The Virtual Foundry
211 S Water St
Stoughton WI 53589, USA
www.thevirtualfoundry.com

How To 3D Print Metal

Filament and pellets for 3D printing mean you can easily – and affordably – print Pure metal, ceramic and glass parts. The materials are Open Architecture – meaning they work in common, off-the-shelf 3D printers. No special hardware required.

Working With Filamet™

Due to its high metal content, Filamet™ will inherently break more easily than standard PLA. Following these instructions will make Filamet™ easy to use.

Spool Placement

- Place the spool so that pull and friction are reduced as much as possible. The filament should come off the spool straight into the feeder. For Direct Drive, this means you simply hang the spool right above the printer. For Bowden fed printers, this means placing the spool next to or under the feeder.
- Use a FilaWarmer to ease the path from spool to printer.
- The metal particles in Filamet™ are surrounded by plastic. This plastic keeps the memory of its shape on the spool. As Filamet™ passes through the warmer, the memory of the Filamet™ is reset and prints with ease. This effect lasts for about 24 hours.
- Caution! Heating the entire spool at once will cause the filament to become extremely brittle. It's important to heat only the single strand as it goes into the printer.
- To report any issues with Filamet™ after trying a Filawarmer, please contact info@thevirtualfoundry.com.

Filawarmer Setup

The Filawarmer warms, strengthens, relaxes, and anneals the filament as it comes off the spool. It comes pre-programmed to the perfect temperature.

Hang the Filawarmer so that the top of the warming tube is at the same level as the spool center hole.

(Purchase a Filawarmer in our Online Store.)

The Best Nozzle

Use a 0.6mm or larger stainless steel nozzle for the following filaments:

- Aluminum 6061 Filamet™
- Amaco 46-D Ceramic Clay Filamet™
- Bronze Filamet™
- Copper Filamet™
- Inconel® 718 Filamet™
- Stainless Steel 17-4 Filamet™
- Stainless Steel 316L Filamet™
- Titanium 64-5 Filamet™
- Zirconium Silicate Ceramic Filamet™

Use a 0.6mm or larger hardened steel nozzle for the following filaments:

- Rapid 3DShield Tungsten Filament
- Pyrex® (Borosilicate) Filamet™
- Silicon Carbide Filamet™

Use a 0.8mm or larger hardened steel nozzle for the following filaments:

- High Carbon Iron Filamet™

Printer Heat Settings

Nozzle temperature: Start at 210°C (410°F) and tune in the range of 190-230°C (374/446°F).

Build Plate Preparation

With a glass build plate, apply a layer of glue using a glue stick. To remove the print, wait for the bed to cool and use water and a razor blade or freeze the build plate.

With a powder coated spring steel build plate, no preparation is required.

With a PEI, aluminum, or other build plate type not mentioned, apply a layer of blue painters tape. For easier removal of prints, heat the build plate before removing the print.

Optionally, set the print bed to 40-50°C (104-122°F).

Note: Do not print Filamet™ directly onto PEI. Prints will weld to the build plate.

Printing Tips

Set the flow rate to 135% to start.
For recommended print settings by filament, checkout the technical data sheets.
Note: With heat, our metal filament becomes clay-like. It can be carved, re-sculpted, pieces can be added and seams smoothed.

Debinding and Sintering Filamet

Debinding and Sintering Copper and Bronze Filamet™

Items Needed:

Kiln / Sintering Furnace
Refractory Container (Crucible)
Sintering Refractory Ballast: Al_2O_3 & Talc
Sintering Carbon

Pack:

BC1: Place Al_2O_3 refractory in the crucible
BC2: Bury the print in the Al_2O_3, centered in the crucible
BC3: Tamp down and pat the sides of the crucible
BC4: Part should be surrounded by refractory
BC5: Keep at least 15mm between the part and the crucible walls and top of refractory
BC6: Put the crucible in the kiln

Debind:

BC7: Ramp furnace at a rate of 55.6°C (100°F) per hour to 482°C (900°F)
BC8: Hold at 482°C (900°F) for 4 hours*
BC9: Let furnace cool to room temperature

Debinding and Sintering Stainless Steel 316L, Stainless Steel 17-4, and Inconel® 718 Filamet™

Items Needed:

Kiln / Sintering Furnace
Refractory Container (Crucible)
Sintering Refractory Ballast: Steel Blend
Sintering Carbon

Pack:

S1: Place Steel Blend refractory in crucible
S2: Bury the print in the Steel Blend
S3: Tamp down, don't pack or smoosh
S4: Leave about 40mm of room on top
S5: Part should be surrounded by refractory
S6: Keep at least 15mm between the part and the crucible walls and top of refractory
S7: Fill that 40mm of room at the top of the crucible with Sintering Carbon
S8: Put the crucible in the kiln

Debind:

S9: Ramp furnace to 204°C (400°F)
S10: Hold at 204°C (400°F) for 2 hours*
S11: Over the course of 2 hours, ramp to 427°C (800°F)

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Apply Sintering Carbon:

BC10: Turn off the kiln and unplug it to cut the power
BC11: Remove the part and refractory from the crucible
BC12: Place Talc refractory in the now empty crucible
BC13: Bury the part in the Talc, centered in the crucible, leaving at least 25mm empty at the top of the crucible
BC14: Tamp down and pat the sides of the crucible
BC15: Part should be surrounded by refractory
BC16: Keep at least 15mm between the part and the crucible walls and top of refractory
BC17: Fill up the whole 25mm of space on the top with the Sintering Carbon
BC18: If possible, place a cover over the crucible – Don't seal it (the cover can be tool wrap, ceramic or kiln paper. It is used to preserve Sintering Carbon.)
BC19: Put the crucible back in the kiln

Sinter:

BC20: Ramp furnace at a rate of 111.1°C (200°F) per hour to the Sinter Temp (chart below)
BC21: Hold at the Sinter Temp for 5 hours

Cool Down:

BC22: Program ends – let furnace cool to room temp from Sinter Temp

S12: Hold at 427°C (800°F) for 2 hours*

Sinter:

S13: Over the course of 1.5 hours, ramp to 593°C (1100°F)
S14: Hold at 593°C (1100°F) for 2 hours*
S15: Over the course of 2 hours, ramp to Sinter Temp (chart below)
S16: Hold at Sinter Temp for 4 hours*

Cool Down:

S17: Over the course of 6 hours, ramp down to 593°C (1100°F) – do not hold
S18: Program ends. Let furnace cool to room temp from 593°C (1100°F)

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	Crucible Type							
	Alumina	Graphite	Stainless Steel	Refractory	Debind Temp	Ramp Time	Sub Sinter Temp	Sinter Temp
Bronze	Recommended	Good	Good	Al_2O_3 & Talc Sintering Carbon	482°C (900°F)	7.635 Hours (Step BC20)	-	885°C (1625°F) (Step BC20)
Copper	Recommended	Good	Good	Al_2O_3 & Talc Sintering Carbon	482°C (900°F)	9.46 Hours (Step BC20)	-	1052°C (1925°F) (Step BC20)
316L	Recommended	Good	X	Steel Blend Sintering Carbon	427°C (800°F)	-	593°C (1100°F) (Step S14)	1260°C (2300°F) (Step S15)
Inconel	Recommended	Good	X	Steel Blend Sintering Carbon	427°C (800°F)	-	593°C (1100°F) (Step S14)	1260°C (2300°F) (Step S15)
17-4	Recommended	Good	X	Steel Blend Sintering Carbon	427°C (800°F)	-	593°C (1100°F) (Step S14)	1232°C (2250°F) (Step S15)

Stainless Steel Crucibles will be used up after a few cycles.
Al2O3 and Steel Blend can be reused for multiple sinter cycles.
Note: Furnaces can vary in temperature by 38°C (100°F) from the furnace readout which can adversely affect results. Test furnace temperature with an independent thermometer.
No sintering support is available for High Carbon Iron, Aluminum 6061, Rapid 3DShield Tungsten and Titanium 64-5 Filamet™ materials. To partner on the development of these processes, contact us.
Aluminum's Oxides pose a challenge in the sintering process and it needs more than just an oxygen-free environment. Aluminum and its alloys can only be effectively sintered in pure nitrogen or in a vacuum. Argon has been used in the past, but can create some bonding issues between particles. There are conditions that aluminum requires depending on the alloy and geometry. Simple aluminum alloys such as 2014 can be sintered in dry nitrogen, but the furnace needs to be tight (-50 dewpoint) and uniform (±1°F) temperature control.
Oxygen is damaging to the metal sintering process. Sintering Carbon is used to combat this. Titanium is extra troublesome because it absorbs oxygen like crazy. It will pull oxygen out of a standard kiln's insulation. Compounding the issue is titanium's reactivity in the presence of oxygen and heat. The solution that we understand today is to use an all-metal kiln and a chamber thoroughly flooded with ultra high-purity argon.
*Hold times listed are ideal for a part that is less than a 25mm cube. Hold longer for larger or very thick parts and/or larger crucibles Experiment with hold times if the parts are not sintered correctly.

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Debinding and Sintering Amaco 46-D, White 25-D, and X-23 Ceramic Clay Filamet™

Items Needed:

Kiln / Sintering Furnace
Refractory Container (Crucible)
Sintering Refractory Ballast: Al_2O_3 or sand

Pack:

CC7: Ramp furnace to 204°C (400°F)
CC8: Hold at 204°C (400°F) for 2 hours*
CC9: Over the course of 2 hours, ramp to 427°C (800°F)
CC10: Hold at 427°C (800°F) for 3 hours*

Sinter:

CC11: Over the course of 4 hours, ramp to the 649°C (1200°F) – do not hold
CC12: Over the course of 5 hours, ramp to 1232°C (2250°F)
CC13: Hold at 1232°C (2250°F) for 4 hours*

Cool Down:

CC14: Program ends – let furnace cool to room temp

Debinding and Sintering Pyrex® (Borosilicate) Filamet™

Items Needed:

Kiln / Sintering Furnace
Refractory Container (Crucible)
Sintering Refractory Ballast: Talc

Pack:

PB1: Place Talc refractory in the crucible
PB2: Bury the print in the Talc
PB3: Tamp down, don't pack or smoosh
PB4: Part should be surrounded by refractory
PB5: Keep at least 15mm between the part and the crucible walls and top of refractory
PB6: Put the crucible in the kiln

Debind:

PB7: Ramp furnace to 204°C (400°F)
PB8: Hold at 204°C (400°F) for 2 hours*

Sinter:

PB9: Over the course of 5 hours, ramp to 843°C (1550°F)
PB10: Hold at 843°C (1550°F) for 3 hours

Cool Down:

PB11: Program ends – let furnace cool to room temp from Sinter Temp

These sintering cycles were developed using the Starter and Pro kiln. Temperatures may vary based on kiln brand and size.
Note: Furnaces can vary in temperature by 38°C (100°F) from the furnace readout which can adversely affect results. Test furnace temperature with an independent thermometer.
No sintering support is available for Zirconium Silicate (Zircopax®) Ceramic Filamet™ material. To partner on the development of this process, contact us.
*Hold times listed are ideal for a part that is less than a 25mm cube. Hold longer for larger or very thick parts and/or larger crucibles Experiment with hold times if the parts are not sintered correctly.

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Sanding and Polishing Your Green Prints

Manipulating Prints

With heat, our metal filament becomes clay-like. It can be carved, re-sculpted, pieces can be added and seams smoothed. Soldering irons or wood burning tools work well for this. For best results, use a tip that won't be used for soldering/wood burning and set the temperature to 200-235°C (392-455°F).

How To Avoid Melting When Sanding Metal FIlament

Important! Constant movement to different areas of the part is necessary when sanding to avoid unintentional melting. Experimenting is worthwhile.

Needle File

To make print lines vanish, sand the surface even. The loose particles from sanding are smashed into the print line gaps with the heat from the friction, fixing them in place. This step is complete once the entire print's surface is smooth and even.

Sandpaper or 3M Radial Disc

Start with 120 grit sandpaper or 80 grit 3M Radial Disc, and go over every part of the print. The matte surface will become shiny as finer grits are used. Complete the entire surface of the print before moving to the next grit. The Virtual Foundry recommends using 4 grits with 3M and 6 or 7 grits with sandpaper. A nice shine can be achieved with less, but the mirror shine comes closer to the 7, ending around 3000 grit. After sanding, rub the print down with some flannel or a sunshine cloth to clean off loose particles. A mirror shine should be evident at this phase, even before the last step.

Sewn Buffing Wheel and Zam

Place sewn buff on a rotary tool, then liberally apply zam to the buff and to your print. The print will melt if it gets too hot, so it is critical to keep the buffer moving and continue to apply zam liberally. It may be useful to practice this step on a simple print or a "failed print."

If You Will Be Sintering Your Print

Polishing before sintering is not necessary. Post-sinter, the print will behave as the metal it's made of – file it, weld it, polish it.