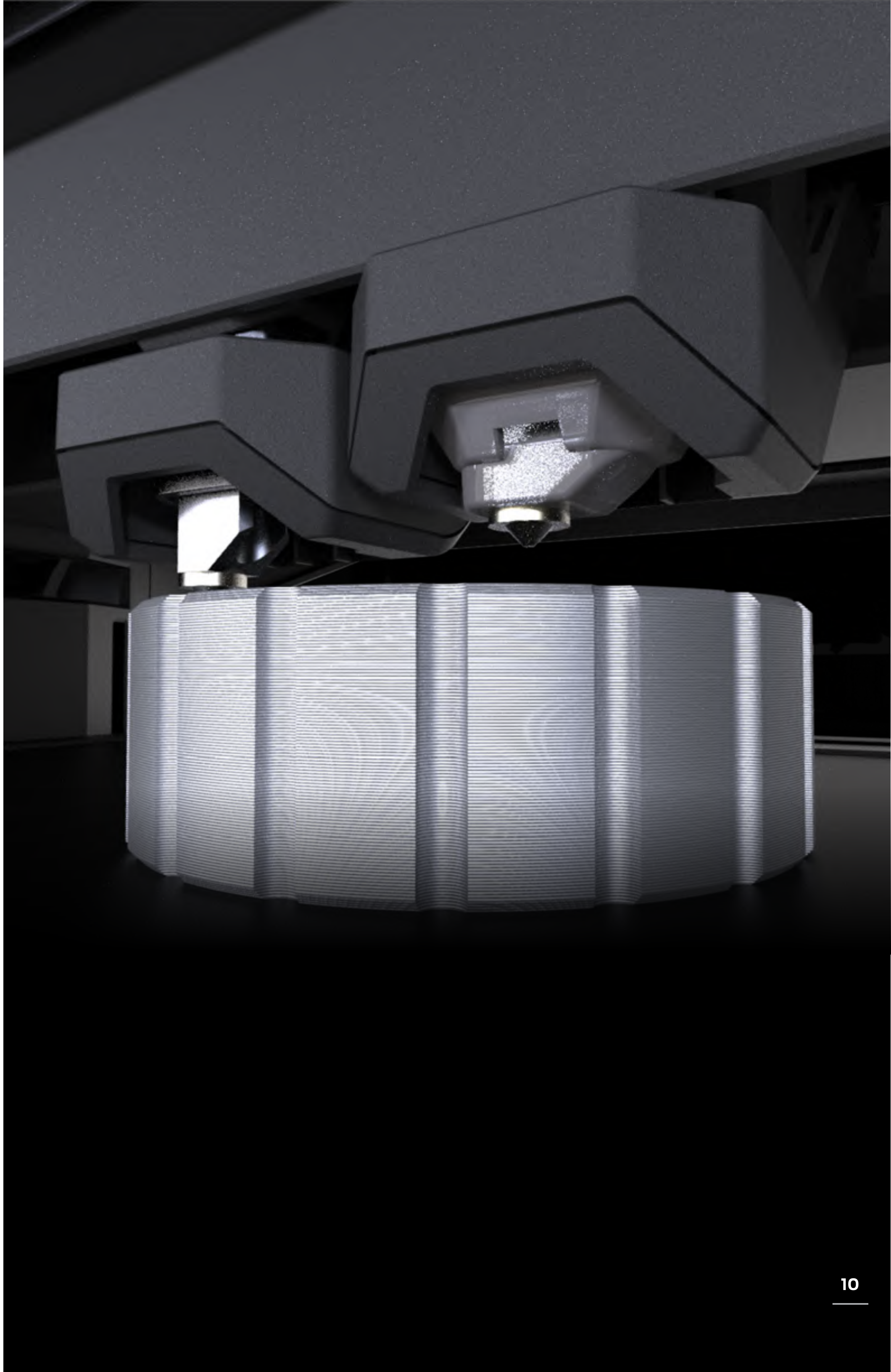
Who is FDM metal 3D printing for?

While the idea of metal 3D printing is exciting to most designers, engineers, and makers, it may not be for everyone. There are certainly many benefits, such as the ability to produce metal parts that have superior mechanical properties to polymers or composites, but there are also many process considerations.

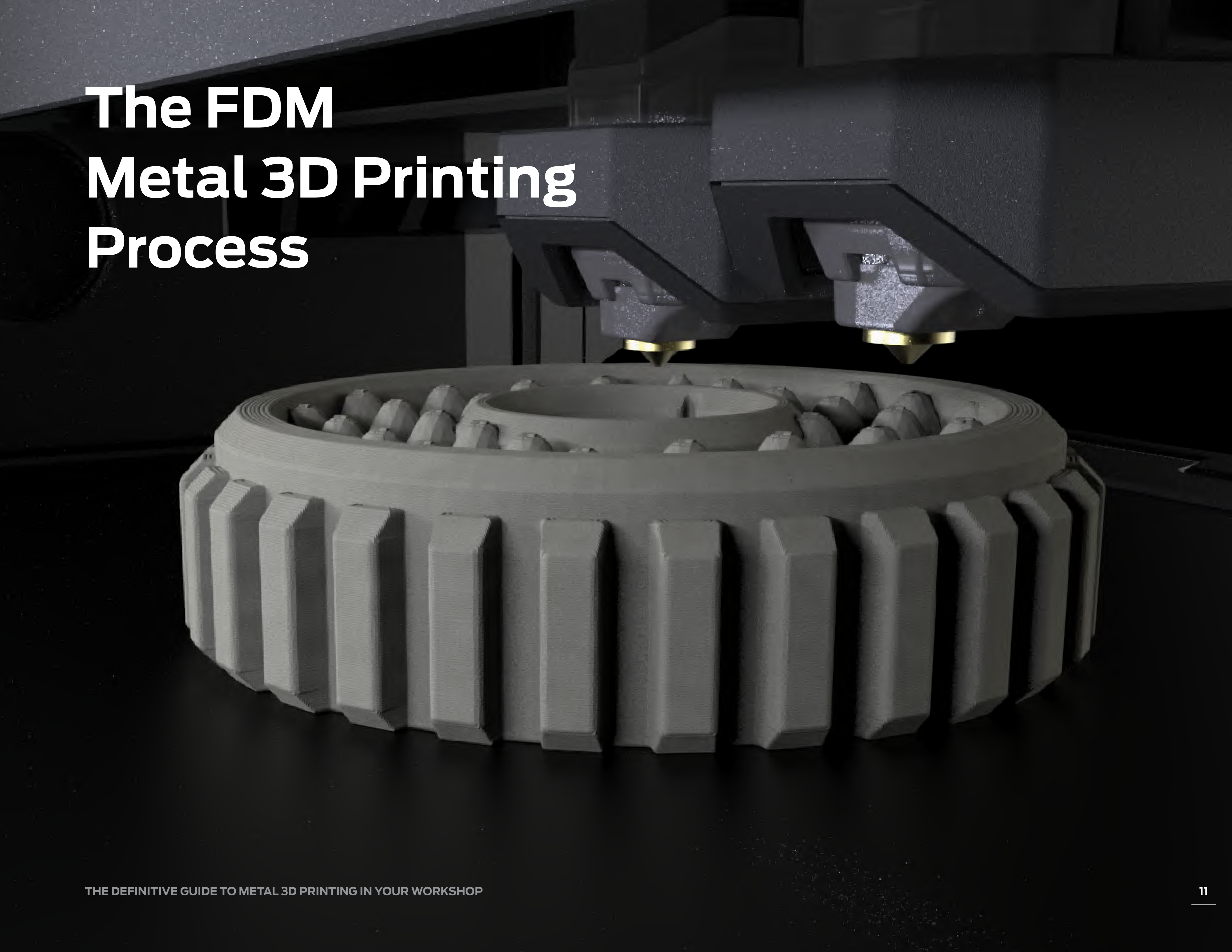
FDM metal 3D printing opens up the possibility of using metal for some parts, but the ideal user will also have applications for polymers and composites. Due to the process considerations, users who need 100% of their parts to be metal are better off using traditional metal processes or industrial metal 3D printers.



Ideally, FDM users will produce 90% or more of their parts using polymers and composites due to the extra process steps required with metal parts.



The FDM Metal 3D Printing Process

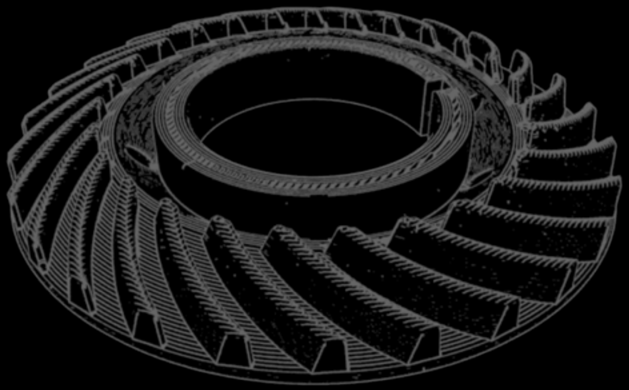


Step 1

PRINT

Launch your print from anywhere via MakerBot CloudPrint to your personal or team-shared METHOD 3D printer equipped with a LABS GEN 2 Extruder and BASF Ultrafuse 316L material.

60°C Circulating Heated Build Chamber
ensures maximum part density

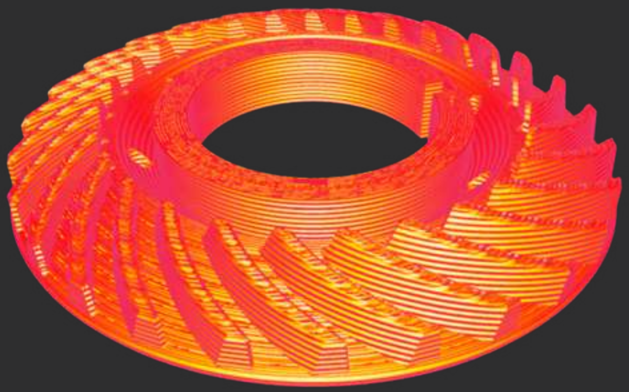


Step 2

SEND IN YOUR GREEN PART

Once your “Green” part is complete, send it in to your sintering service provider such as Matterhackers where parts are debinded and sintered in a high heat, pure hydrogen atmosphere resulting in pure 316L Stainless Steel.

1380°C sintering temperatures
result in parts that can withstand 550°C



Step 3

RECEIVE SOLID METAL PART

You receive the solid steel part in as little as 5 days - up to half the time and the cost of a typical 3D printing service bureau. Install the part as needed or incorporate with other printed parts in MakerBot composites and polymers for a more dynamic assembly.

Up to ½ the time and the cost
of a leading metal 3D printing service

Design Considerations

If you want to have a successful metal 3D print, it all starts with the design. Consider a number of factors not only because of the way the bound metal material prints, but also because it must undergo extreme conditions in debinding and sintering. Luckily, our friends at BASF compiled an extensive list of design considerations to achieve up to 99% chance of success!
As they say at BASF - these guidelines are often recommendations not limitations. These guidelines are a living document as we continue to optimize our materials and process knowledge to continuously expand and improve what is possible with Ultrafuse metal filaments.

Part Size

The maximum green part footprint cannot exceed X 100, Y 100, Z 100 mm in order to fit on the ceramic plates that support the parts throughout debinding and sintering. If larger parts are required, special arrangements may be made with the debinding and sintering equipment provider or processor. Although achievable, larger parts can suffer from warpage while printing and often require longer development times.

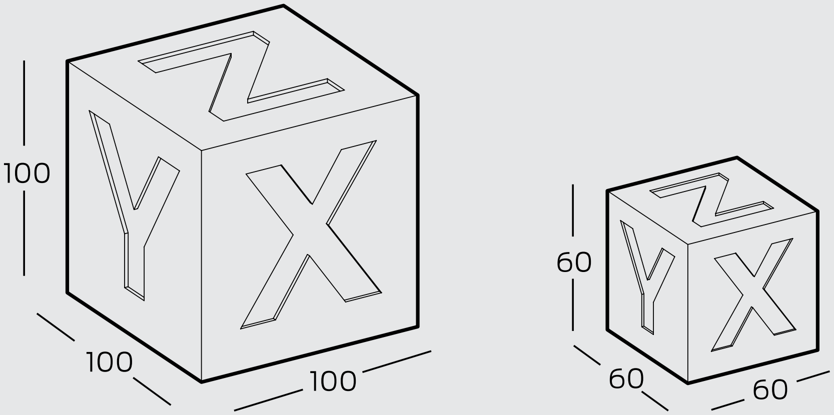


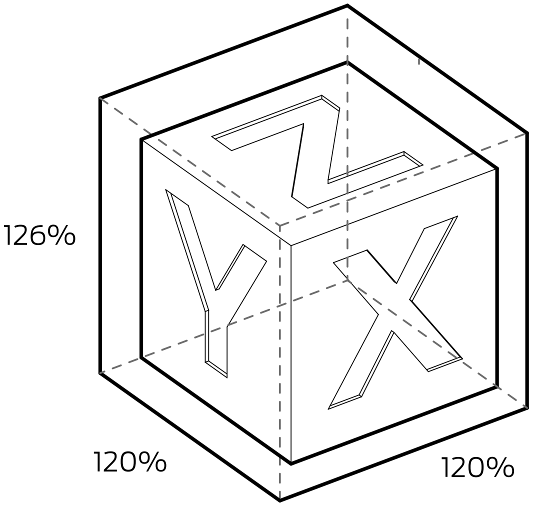
Figure 1

Parts within a 60 mm cube, as seen in the Figure 1 above, have proven to be most successful for new users.

Shrinkage & Scaling

Part shrinkage occurs as the individual metal particles combine into a solid mass during sintering. The printing Z axis shrinkage is normally slightly greater than X and Y due to the layer-by-layer printing process. Referred to as anisotropic shrinkage, oversizing factors are used to scaleup parts for printing. Oversizing your parts helps to ensure that parts are the correct size after shrinkage.

Printing Axis	Average Shrinkage	Scaling / Oversizing Factor
X & Y	16%	120%
Z	20%	126%



This is an example of how to determine the correct part oversizing needed in the slicing process.

Figure 2

Height to Width Ratio

Height to width ratios under 3:1 have proven to be effective in preventing collapse or distortion during debinding and sintering. Ensuring a flat bottom is also critical in reducing possible tilting that can lead to part distortion.

Before the metal particles have been fully fused together, some features can experience sagging at high temperatures. Seen in the viscosity tower example parts in Figure 3. With a 8:1 height to width ratio and an overhanging section, large distortions occur as seen above.

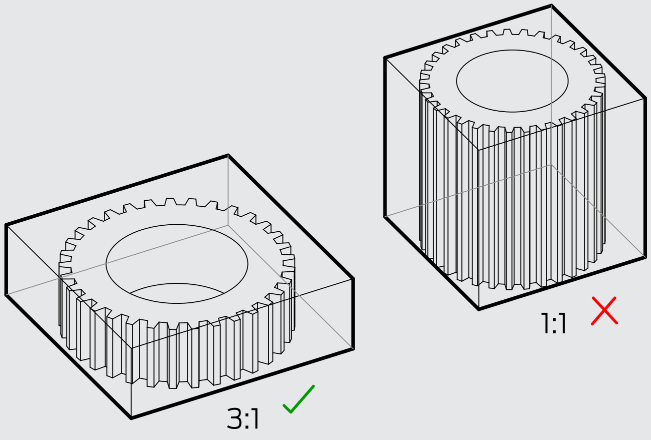
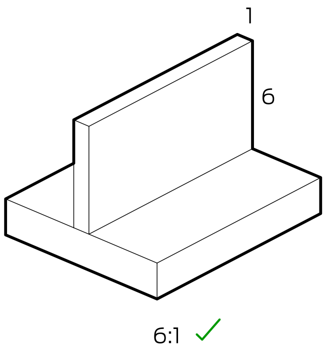


Figure 3

Unsupported Walls

To minimize the chance of collapse and distortion, unsupported wall height to width ratios below 6:1, as seen in Figure 4, have been proven to be most effective. Although easily printed, as seen in the Figure 4, ratios above 6:1 resulted in cracking and part collapse.



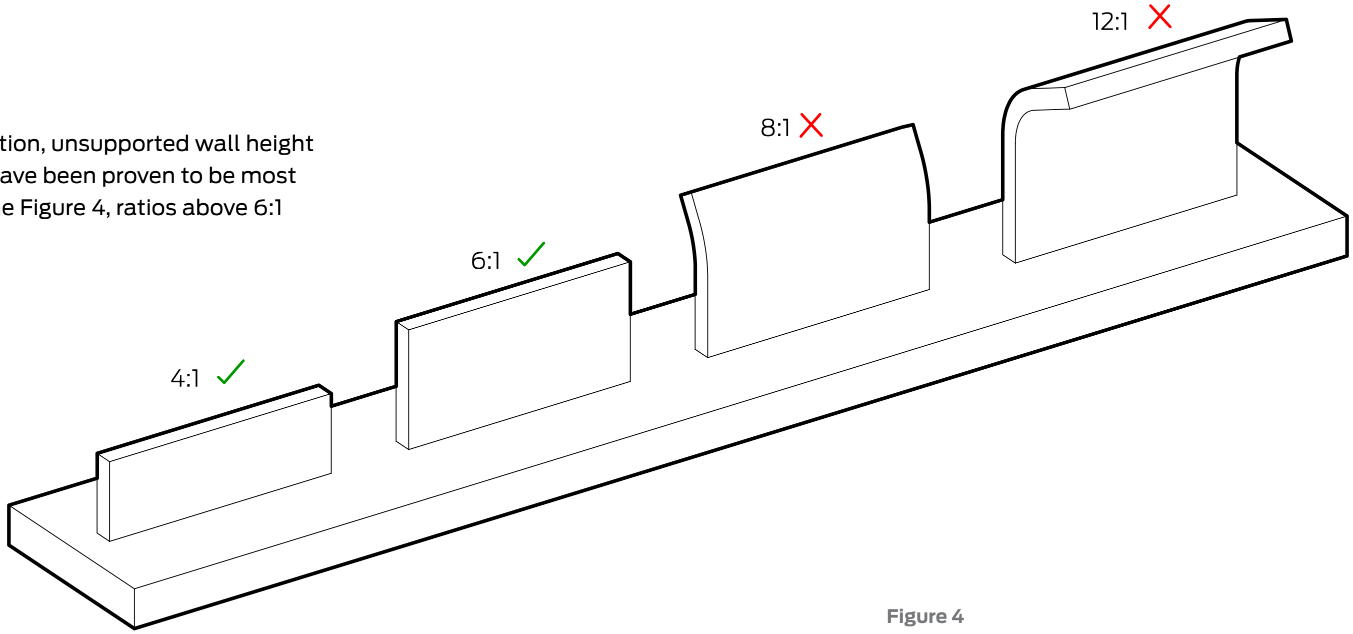


Figure 4

Flat Bottom

The bottom surfaces of parts must be flat to prevent cracking and the potential for collapse in debinding and sintering. Warped bottom surfaces, often resulting from poor print bed adhesion, can cause parts to tilt and distort like the viscosity tower example above, or even collapse in debinding and sintering. Sanding the bottom surface in such a way as to ensure that parts are as balanced and stable as possible is the easiest method for improving debinding and sintering outcomes.

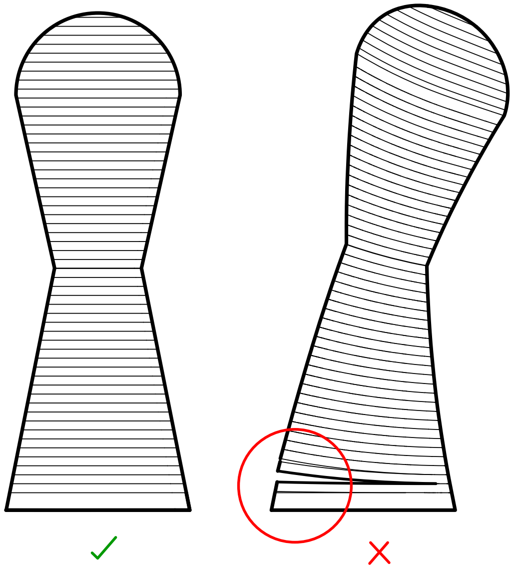
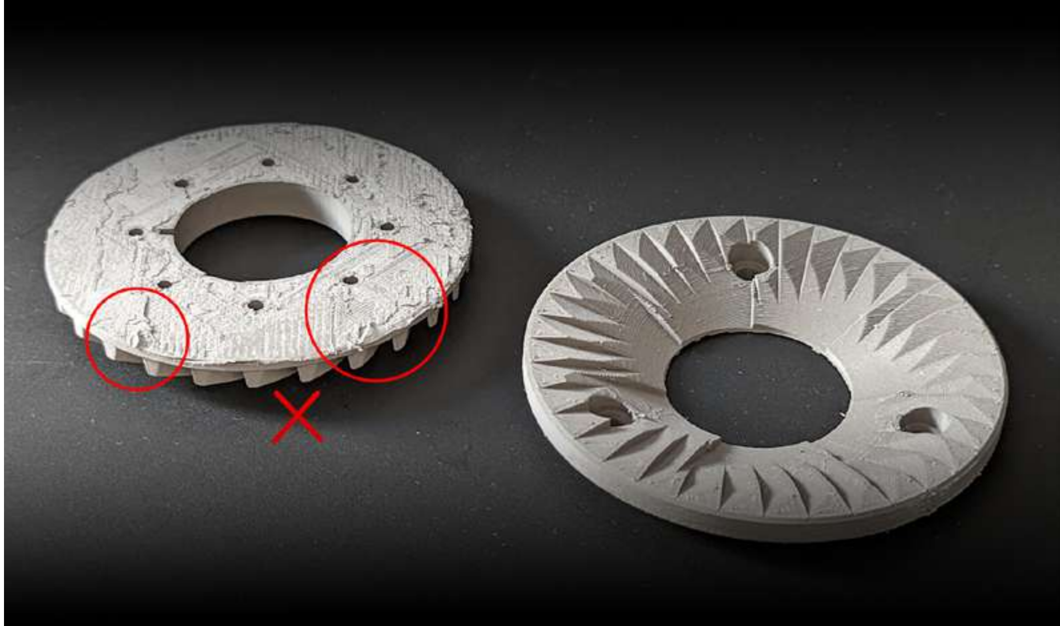


Figure 5

Not only taller parts suffer from failures due to not having a truly flat bottom. The spring barrel gear seen in Figure 15 at 100mm in diameter and only 8mm in height is well within a safe height to width and feature thickness; however warping from printing was not removed resulting in collapse and cracking.



Circular Features

Circular features are best produced when their axis of rotation is in line with the print direction. Typical FDM printers provide dimensional accuracies of the order of the extrusion width. For an extrusion width of 0.4mm, typical dimensional accuracies in the XY plane are approximately ±0.4 mm. Layer height is directly related to the accuracy and the level of fidelity achievable and is mostly dependent on the printer used. The relation between layer height and dimensional accuracy is most pronounced for circular features in the printing direction (Z-Axis).

It is recommended to rework threaded holes regardless of printing direction or size. The diameter of the hole should be reduced to the diameter of the core hole so that the thread can then be re-tapped.

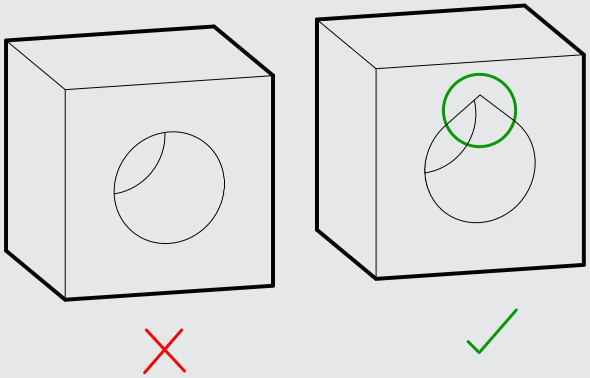


Figure 6

Wall Thickness

Thin walls should be no less than 1mm in their green state. In the thin walls seen in Figure 18 below, we printed with only one extrusion width of 0.4mm and thus suffered major distortion in the sintering process.

Good adhesion between wall sections is required to minimize wall failures in sintering like that seen in Figure 7. When the extrusion width and wall thickness do not match, the inner portions can be left either with no infill or partial infill resulting in a lower density and a reduced structural stability.

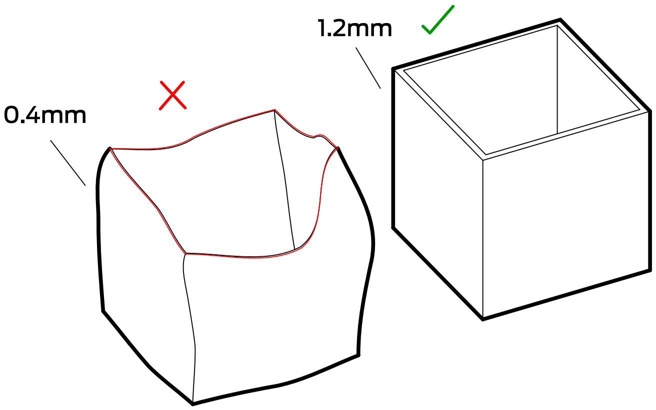


Figure 7

Infill

Although many parts utilize 100% infill to provide the highest final part density and stability during debinding and sintering, dramatic reductions in part mass can be achieved with infill structures. Not possible in most other metal 3D printing methods, FDM's infill structures can create true hollow enclosed part features. Typically, infill under 50% is not recommended without special considerations or adaptations to part design.

A 60% rectilinear infill pattern was used to produce the artistic parts seen in Figure 8 and provided a weight reduction greater than 40% compared to a full density print. Although higher infill amounts tend toward greater first-time success, a dramatic increase in the variety of available infill patterns continue to improve part stability while providing weight saving opportunities.

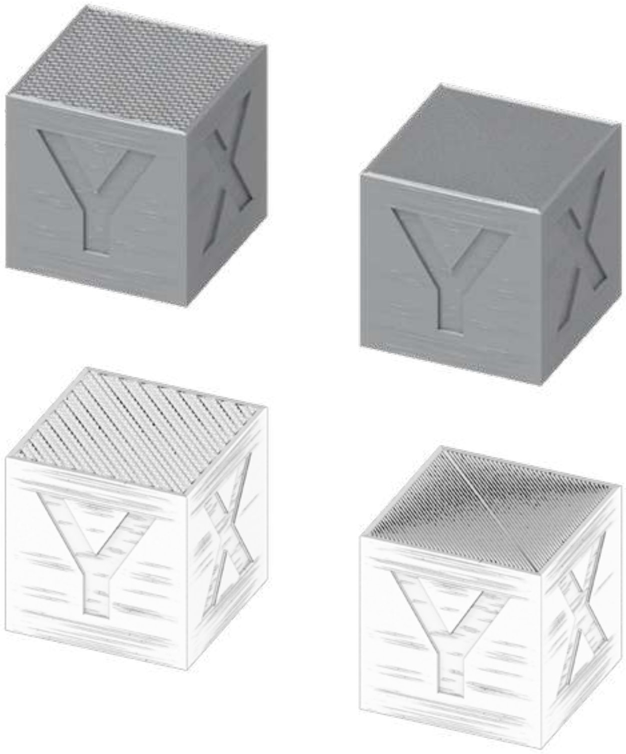


Figure 8

Part Cooling

Although common for some FDM materials such as PLA, Ultrafuse metal filaments do not require active cooling during printing. Using cooling normally results in delamination as seen in Figure 22 below. One exception is the limited use of cooling to enable better bridging results.

Designed Supports

Print parts as flat as possible and add as much support as possible to increase the survivability of parts during debinding and sintering. As with typical FDM part printing, overhangs are a critical concern when using Ultrafuse 316L. During the transition from debinding to sintering, structural stability is at its minimum. Through the strategic use of part orientation and support structures in the printing and post-processing phases, part collapse and deformation can be significantly reduced.

When printing, an overhang angle greater than 45º is easily achievable but may suffer from collapse during debinding and sintering if not properly supported. Therefore, additional support structures, not typically required during printing, are necessary to reduce part distortion and to avoid collapse.

Transition

Thermal stresses during debinding and sintering may intensify and exaggerate layer delamination or cracking present in the green part and may be amplified by notches or abrupt cross-sectional changes. The addition of fillets or chamfers, as seen in Figure 9, have been shown to reduce part cracking layer separations. If part geometry constraints limit redesign, the print orientation can often be adapted to reduce geometric distortion.

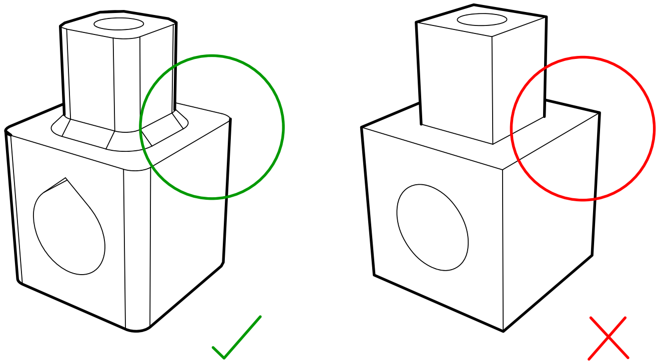
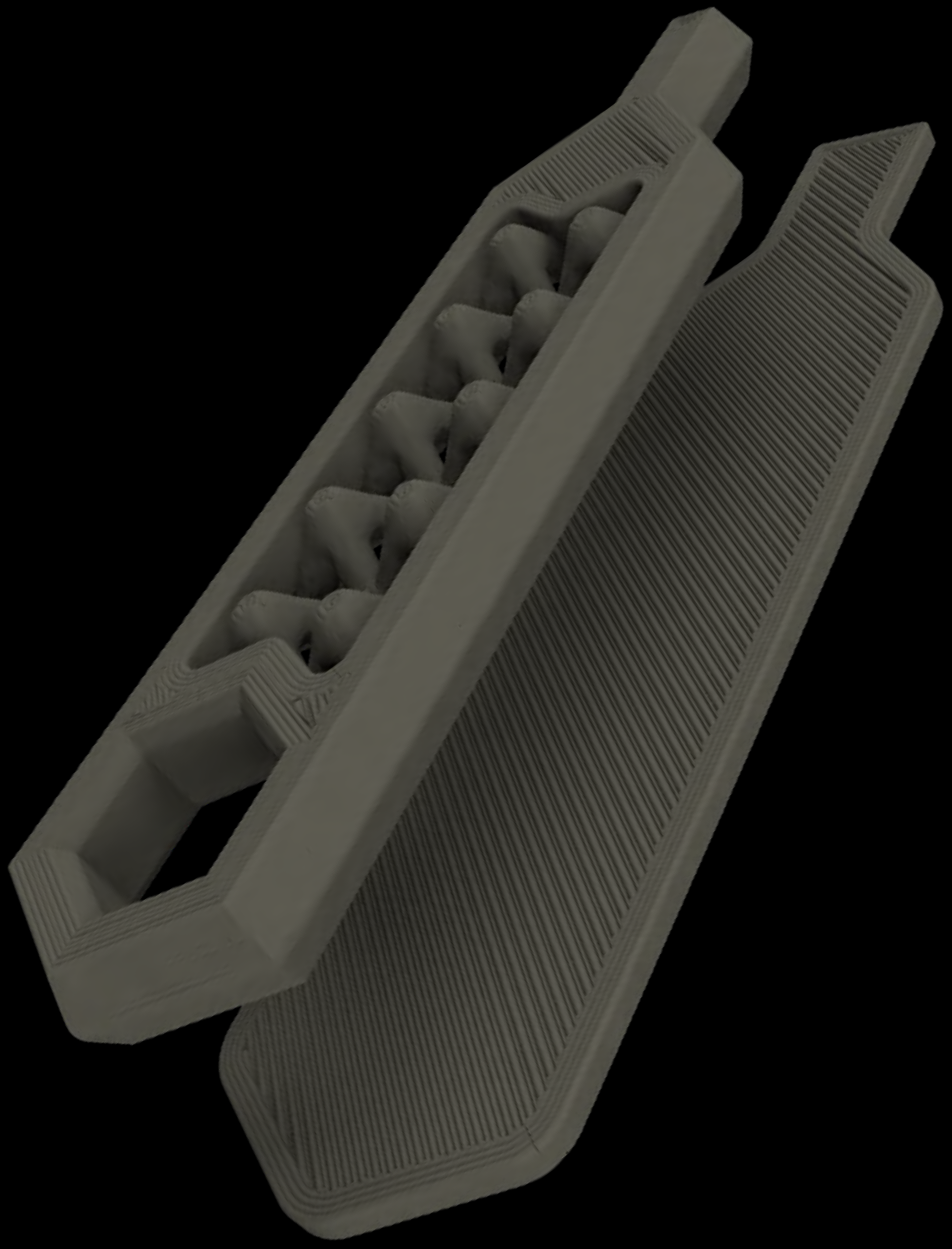


Figure 9



Design and Print a “Sintering Raft”

While you may choose not to print your “green” part with a raft, it is recommended that you design a flat platform that matches the XY dimensions of your print, and print it as well. This flat platform would not be used in actual printing, but would be used by the service provider during sintering. It acts as a sacrificial buffer between the print and the sintering plate which will heat and cool more rapidly than the surrounding environment. The goal is to avoid uneven heating and cooling of the part itself and therefore achieve better accuracy and overall quality.

Printing

Suggested Printing Parameters

While MakerBot METHOD Series 3D printers have worked with BASF to test and create an optimized material profile for BASF Ultrafuse Metal within CloudPrint, people reading this might like to know how the sauce is made so we've included the basic printing parameters below.

The suggested parameters seen in **Table 1** serve as a starting point for users looking to better understand how they may use Ultrafuse metal in general with desktop 3D printers.

Parameter	Value	Comment
Nozzle Size	0.3 - 0.8 mm	Depending on level of detail required and print time
Extrusion Width	Nozzle size ± 10-20%	100 - 110% of nozzle size
Retraction Distance	1.5mm / 5.0mm	Direct / Bowden extruder
Retraction Speed	45 mm/s	Recommended
Layer Height	0.10 - 0.25mm	No more than 60% of the nozzle size recommended
Outlines	1 - 3	Too many outlines can result in wall separation
Outline Overlap %	20 - 35%	Overlap between the outlines must be ensured
Infill (Solid Part) %	100% Lines	Rectilinear types have shown to produce highest densities
Infill Type (Hollow)	>60% Grid or Triangle	Minimum infill above 60% for best results, but lower values possible with testing
NozzleTemperature	220 - 245°C	Calibrate to ensure actual temperature matches slicer temperature settings
Bed Temperature	90 - 100°C	Calibrate to ensure actual temperature matches slicer temperature settings
Cooling	None	Part cooling generally increases warpage but can be helpful during bridging
Print Speed	30 mm/s	Slower printing speeds produce denser more accurate results
Scaling	XY 120% Z 126%	See Shrinkage and scaling on Page 13

Table 1: Suggested Initial Printing Parameters

Part Orientation

The alignment of a part on the printer's build plate can critically affect the accuracy, strength, print time, and stability or survival during the debinding and sintering processes. In general, parts should be orientated to provide the maximum amount of a part's surface on the build plate, as seen in Figure 10, to provide sufficient connection to the print surface during printing and stability during post printing steps.

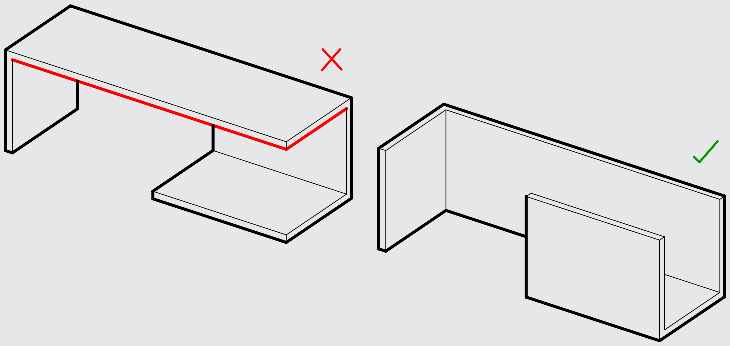
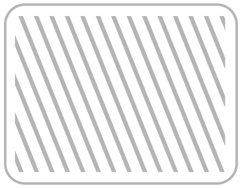


Figure 10

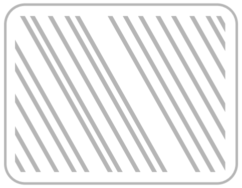
First Layer

Printing a perfect first layer is the first step in a successful FDM part. The first layer attaches the part to the build surface; when it fails so will the print job. Warping during printing often occurs due to a lack of adhesion between the part and build surface resulting in poor part accuracy or potentially total loss of the part during debinding and sintering.

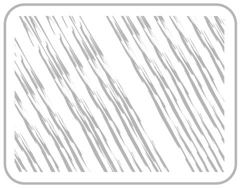
A clean and leveled build surface is recommended. To dramatically reduce first layer separation and warpage at the build surface, approved adhesives may be used. Dimafix or Magigoo Pro Metal are two approved products proven to provide both ease of use and excellent part adhesion.



Even and closed.
No swelling, not too "loose".



Nozzle is too far away from the print bed. First layer is not closed and thus there is not good adhesion of the first layer to the printing.



Nozzle is too close to the print bed. The extrudate swells, and the layer is heavily smeared and uneven.

Extrusion Width Selection

The width of the material being extruded from the printer's nozzle is referred to as the extrusion width (EW). EW tuning is critical to part accuracy and density. Because most slicers create toolpaths from the outer shell to the part's center, gaps can be formed when the requested EW does not match the feature to be printed. The selection of an appropriate EW must be calibrated prior to printing because it may dramatically affect the material infill and thus the mechanical properties and survival of thin walls.

An example of EW-feature mismatch may be seen in the hexagonal sections seen in **Figure 11** below. Proper EW use or part design will produce a fully filled wall of high density and stability.

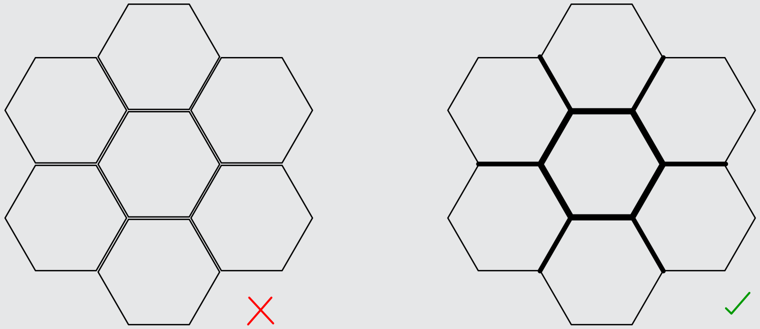


Figure 11

Scaling must also be considered during design and slicing. Because parts need to be scaled up to account for shrinkage in sintering, designed features may not result in appropriate filling once scaled. Often recalibration or adjustment of EW is the fastest method for adapting an existing printing profile to a specific part's needs.

Positioning of Filament Spool

The Ultrafuse 316L and 19-4 spools are significantly heavier than what you might be used to if you've printed with polymers or composites - after all the material is predominantly metal. Some printers may have difficulty pulling the filament which can lead to jams or failures. To avoid this, orient your spool so that it has as straight of a line to the printer as possible. When you mount, hand, or place your spool, be sure that the spool spins relatively easily. Failure to do either of these will increase the load on the extruder.

Supports “Not Just for Printing”

Ultrafuse metal filament printing requires a greater amount of supports compared to typical plastic FDM. To print an overhanging feature, it is recommended to use supports with overhang angles under 45º as seen in Figure 12 below. During debinding and sintering Ultrafuse metal parts require increased amounts of support to minimize the chance of part collapse or distortion. Support structures have the greatest effect when they are created with full density. The use of support should be minimized during part design to increase stability and minimize the need for post sintering removal of full metal supports.

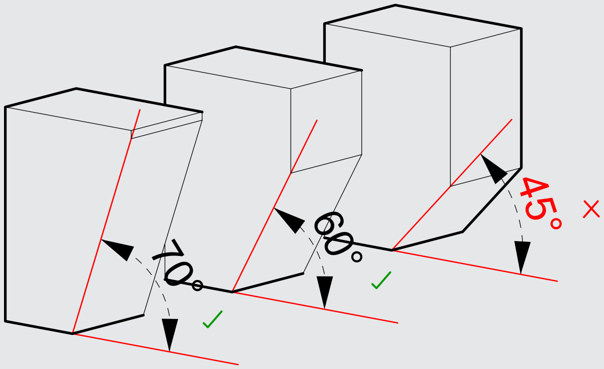
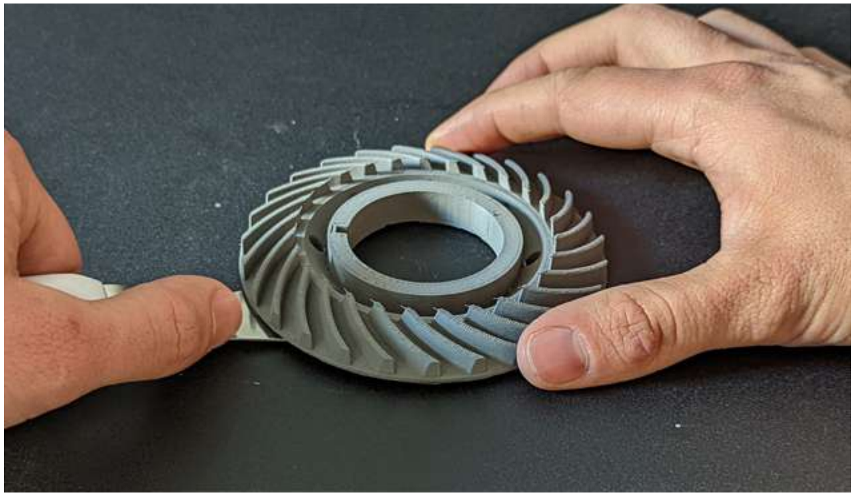


Figure 12

Removal from plate

Caution must be exercised when removing parts from the build surface. Removing a part before it has cooled down can distort the part and even remove bottom layers as seen in Figure 16 below. Due to a poor bottom surface, cracks can often occur on the opposite side of parts as they settle into unsupported areas during sintering.



Pre-Sintering, Post-Processing

Although, in principle, nearly any geometry imaginable may be produced, post-processing of a sintered metal part may be required to achieve a surface quality or dimensional accuracy greater than that typically achievable with FDM. Unlike many other metal additive manufacturing processes, Ultrafuse metal green parts are easily smoothed using abrasive or cutting methods. Green state machining, prior to sintering, enables dramatic reductions in machining costs and capital investment due to Ultrafuse filament's high machinability in the green state.

Parts requiring high tolerances may take advantage of traditional metal working methods to produce functional faces. Higher tolerances and surface quality requirements may require further post-processing methods, such as polishing, milling, heat treating, and coating.

The industrial gripper, was printed and sintered. After sintering, the supports were removed and higher tolerance features were finished, followed by tapping.

Recommendations

- Print separate sintering raft alongside your print
- Submerge in water for easier removal from build plate
- Sand down rough edges
- Removing defects
- Flatten base by sanding

Debinding and Sintering

The debinding and sintering processes that produce full metal parts are critical differentiators from typical FDM 3D printing materials. The following is a brief introduction to both processes in order to better understand and optimize your part needs.

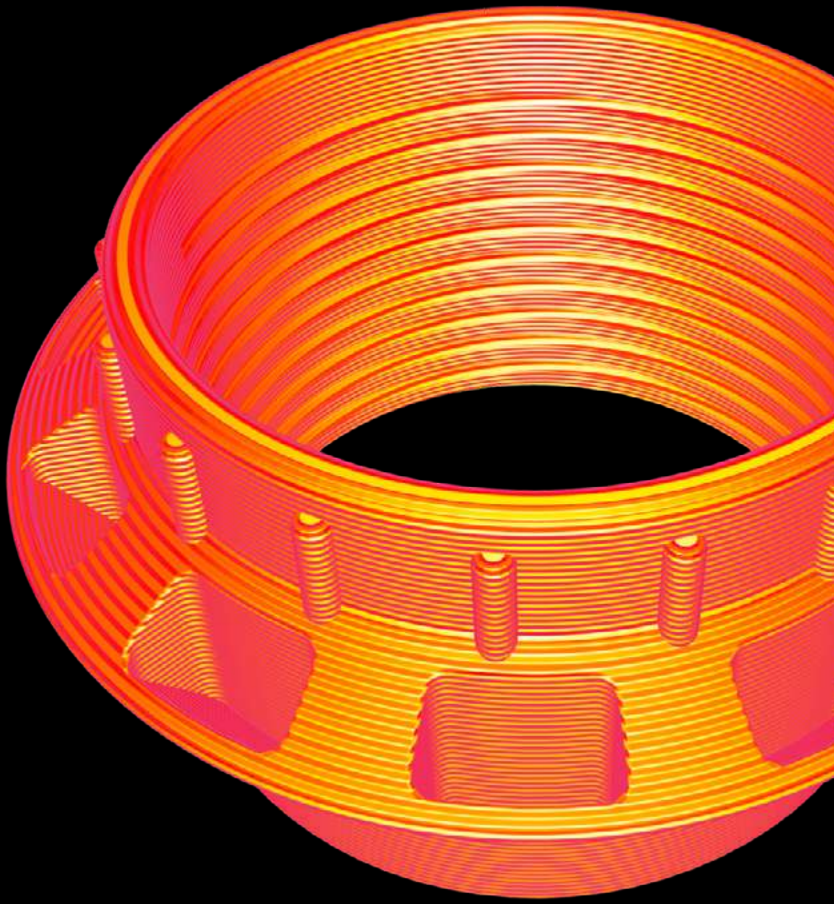
Catalytic Debinding (Green to Brown)

Debinding is the removal of binders which are required to enable the printing process. Ultrafuse metal filaments use multiple binder systems to ensure rapid and controlled removal of the binding material. Catalytic debinding is a thermochemical process in which green parts are exposed to gaseous nitric acid (HNO3) in a nitrogen atmosphere and heated. It removes the binder material very rapidly compared to other binding methods (1–2 mm/hr for each external surface). The thicker the part, the longer the debinding time required. Once the polymer-based binder has been removed, the part is referred to as a brown part and is ready to be solidified into a fully metallic part by sintering.

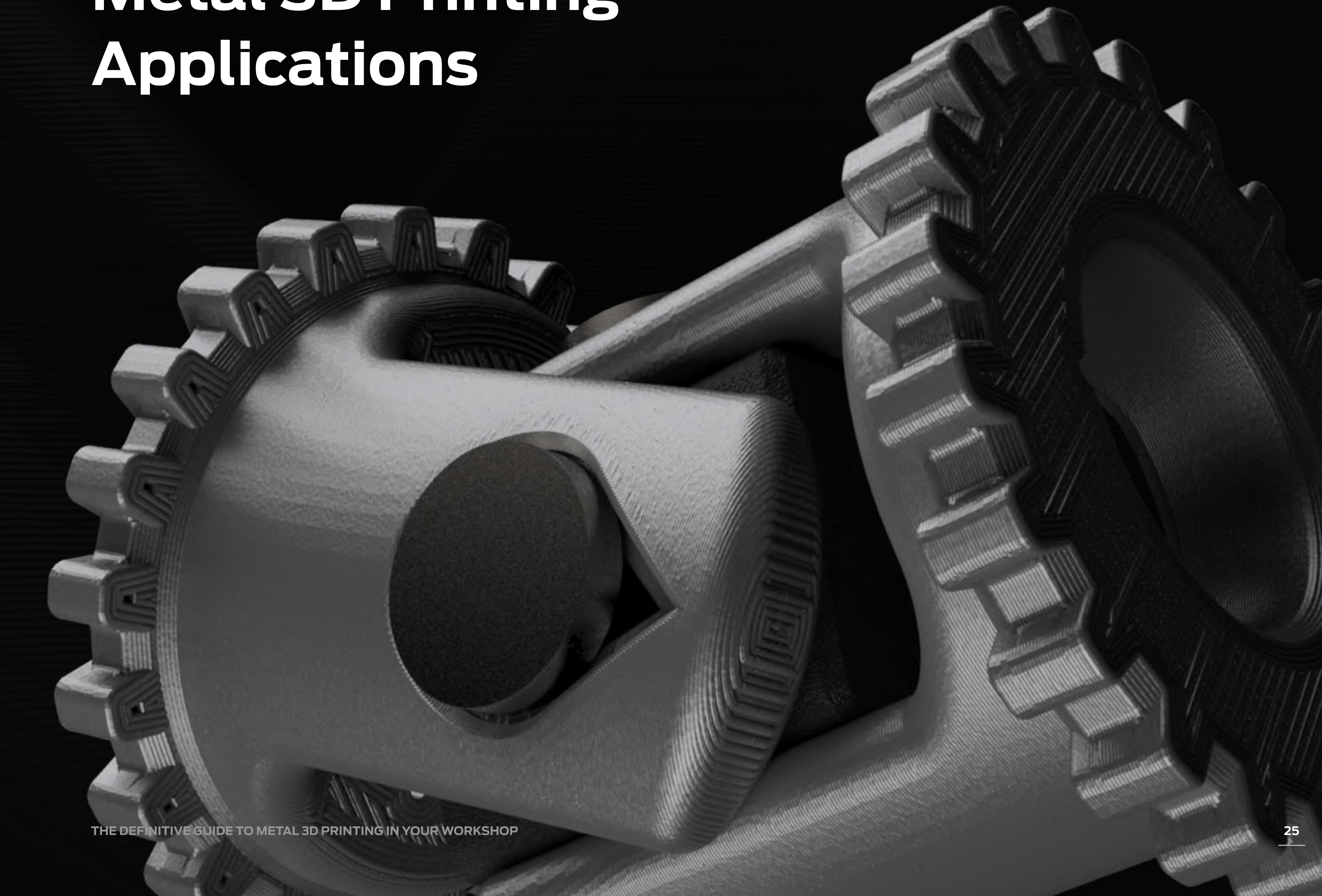
Sintering (Brown to White)

Brown parts are relatively porous and require sintering to produce a solid densified material. Sintering combines the metal particles in the brown part into a solid mass and is carried out under pressures and temperatures below the melting point of the material to maintain the part's shape.

Sintering in a pure hydrogen atmosphere enables the production of a finished stainless steel component that is almost fully dense. Printing direction and parameters have a large influence on shrinkage magnitudes. Support structures, as with any FDM part, are required when printing overhangs or other horizontal structures. Unlike typical FDM, Ultrafuse metal components require increased support structures to ensure structural integrity throughout the sintering process. Due to its transition from a porous brown part to a dense "white" state, dimensions of the part are reduced. This reduction in size is typically referred to as shrinkage and must be considered during the design phase.



Part being sintered

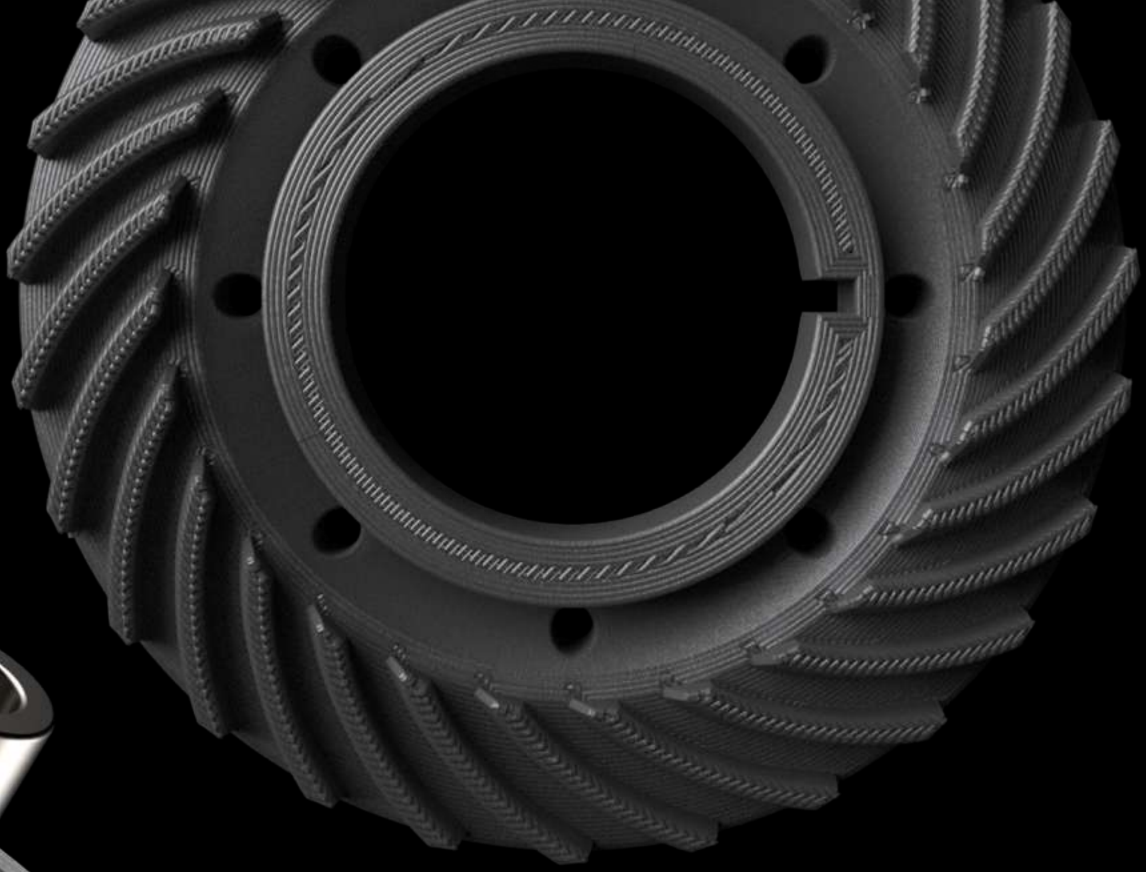


Metal 3D Printing Applications

Helical Gear

Gears within assemblies can have a seemingly infinite variety of sizes and teeth structures. Metal is typically the preferred material for gears due to the forces, temperatures, and abrasion that can occur. CAD design combined with 3D printing make production of more complex gears or batches of gears a useful application.

Print time 6h 33m



Lattice Gear

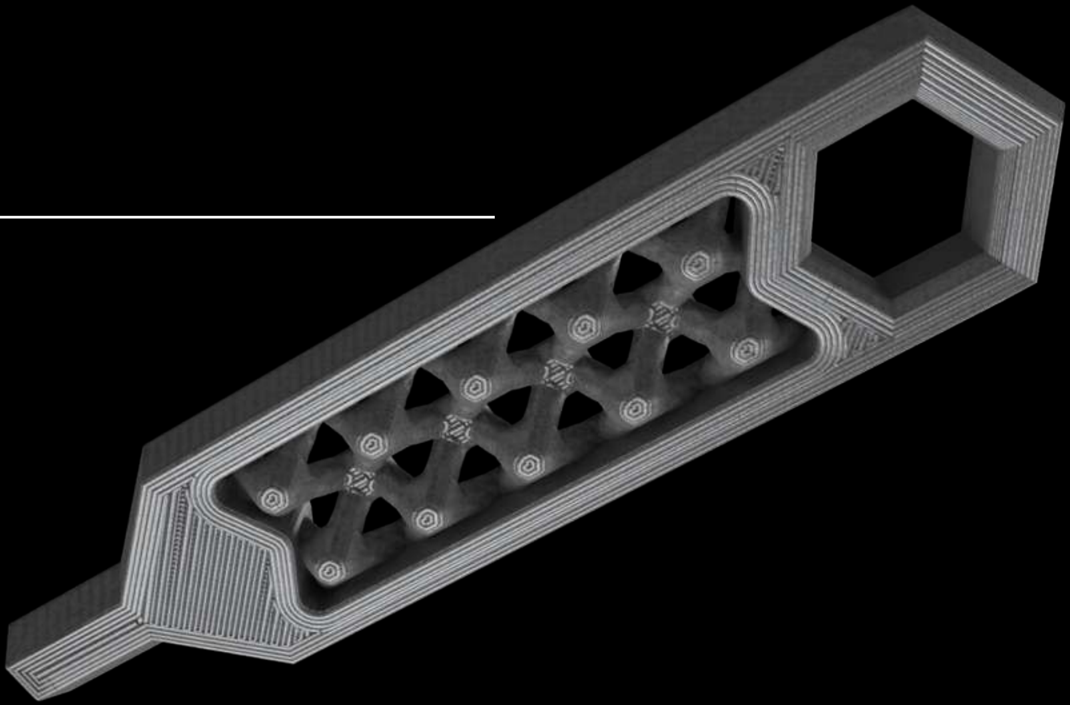
Lattice structures allow for lightweighting by creating strong structures with less material. This gear is a good example and shows the versatility of geometric freedom afforded by 3D printing while also allowing for further complexity with gear teeth.

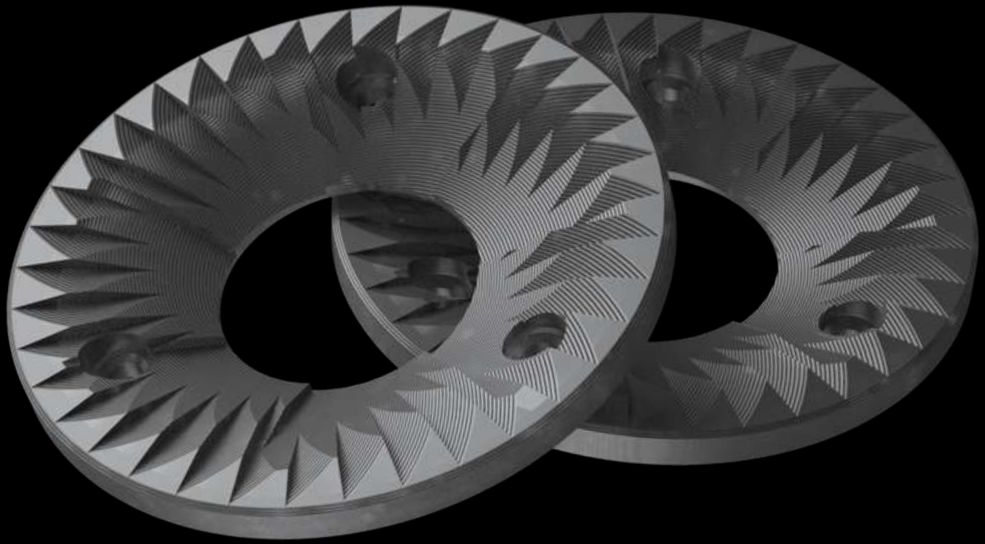
Print time 15h 20m

15mm Lattice Wrench

Another example of lightweighting with lattice structures, this 15mm wrench is an example of a handheld or possibly end of arm tool that has been lightweighted to reduce the load on a technician or robotic arm - allowing either to apply additional force with reduced stress.

Print time 2h 28m

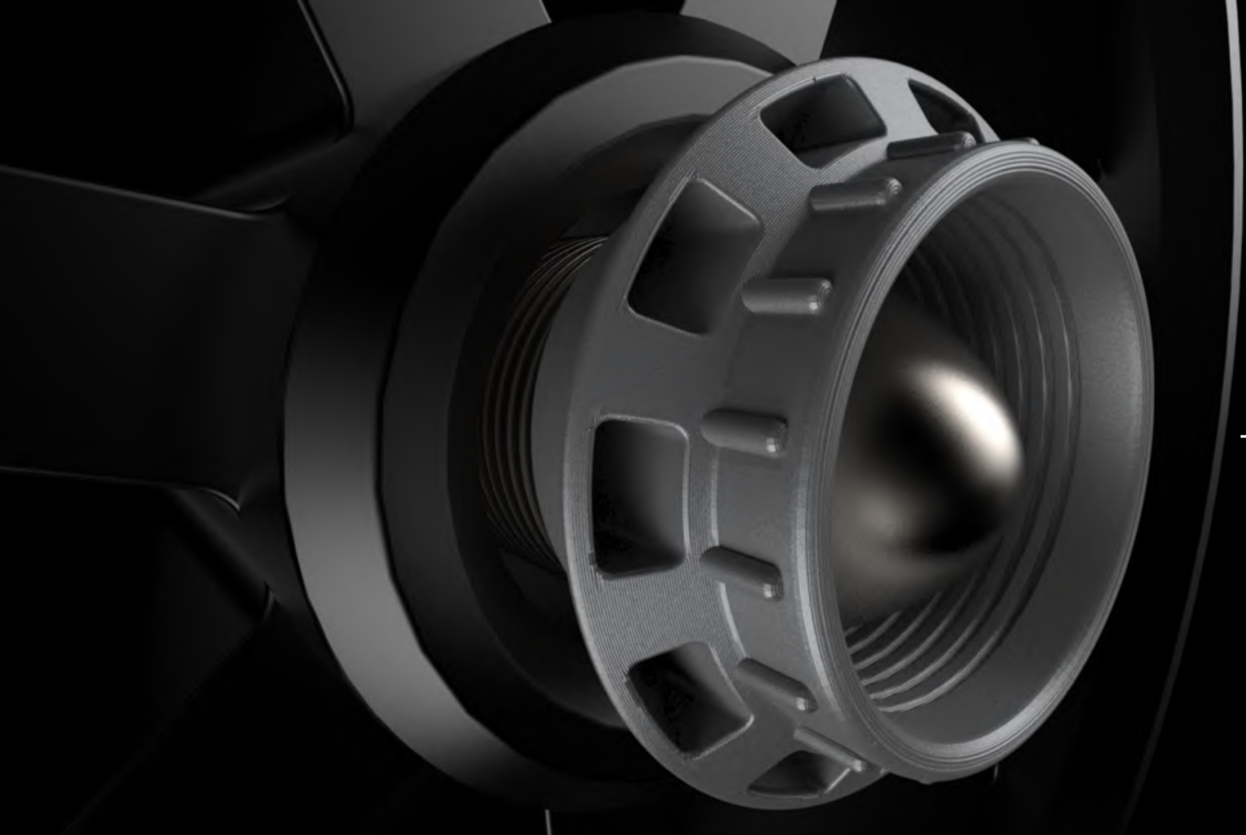




Flat Burr (Grinder)

A flat burr or really any kind of grinding element needs hardness, durability, and force to achieve its goal - hence the need for metal material. Similar to gears, a burr can have various teeth patterns that can make machining more difficult and lend well to 3D printing.

Print time 7h 16m



F1 Wheel Nut

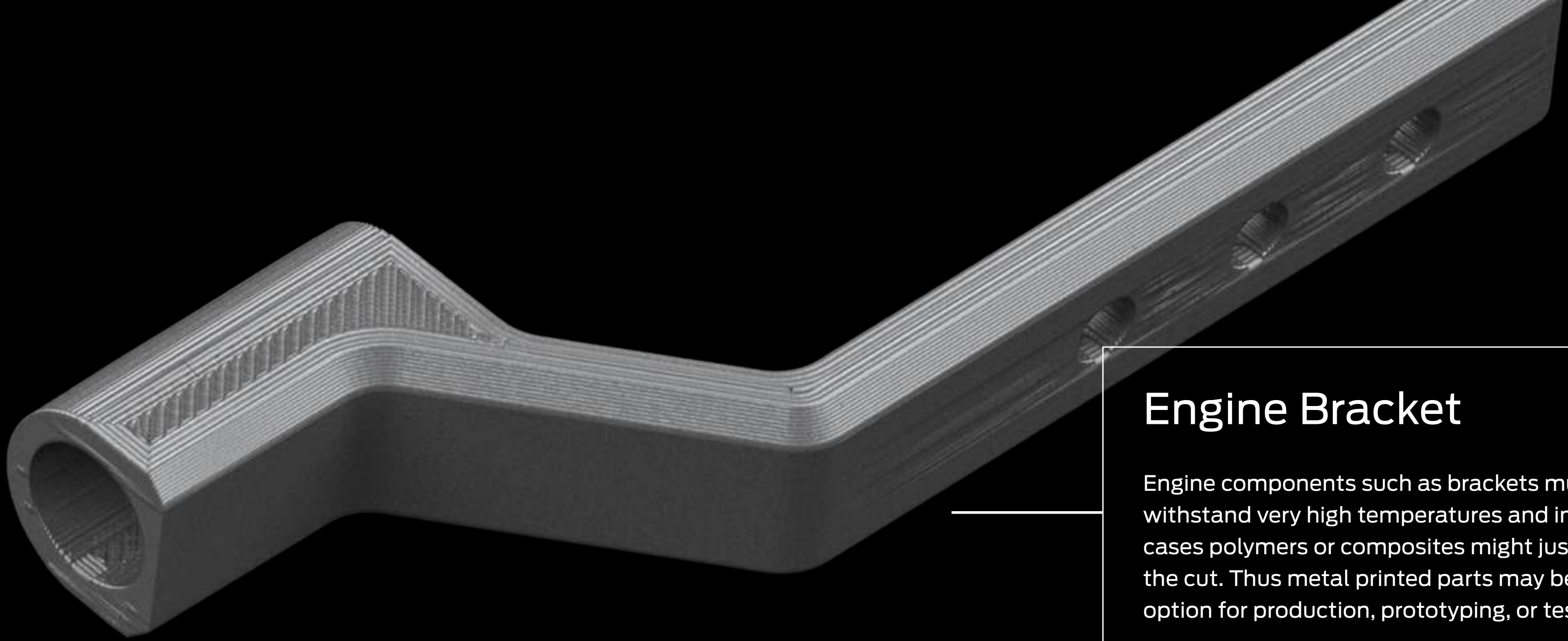
The F1 wheel nut must withstand extreme force and temperature as it is exposed to peak racing conditions. It also must hold up during tire change to even more direct forces to avoid stripping - once again necessitating metal as the choice material. At the same time F1 and other race cars aim to minimize weight. In this case lightweighting elements have been introduced utilizing the additional dimensional freedom of 3D printing.

Print time 25h 56m

Universal Joint

A universal joint may be required for a mechanical architecture and is a relatively straightforward piece to print. This example could be used during prototyping or production, once again metal is the choice material for withstanding high force loads.

Print time 4h 05m



Engine Bracket

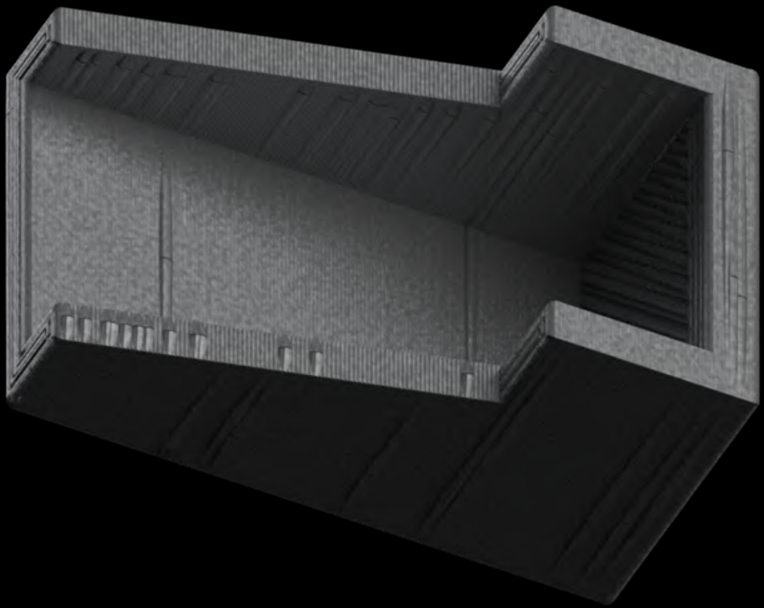
Engine components such as brackets must withstand very high temperatures and in these cases polymers or composites might just not make the cut. Thus metal printed parts may be a viable option for production, prototyping, or testing.

Print time 2h 10m

Electronics Board Manufacturing Cap

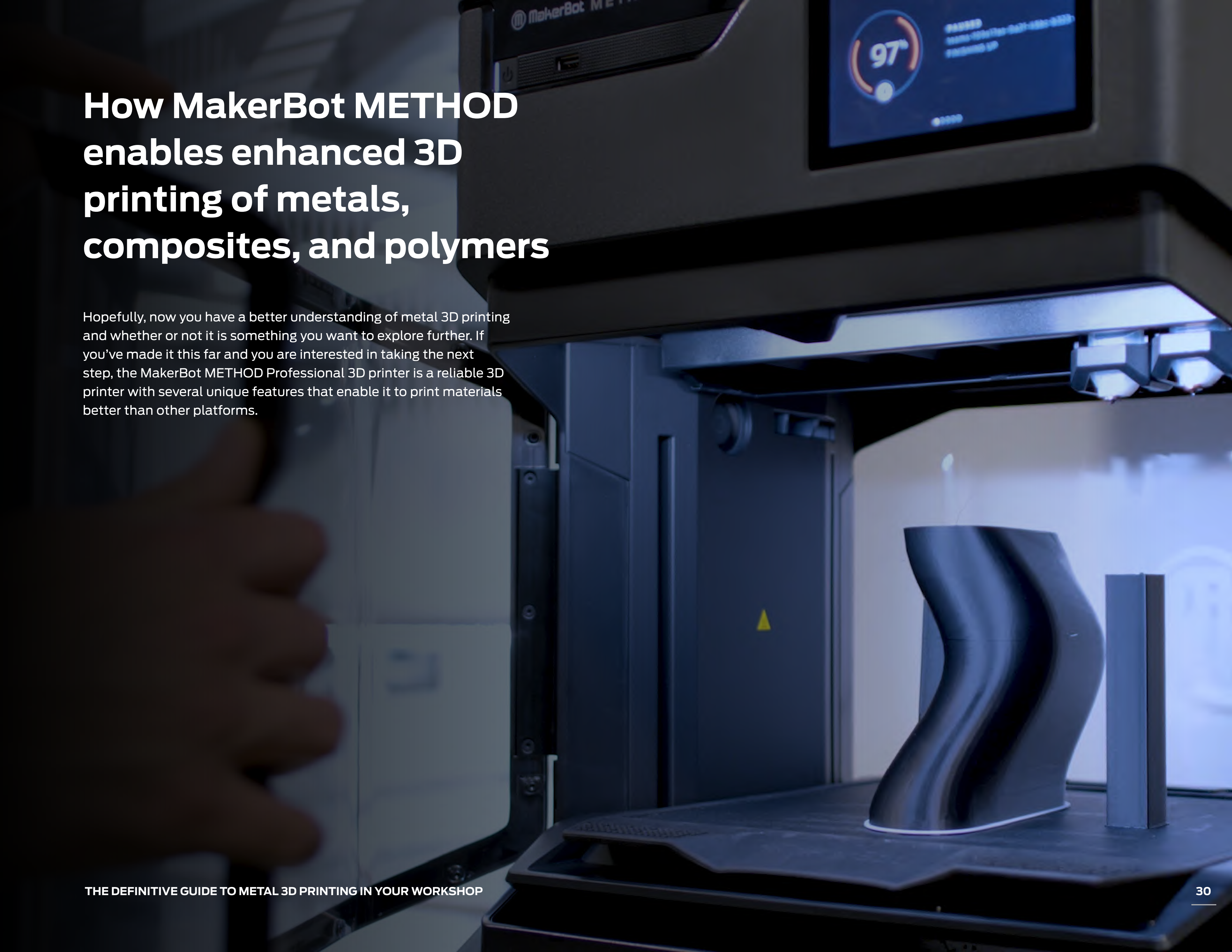
Electronic board manufacturing processes have different requirements. One notable process features components that are sprayed with soldering flux and then soldered - which produces very high heat. A metal 3D printed enclosure was used to isolate the area of spray and protect other sensitive components from the spray and heat.

Print time 1h 4m



How MakerBot METHOD enables enhanced 3D printing of metals, composites, and polymers

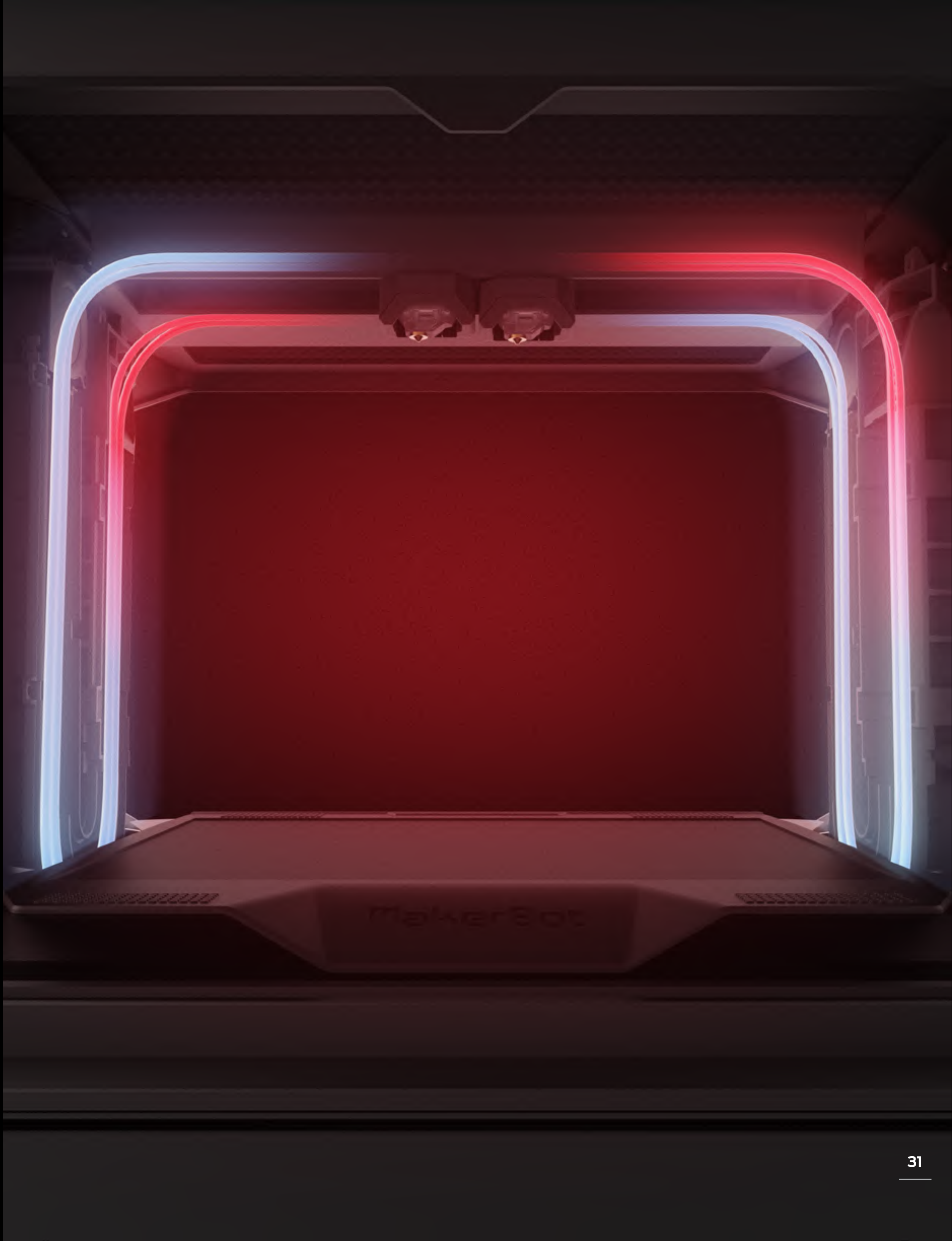
Hopefully, now you have a better understanding of metal 3D printing and whether or not it is something you want to explore further. If you've made it this far and you are interested in taking the next step, the MakerBot METHOD Professional 3D printer is a reliable 3D printer with several unique features that enable it to print materials better than other platforms.



VECT™ Thermal Regulation

Many desktop 3D printers use heated build plates to try and regulate their environment and prevent warping on the print bed. This improves adhesion to the build plate for the first layer and... that's about it. METHOD uses the patented Variable Environmental Controlled Temperature (VECT) to rapidly warm the entire build chamber up to 110ºC providing optimal print conditions from first layer to last.

The result is a degree of dimensional accuracy typically reserved for industrial 3D printers (±0.007 in) - parts that are 2x stronger on the z-axis, and 2x more accurate across the board.



6-in-1 Modular Performance Extruders

When it comes to FDM 3D printing, the toolhead or extruder is one of the most important features. Based on an industrial-grade design from Stratasys, METHOD's extruder was designed from the ground up with the professional in mind. With a lengthened thermal core, dual drive gears with 19:1 gear ratio of torque, and MakerBot's industry-leading intelligent sensor suite, METHOD comes with significantly improved print quality and speed.

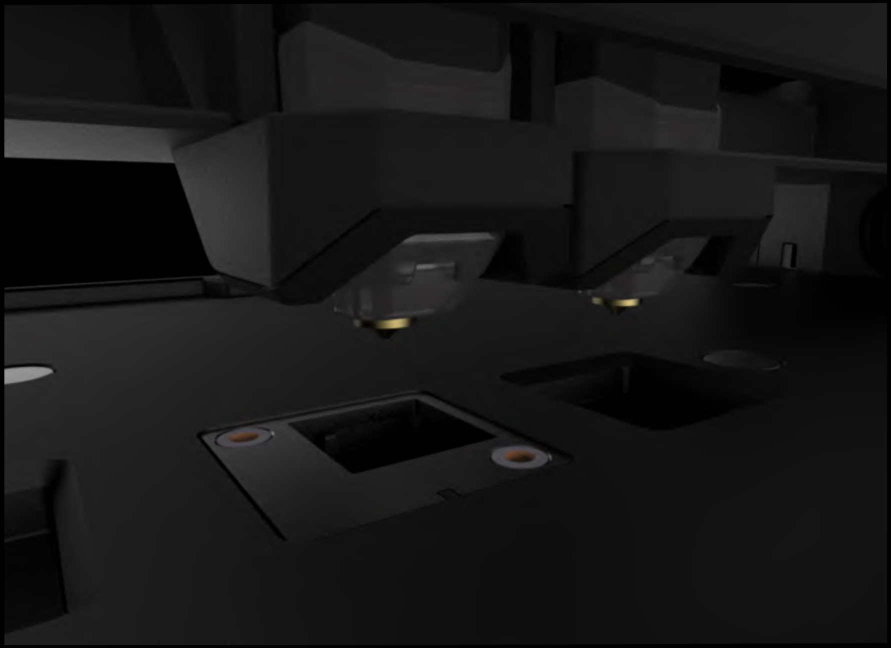
With six modular extruder options and two slots on METHOD and METHOD X, you have hardware options that are specifically tuned for the material group you are printing. Support your print with dissolvable supports in PVA, SR-30, and new RapidRinse - allowing you to design AND print real world production parts with the utmost complexity.

SmartAssist™ Material Loading and Management

METHOD's material bays are both smart and protective of your filaments. The autoloading feature makes changing materials a breeze, while the sealing bays provide a barrier from moisture. The embedded sensors ensure the system is fully aware of the material type, color, and amount so when you go to start a print remotely from CloudPrint, you know exactly what you're getting.

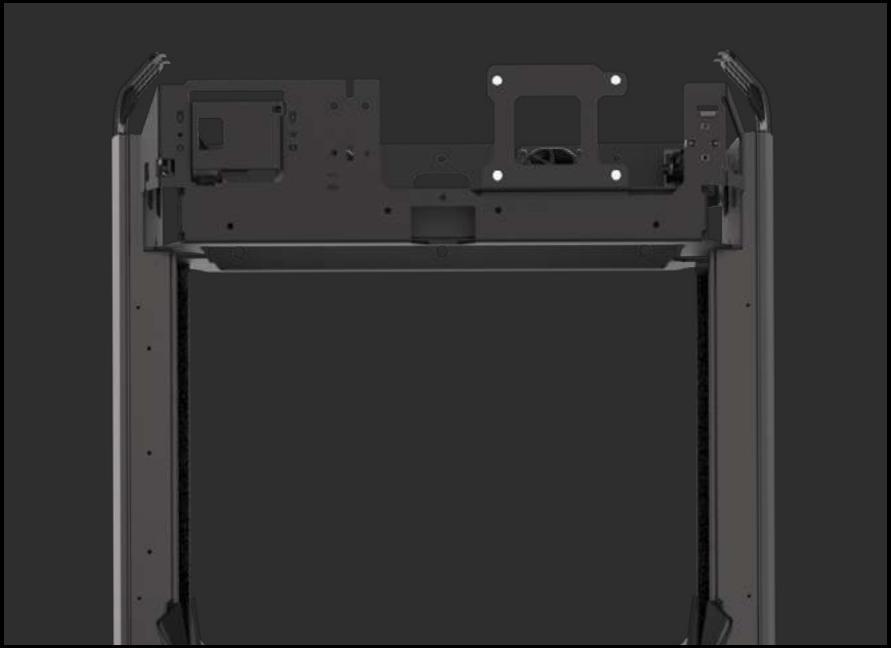
Auto-Calibration

One of the dirty little secrets of dual-extrusion 3D printers is the frustration that can come with the manual calibration of the extruders on most desktop machines. METHOD automates this process so you can focus more on product design and less on maintenance.



Ultra-Rigid Metal Frame

Print continuously for hours, days, or weeks, thanks to METHOD's unmatched industrial build quality. A structurally-optimized metal frame runs the full length of the body to offset flexing. Less flexing means more consistent prints with better part accuracy and fewer failures.



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