MANTLE

The Ultimate Guide to 3D Printing for Mold Tooling

While many metal 3D printing methods have established a niche in their respective applications – for example, powder bed fusion for medical implants or binder jet for MIM components – tooling has long been a target for various approaches. This white paper serves as a guide to understanding the major metal 3D printing technologies and their role in printing injection mold tooling.

Note, this document is a general guide to 3D printing for mold tooling but benefits, limitations, and specs. can vary based on specific printer and the actual application.

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Plastic Solutions

Plastic 3D printing technologies have long been used for prototyping, jigs, and fixtures. Plastic printing technologies offer incredibly fast lead times, often just hours, and low costs. But when it comes to tooling, they wear quickly and have poor thermal properties, resulting in short tool life and long cooling rates in molding.

Vat polymerization has long been the go-to method for producing prototype injection mold tooling. Vat polymerization uses light to cure a UV-curable resin, building up the part layer by layer. The two most common methods of vat polymerization are SLA and DLP. SLA uses a single UV light source (point) to scan the print bed. DLP uses a projector UV light source to expose the whole print bed simultaneously.

SLA and DLP feature incredible feature detail and smooth surface finishes, allowing for their printed tools to be used with little to no post-processing. When an end-use polymer is needed for a prototype, these vat polymerization methods are often the go-to method for producing a mold that can inject anywhere from 1 - 1,000 parts, depending on the molded material.

In recent years, advances in SLA and DLP material have allowed for longer tool lives, mostly resulting from fillers such as ceramics and chopped fibers being added to the printed resin.

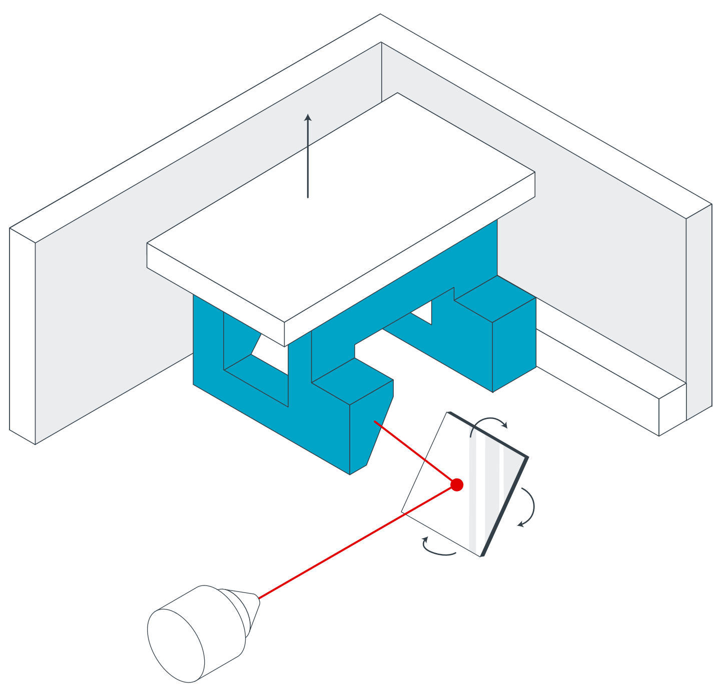
BENEFITS

- Very fast, often just hours
- Very inexpensive

LIMITATIONS

- Short tool life (1 - 1,000 parts). Tool life is defined by the injected materials' abrasion, injection pressure and temperature
- Poor thermal properties can result in long cycle times, unexpected shrink rates, and warping
- Inability to iterate on molding parameters since tool material has unique properties that can't be replicated in metal tools

OEMs: Formlabs, Carbon, EnvisionTEC, Fortify, 3D Systems, Nexa3D



Powder Bed Fusion (DMLS / SLM)

In powder bed fusion systems, printing occurs in a heated chamber filled with an inert gas at or under near-vacuum to create a clean, inert environment. A layer of metal powder is spread across the build plate via a roller or blade, and thermal energy (typically a laser or electron beam) traces the cross-section of the part, fusing the metal powder and forming each layer of the part. The process repeats until the full part is formed.

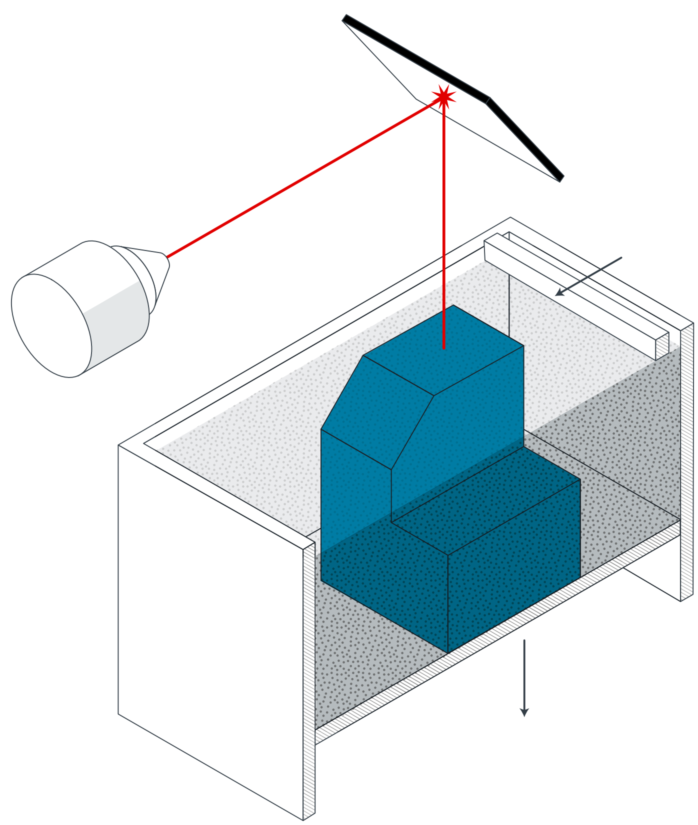
Parts printed via powder bed fusion typically require extensive post-process machining to meet accuracy and surface finish requirements. With nearly limitless geometric freedom and the ability to process materials like titanium and superalloys, this printing method has been very successful in aerospace and medical implant applications.

COMMON NAMES

- Direct metal laser sintering or direct metal laser solidification (DMLS)
- Selective laser melting (SLM)
- Selective laser sintering (SLS)
- Electron-beam melting (EBM)

BENEFITS

- The ability to print incredibly complex geometry, including conformal cooling channels
- A broad range of available metals, including precious metals, super alloys, steels, aluminum and titanium alloys
- Mechanical properties are comparable or superior to forged metal parts
- Micro-scale holes can be printed, producing localized porosity which can be used for mold venting
- Ability to print on top of existing tools and stock material



LIMITATIONS

- Does not achieve the accuracy and surface finish required for most tooling. Many post-processing steps are required to meet these requirements, increasing time and cost
  - General tolerance in XY of +/- 0.005” + 0.002” per inch (For a 4” part: +/- 0.005” + 4 x 0.002” = +/- 0.013”)
  - General surface finish: 3 - 5 Ra um / D3 / Charmilles 30-35
- High cost and difficulty of use make systems inaccessible to most tool shops and molders
- No familiar tool steels (Maraging steel commonly used instead)
- Parts are attached to the build plate and need to be mechanically removed (sawed or wire EDM) from the plate after printing, adding labor and cost
- The process can be slow, especially for intricate details
- Specialized rooms are recommended for the printer and strict process controls are required when handling metal powders as, if dispersed in air, the fine metal powders can pose explosion hazards.
- Systems require loose metal powders that require facility modifications like ventilation and extensive PPE to handle

OEMs: EOS, Nikon SLM, Xact metal, AddUp, Farsoon, Velo3D, Concept Laser (GE Additive), Trumpf, DMG Mori, 3D Systems, GE Additive

Binder Jetting

In the binder jetting process, a thin layer of metal powder is deposited on a build plate with a roller. Next, an inkjet print head moves over the powder and selectively sprays binder to define a layer of the part geometry. The process repeats until green parts (metal powder held together with binder) have been fully formed within the powder bed. The entire build box is then crosslinked in an oven to increase the binder strength, allowing for handling the green parts. Users can then remove parts from the build box by manually sifting through the powder, extracting each part, and brushing away any unbound powder. Once depowdering is complete, parts are placed in a sintering furnace where the binder is removed, and the parts shrink 15 to 20 percent as they densify.

The binder jetting process can produce rough parts that require post-process machining and other finishing work to meet the accuracy and surface finish requirements of tooling. This printing method has had success in producing low- to mid-volume small complex parts, as the properties are very similar to metal injection molding (MIM).

COMMON NAMES

- Binder jetting

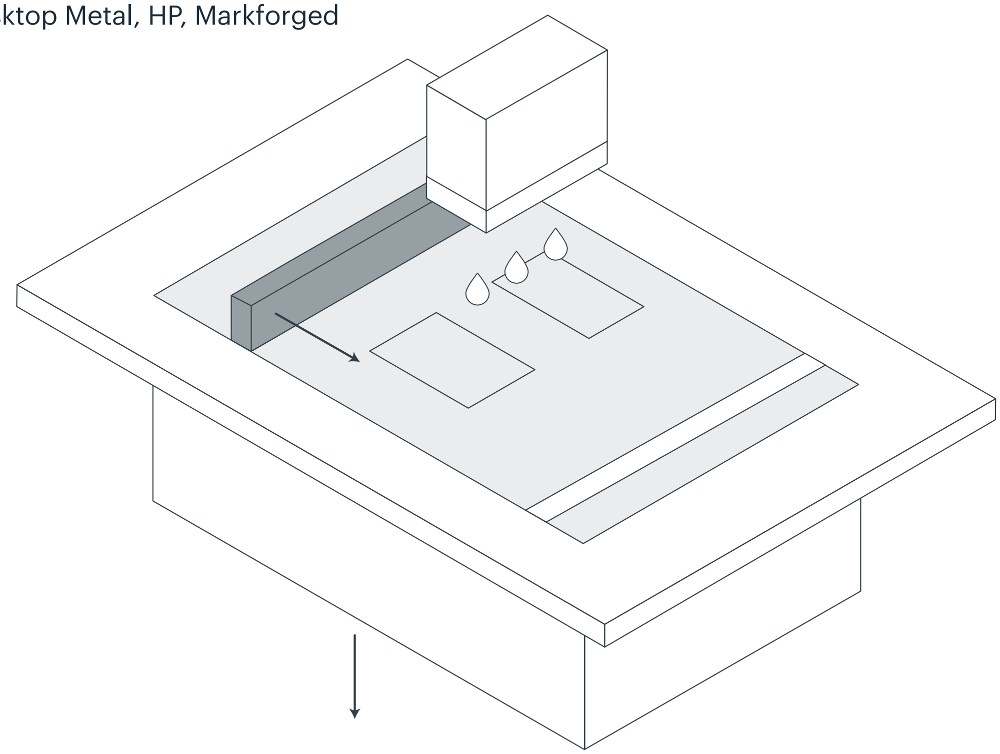
BENEFITS

- Many material options
- Relatively fast printing speeds
- Relatively low per-part cost
- Large bed size and the ability to nest parts enable many parts to be printed at the same time, lowering per-part cost

LIMITATIONS

- Does not achieve the accuracy and surface finish required for most tooling. Many post-processing steps are required to meet these requirements, which increases time and cost. Binder jet tolerances are lost during sintering, as predicting how much or little a part will shrink is challenging.
  - General tolerances: Binder Jet generally talks about tolerances in percentages, often stating 3% tolerance with 1% tolerance possible with sintering simulation. (4-inch part: +/- 0.040” to 0.120”)
  - General surface finish: 6 Ra um / D3 / Charmilles 35 - 36
- Large, dense parts are difficult due to the high shrinkage rate and high binder content, causing warping and cracking from the forces during sintering
- High equipment cost and difficulty of use make the technology inaccessible to most tool shops and molders
- Printing, curing, debinding, and sintering processes can take multiple days
- Cannot print conformal cooling/heating channels, as open spaces fill with powder

OEMs: Desktop Metal, HP, Markforged



Material Extrusion (MEX)

In material extrusion systems, filaments are made of metal powder mixed with a binder and encapsulated in wax. The filament is heated and extruded through a nozzle and selectively deposited onto a build plate, printing a green part one layer at a time. Each layer is printed on top of the previous one, with the binder holding each layer together. Printed parts are removed from the printer and undergo a solvent debinding step (bath) to remove much of the binder and wax, producing a brown part with just enough binder left to hold the metal powder together. Next, parts are sintered in a high-temperature furnace, removing any remaining binders and causing parts to shrink by 15 to 20 percent as they densify.

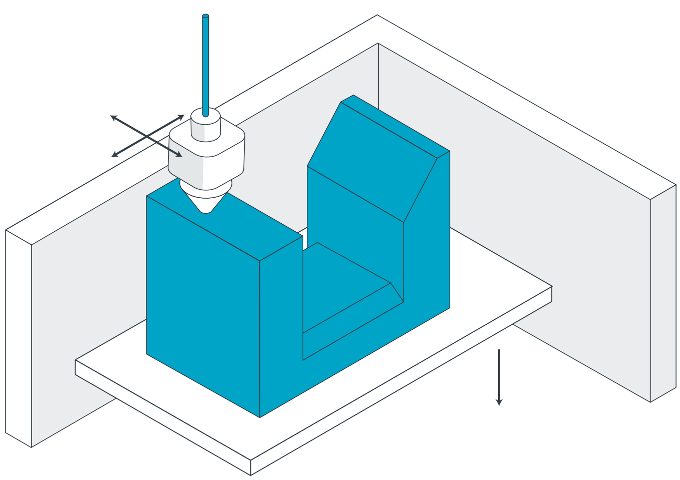
This process produces rough parts that require extensive post-processing to meet most tooling applications' accuracy and surface finish requirements. Their relatively low cost and ease of use have made material extrusion systems popular for universities, design labs, and those just getting started with metal 3D printing.

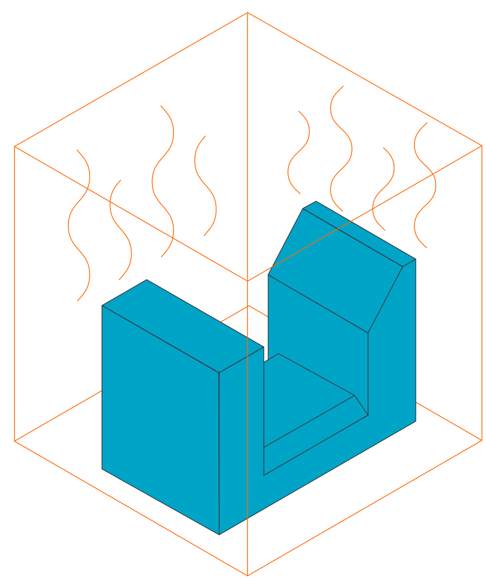
COMMON NAMES

- Metal Injection Molding (MIM)-based 3D printing
- Fused-Filament Fabrication (FFF)
- Bound Metal Deposition (BMD)
- Bound Powder Extrusion (BPE)

BENEFITS

- Very easy to use
- Wide material selection
- Lower machine and material costs
- Little to no facility requirements to install





LIMITATIONS

- Does not achieve the accuracy and surface finish required for most tooling. Many post-processing steps are required to meet these requirements, increasing the time and cost (similarly to binder jetting, tolerance is lost during sintering since shrink rate is high (15-25%), predicting how much or little a part will shrink is challenging.)
- Cannot achieve high surface finish from polishing due to pitting in the material caused by low dentistry
- High shrinkage rates during sintering make it difficult to hold tight tolerances (15-25% common)
- It can be among the slowest printing processes – the printing, debinding, and sintering processes can take multiple days
- Fully dense parts cannot be printed (infill is required unless the part has lower than 10mm wall thickness) as the high binder percentage makes debinding thick sections impossible
- Parts may be weaker in the vertical (Z) axis

OEMs: Desktop Metal, Markforged, Rapidia

Hybrid Powder Bed Fusion

In the hybrid powder bed fusion process, powder bed fusion technology is combined with a subtractive CNC mill. A layer of metal powder is applied to the build plate via a roller or blade, and thermal energy (typically a laser or electron beam) traces the cross-section of the part, fusing the metal powder and forming each layer of the part. After printing the layer, CNC cutting tools machine the part to improve surface finish and tolerances. This process can also be used to add material to an existing part, making it a popular manufacturing choice for repair.

The parts that emerged from the Hybrid Powder Bed Fusion process have CNC tolerance and surface finish and look identical to machined parts.

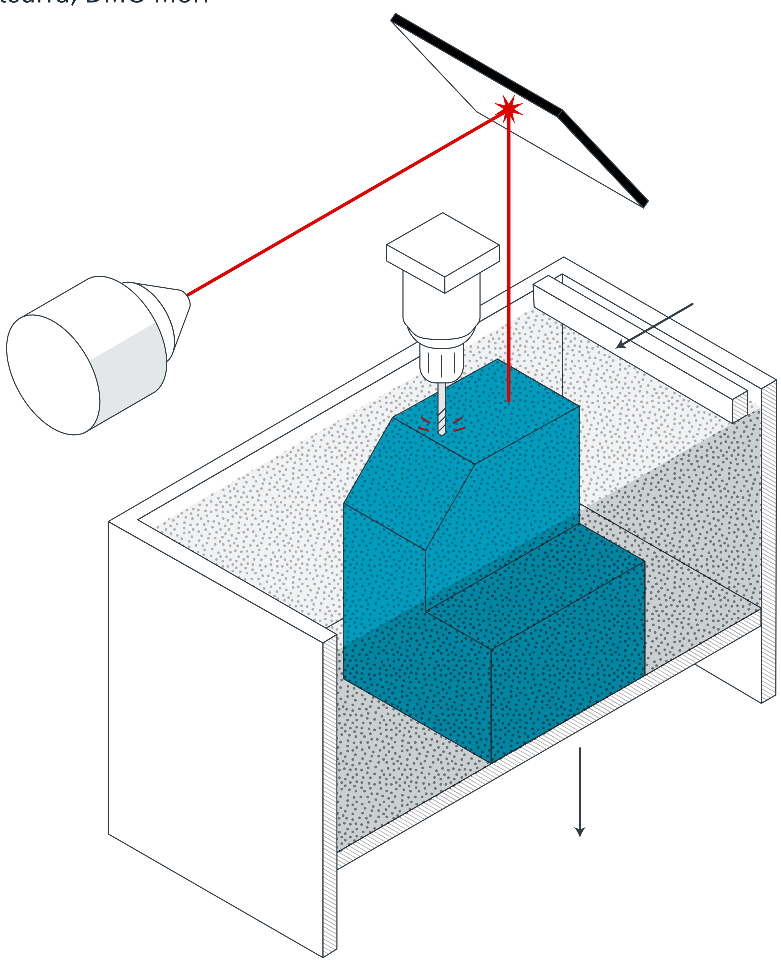
BENEFITS

- Produces highly accurate parts with a surface finish suitable for most tooling
  - General tolerances: CNC tolerances: +/- 0.005”
  - General surface finish: CNC finish (variable): 0.4 um Ra - 12.5 um Ra
- Broad range of available metals, including tool steels, precious metals, and nickel and titanium alloys
- Mechanical properties are comparable or superior to forged metal parts
- Micro-scale holes can be printed, producing porous parts that can be used for mold venting
- Complex conformal cooling/heating channels can be printed and have their tolerances and finished improved during the subtractive milling steps

LIMITATIONS

- High cost of printers and printed parts
- Systems require loose metal powders that require facility modifications like ventilation and extensive PPE to handle
- Difficult to use, complex programming and tight process control
- Nonstandard tooling materials, generally maraging steel used
- High risk of the part warping during machining due to residual stress from high heat during printing often annealing is required after printing to reduce residual stresses
- Parts are attached to the build plate and need to be mechanically removed (sawed or wire EDM) from the plate after printing
- Machining of hardened materials is time-consuming and requires moving slowly with small cutters to refine the surface finish and tolerance of the printed part
- Specialized rooms are recommended for the printer and strict process controls are required when handling metal powders as if dispersed in air, the fine metal powders can pose explosion hazards.

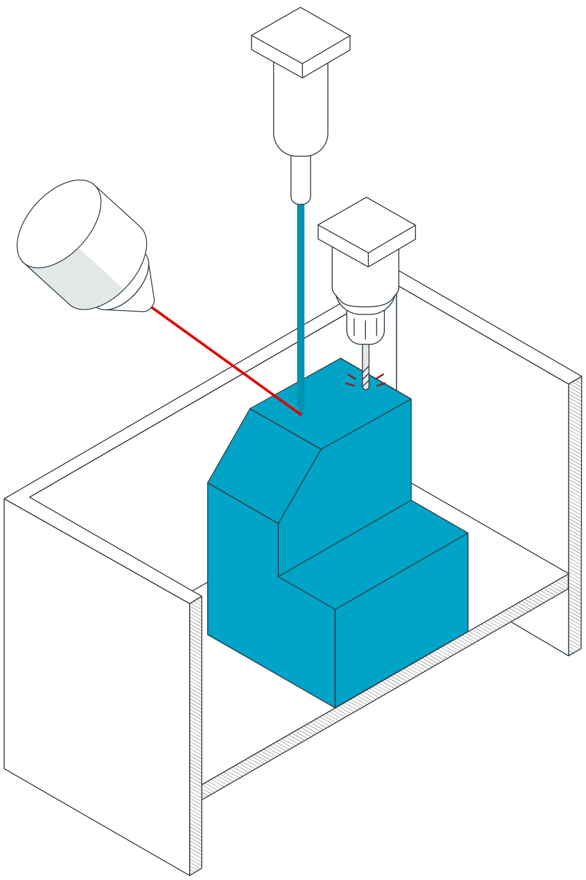
OEMs: Sodick, Matsurra, DMG Mori



Hybrid Direct Energy Deposition (DED)

This hybrid process combines metal directed energy deposition (DED) with subtractive CNC machining. DED feeds metal powder or wire into a focused energy source, typically a laser. It melts the material and deposits it layer by layer to build a three-dimensional structure. DED can be used to make very rough parts quickly. Hybrid DED combines subtractive CNC with the DED process. Unlike the Hybrid Powder-Bed Fusion process, Hybrid DED typically waits until the entire part has been printed (deposited) before machining.

The parts that emerged from the Hybrid DED process have CNC tolerance and surface finish and look identical to machined parts. This hybrid method is commonly used for repair, as you can build onto an existing part.



BENEFITS

- Finished part after printing with tolerances and surface finish suitable for tooling applications
  - General tolerances: CNC tolerances: +/- 0.005”
  - General surface finish: CNC finish (variable): 0.8 um Ra - 25 um Ra
- Can process a wide spectrum of metals, from stainless steel to superalloys, and use low-cost feedstock like welding wire
- Printing modules can be incorporated into existing CNC equipment

LIMITATIONS

- Limited design capabilities since the part is machined after all printing is complete. Parts are limited to CNC design capabilities, conformal cooling channels can’t be machined and are very rough
- High cost of printers and printed parts
- Complex, difficult-to-use process
- Systems may require loose metal powders that require facility modifications like ventilation and extensive PPE to handle
- High risk of the part warping during machining due to residual stress from high heat during printing, often annealing is required after printing to reduce residual stresses
- Machining of hardened materials is time-consuming and requires moving slowly with small cutters to machine the surface finish and tolerance of the printed part
- Parts are attached to the build plate and need to be mechanically removed (sawed or wire EDM) from the plate after printing, adding labor and cost

OEMs: DMG Mori, Meltio, Mazak, Optomec

Mantle TrueShape™

Mantle's TrueShape process is a metal 3D printing approach designed specifically for printing tooling. A hybrid process that combines material extrusion with subtractive machining, TrueShape uses a paste containing metal particles mixed with binder and solvent. This paste can flow without being heated, allowing it to be extruded to build a part layer-by-layer. After each layer is printed, the part is heated and dried to remove the solvent, resulting in a part with a very high green body density (densely packed metal powder). Every layer of the print is machined to refine the surface finish and tolerances and to add features that couldn't be directly printed. After printing and machining, the part is placed in Mantle's high-temperature furnace for sintering. Since the part has a high green body density and very little binder (the solvent is removed during the drying process), the part shrinks less than 9%, dramatically improving the final part dimensions.

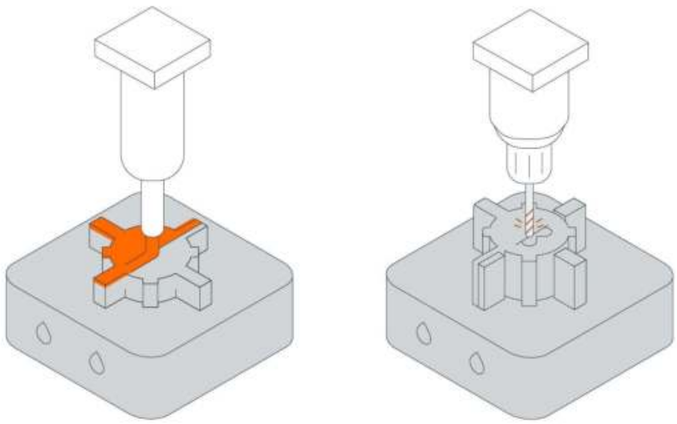
Tools printed with the Mantle TrueShape process require minimal finishing before molding, often just fitting into the mold base and finishing of ejector pins.

BENEFITS

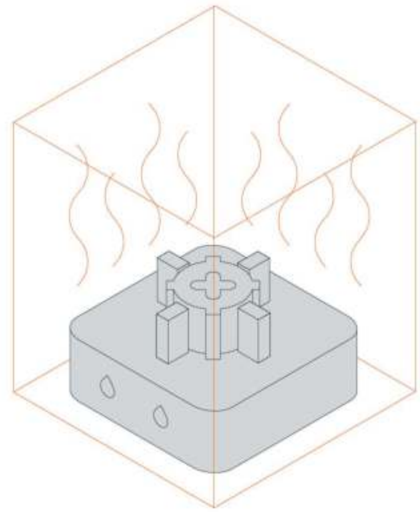
- Produce features that would traditionally be created with sinker EDM. The TrueShape process uses cutting tools as small as 0.006" to machine every layer, allowing it to produce sharp, deep features that would only be possible with the sinker EDM process.
- Produces highly accurate parts with a surface finish suitable for most tooling applications with no additional finishing to feature details
  - General tolerances: +/- 0.001" per inch (for a 4" part, +/- 0.004")
  - General surface finish: 1-3 Ra um / D2 / Charmilles 26
- Industry-standard materials:
  - H13 achieves 42 HRC after sinter, 52HRC post heat treatment
  - P20
  - 420 SS
- Low cost system and printed parts
- Greatly reduces the lead time to produce tooling that is ready for molding
- Can produce complex conformal cooling/heating channels
- When needed, the printed part can be post-processed using standard machining equipment and operating procedures
- Parts can be polished to an A2 finish

LIMITATIONS

- Printing speed can be slower due to integration of machining and drying step(s)
- Currently limited to common tooling materials only
- Cannot print on existing blocks of metal



Print and shape refinment in the printer



Sinter to dense tool steel in the furnace

Mantle accelerates product development by simplifying how mold tool components are made. Mantle's TrueShape™ metal 3D printing technology delivers the accuracy, surface finish, and tool steel properties required for demanding tooling applications. Tools made with Mantle's technology have produced millions of parts while reducing tooling lead times and costs. Mantle is headquartered in San Francisco, California. To learn more, visit mantle3d.com.

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Summary:

Until recently, metal 3D printing has been used in a relatively small percentage of tools. However, as printing technologies evolve, additive manufacturing can be adopted more broadly to reduce cycle time, lead time, and cost for prototype and production tools. Additive manufacturing is becoming a viable resource in a mold maker's toolbox, just like CNC machining and EDM burning have been.

	Powder Bed Fusion	Binder Jetting	Material Extrusion	Hybrid Powder Bed Fusion	Hybrid Metal DED	Mantle TrueShape
Precision Across a 4" Part	+/- 0.013"	+/- 0.040" to 0.120"	+/- 0.0200"	+/- 0.001" to 0.005"	+/- 0.001" to 0.005"	+/- 0.004"
Surface Finish	6 - 10 um Ra	6 - 10 um Ra	40 um Ra	0.8 - 1.5 um Ra	0.8 - 1.5 um Ra	1 - 3 um Ra
System Cost	$$-$$$$	$$$-$$$$	$	$$$-$$$$	$$-$$$$	$
Ease of Use	Low	Low	High	Low	Low	High
Geometry Freedom	Best	Low Limited by depowdering	Low	Best	Low	Medium
Post Processing	High Significant post processing needed for tooling	High Significant post processing needed for tooling	High Significant post processing needed for tooling	Medium Post processing needed to remove part and address warp	Medium Post processing needed to remove part and address warp	Lowest Little to no post processing needed
Total Production Time	Long Due to post processing time	Long Due to post processing time	Long Due to post processing time	Short Due to lower post processing	Short Due to lower post processing	Short Due to lower post processing

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