Best Practices Guide for Stratasys H350 3D Printer

A SAF Selective Absorption Fusion Powered Product

Best Practice

stratasys

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About this Guide

As with other manufacturing techniques, the 3D printing process can be challenging and demands a level of expertise and familiarization.

This guide aims to help designers produce quality and cost-effective parts on the Stratasys® H350™ 3D printer. The guide provides information for both new and experienced users.

The topics covered in this guide describe tools and methods for optimizing design features, strength, and durability of printed parts, and ensuring that the parts meet your expectations. It provides best practices and tips on designing for additive manufacturing, and examples of how to take advantage of Stratasys unique features to get the most out of your H350 printer, while minimizing printing costs and post-processing issues.

If you have any questions or comments about the way information is presented in this guide, or if you have any suggestions for future editions, please send a message to c-support@stratasys.com.

Additional Resources

Visit the Stratasys Support Center to download the latest revision of this document. This document is also available there in other languages.

Stratasys encourages you to learn more about your printer and its capabilities in real-world settings. A wealth of information is available at the Support Center, your portal to thousands of knowledge assets, including information on design, applications, materials and Web-based training. The site also has links to "how-to" videos and the Stratasys blog.

Another source of 3D printing tips is the Tutorials section of GrabCAD Community.

Design for SAF Technology

SAF™ technology has advantages over other 3D printing technologies because support structures are not required. Overhangs and other features, which may require additional supports in other technologies, are supported by the underlying and surrounding unfused powder.

This offers two significant advantages:

- Complex structures
- 3D Nesting

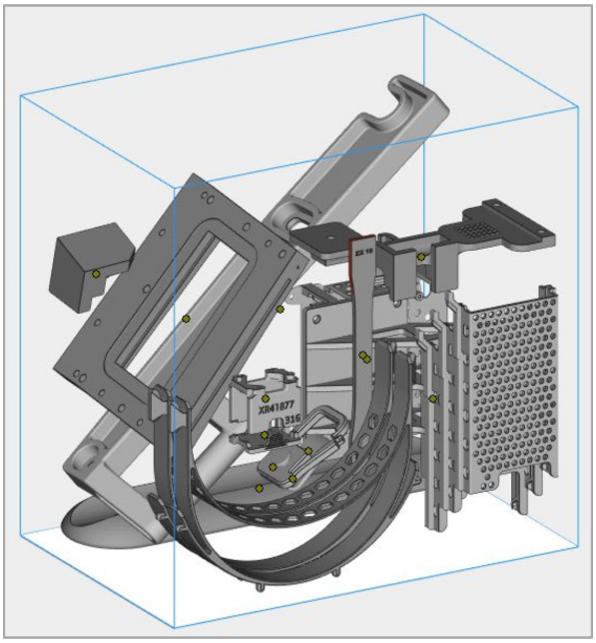


Figure 1: No support structures

Design for SAF Technology

Complex Structures

Parts with lattices or complex internal structures may be built without additional difficulty. An example is the gyroid shown below.

Figure 2: Gyroid

The part shown above has been chemically smoothed and dyed.

SAF technology also allows parts with internal voids, such as manifolds or parts with cooling channels, to be built. However, when building complex structures or parts with internal features, powder removal must be considered.

As the SAF technology self-supports by using unfused powder, parts must be designed appropriately so that any unfused powder can be removed using compressed air or glass media.

Hollow Geometries

Geometries intended to be hollow must not be completely sealed. Otherwise, powder from within will remain inside the completed part. For example, when designing a hollow box, at least one hole must be included in the design so unfused powder can be removed.

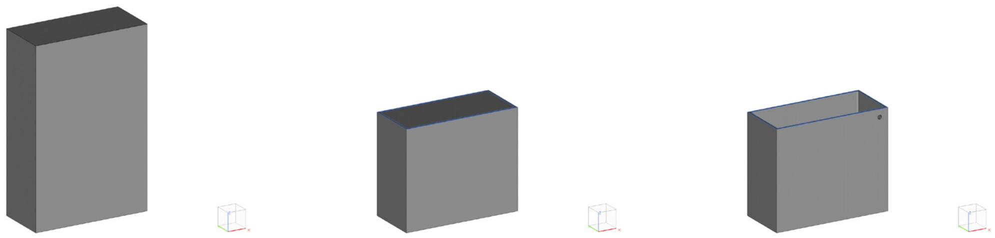


Figure 3: Hollow geometries

Design for SAF Technology

Holes and Negative Features

- Tubes:

  Pay special attention to the width of tubes. If a tube is too narrow, the powder will be difficult to remove. If the tube is large enough, building a removable chain within the tube may help with powder removal. Once removed, the chain will create a channel within the tube through which air or glass beads can flow. This makes powder removal much easier. Typically, once such an airway is established, the powder can be removed.

- Through Holes:

  Powder removal is easier if holes are built using Z as the primary axis. This creates a slight problem as it is not the best orientation for optimum accuracy. It is recommended to build holes with a diameter of at least 1 mm (0.04 in.). If powder cannot be removed by air or glass media, use an appropriately sized drill bit.

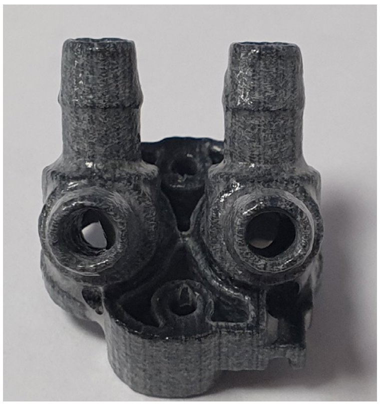


Figure 4: Tubes

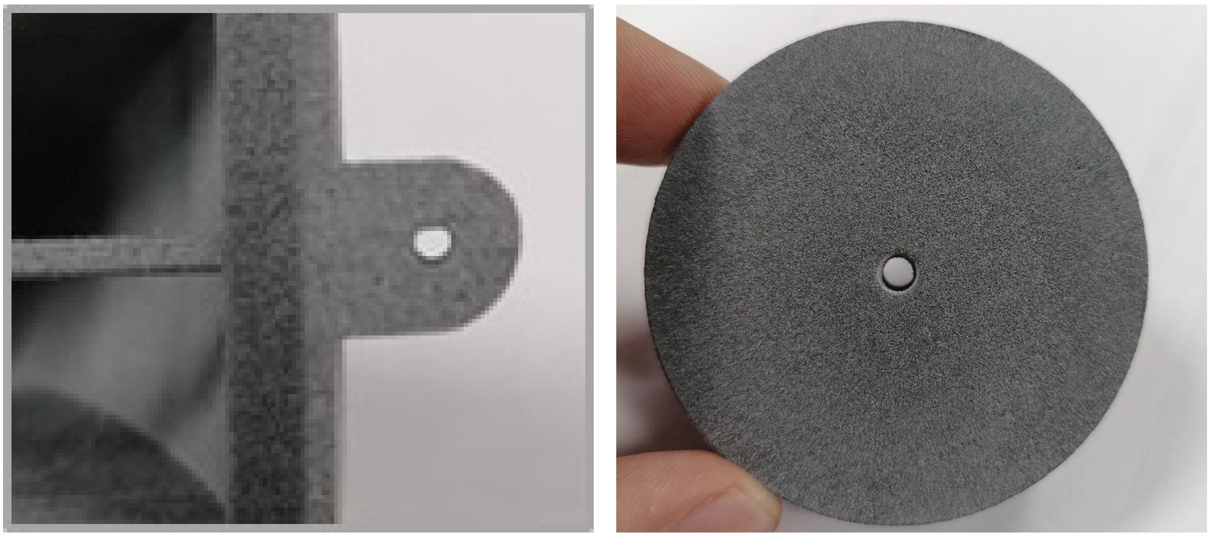


Figure 5: Through holes

Design for SAF Technology

- Blind Holes

  As with through holes, a wider diameter allows for a deeper hole. Powder removal is easier if the primary axis is in the X or Y plane rather than Z. If powder cannot be removed by air or glass media, use an appropriately sized drill bit.

Figure 6: Blind holes

Fine Features

Feature resolution is dependent on the part and geometry; however, the following can act as a guide.

Features such as up-stands and columns can be built as small as 0.5 mm (0.02 in.). The key consideration for such small features, depending on the aspect ratio, is whether or not the powder can be removed without the feature breaking. Although they can be successfully built, small up-stands with a large aspect ratio are very delicate and easily broken. To optimize strength and aesthetics, small features and thin walls should be oriented downward. The width of long walls can be increased to reduce their aspect ratio and make the part more resistant to breaking.

It is important to note that the limiting factor is the powder particle size, not the resolution of the printhead. Average powder particle size is 50 microns. Very small features can be built, but are unlikely to survive unpacking and depowdering.

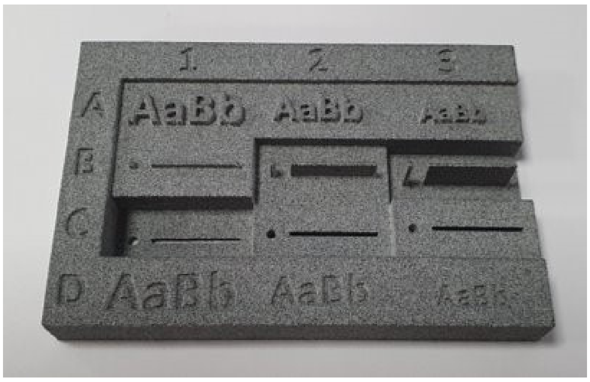


Figure 7: Fine features

Design for SAF **Technology**

Upstands and Columns

Small features such as upstands and columns can be built as small as 0.6 mm (0.024 in.). The recommended minimum wall thickness is 0.6 mm. Pins and upstand should also have a minimum diameter of 0.6 mm (0.024 in.). To avoid a feature breaking while powder is removed, and to optimize strength and aesthetics, small features and thin walls should be placed upside down.

An example of a thin-walled application is ducting:

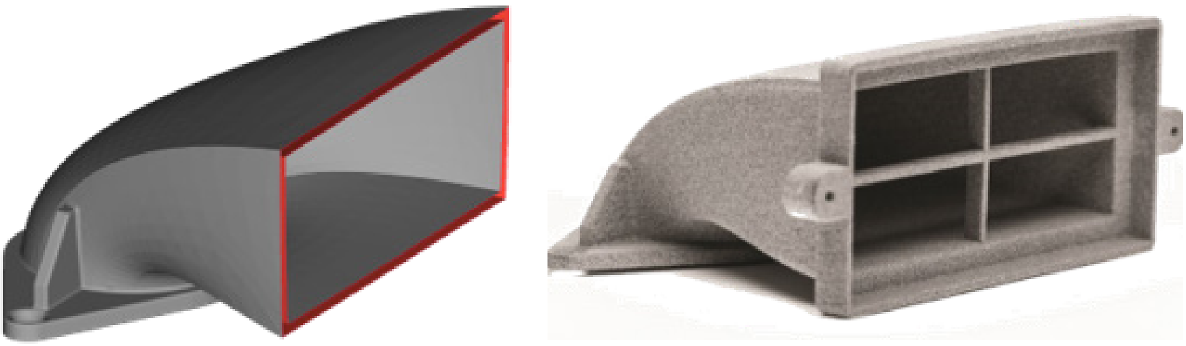


Figure 8: Ducting with thin walls. The cross section highlighted in red is only 1.5 mm (0.59 in.) thick.

Interlocking Parts

It is possible to print interlocking, moving, or assembled parts. However, the individual parts that constitute the assembly must have a gap between them. If two parts interlock, the individual components must have a gap of at least 2 mm (0.079 in.). Otherwise, they will fuse.

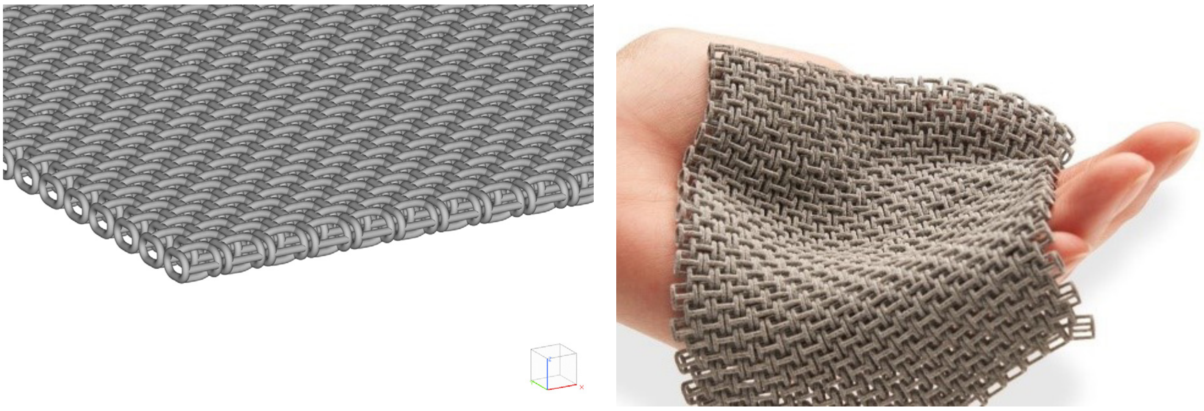


Figure 9: Interlocking parts

Design for SAF Technology

Limits and Fits

The application requirements govern the type of fit. Different fit types require different clearances. Ensure an appropriate clearance between parts so they fit together.

Clearance Fits

The clearance on the 2-piece electrical connector shown below is 0.1 mm.

Figure 10: Electrical connector

This gives an appropriately tight fit when the parts are initially joined together.

Tight fitting parts my loosen over time due to repeated use.

The buckle shown below has a clearance of 0.15 mm (0.006 in.) between the male and female parts.

Figure 11: Buckle

Design for SAF Technology

Cantilevers and Filleting

Features such as up-stands and pins are often prone to breaking at the base. This is because stress is concentrated on sharp features. These stresses can be mitigated by adding fillets as shown below. This is a well-known way to strengthen features that are prone to breaking.

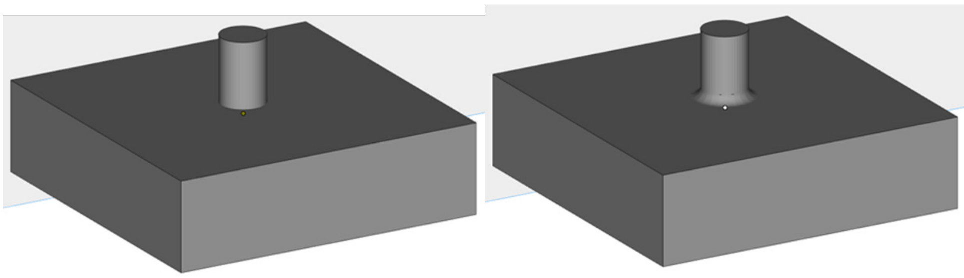


Figure 12: Upstands and fillets

Recommended minimum shaft diameter for 10 mm (0.039 in.) height is 0.75 mm (2.95 in.). Features like this are more robust when built upside down.

Text and Labels

Text or labels that are engraved or embossed may be placed on any surface.

A minimum font size of 8 point and a height or depth of 0.5 mm is recommended. Generally, embossed text has the most clear definition when placed on a downward facing surface.

Engraved text usually looks best on side walls or upward facing surfaces.

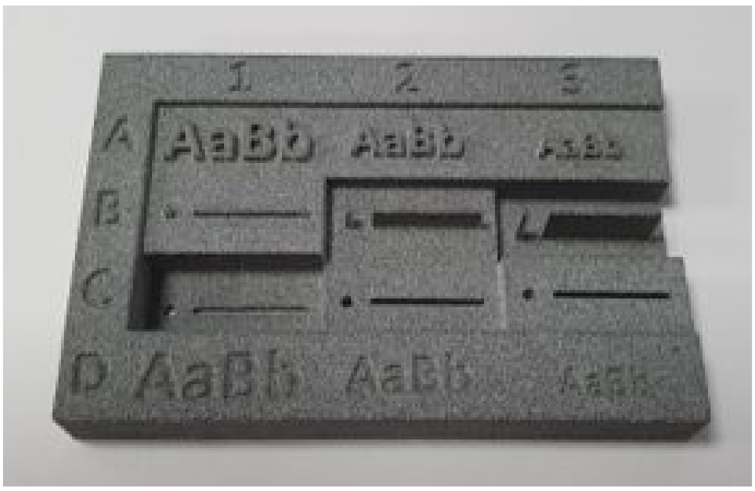


Figure 13: Text and labels

Design for SAF Technology

Screw Threads

The H350 is capable of building integral threads size M4 and larger.

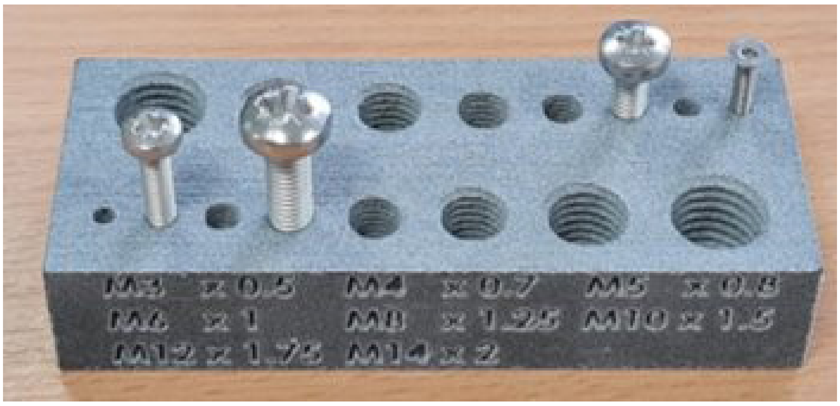


Figure 14: Screw threads

Place threaded features horizontally if possible. Other design considerations, such as changing feature diameter based on print orientation or modifying the applied offset, might be possible if a threaded feature needs to be printed vertically.

Application requirements:

1. Adequate resolution to print the thread.
2. Top face is the most important surface. This is where the text and arrows must be well defined and legible to users.
3. Circularity is important for fit and function.

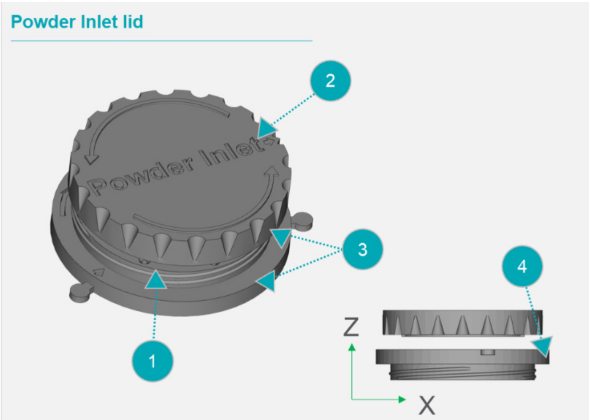


Figure 15: Example

Recommendations:

4. Orient the lid and screw base with the text and arrows face down in the build.

The powder lid and screw base are oriented face down in the build volume. This gives a smooth, even surface with well-defined text and arrows, and results in having the required resolution on the side walls to create a well-defined thread. This orientation also gives the best circularity as printing in the XY plane always results in the part being more circular. The two mating parts are positioned concentrically on top of each other. However, due to the accuracy and repeatability of H350 across the build volume, this is not necessary to ensure both parts screw together.

Design for SAF Technology

For the example at right, the part geometry allows packing at a high nesting density of 22%. This is very high for any powder bed fusion technology and is enabled by the unique thermal control of SAF Technology.

- 624 parts (312 pairs)
- 22% build density
- 274.5 mm (10.8 in.)
- Volume – 4,016cm3 (245 in3)
- Time for printed layers only ~ 9 hours
- Time taken to nest: 15 minutes

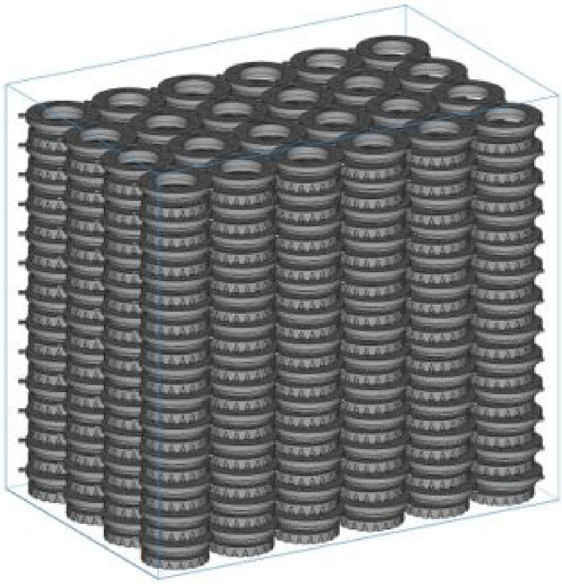


Figure 16: Nested screw base

Fine Feature Example

Feature resolution is part and geometry dependent.

Under certain conditions, it is possible to go beyond the guidelines shown in the zoom image. The item in the zoom image has a 0.4 mm thick wall, 0.4 mm wide fin, and 0.5 mm wide slot.

- Embossed text: Font calibri, bold, 1 mm height, size 14, 11, 8
- Pin: Ø 1 mm, 1, 3, 5 mm tall Fin: 9.5 x 0.4 mm, 1, 3, 5 mm height
- Hole: Ø 1 mm, 1, 3, 5 mm depth Slot: 9.5 x 0.5 mm, 1, 3, 5 mm depth
- Engraved text: Font calibri, bold, 0.5 mm depth, size 14, 11, 8

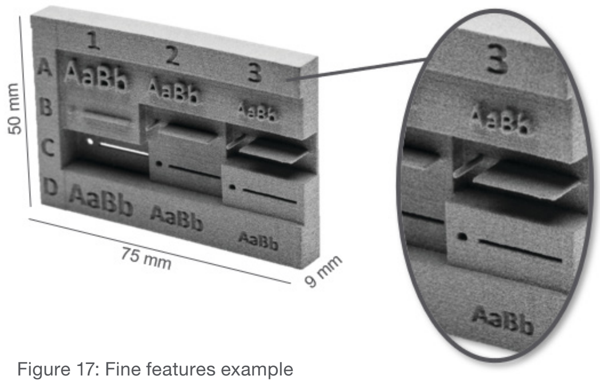


Figure 17: Fine features example

Recommended minimum feature sizes

Minimum font size engraved or embossed ....8 pt

Hole diameter at 5 mm depth.......................... 1 mm

Slot width at 5 mm depth................................ 1 mm

Minimum shaft diameter at 10 mm height .. 0.75 mm

Minimum wall thickness................................. 0.6 mm

Clearance between parts................................ 2 mm

Preprinting Considerations

Nomenclature

It is important to understand axis notation. The H350 axes are:

- X: The axis on which the sleds move back and forth. Left to right from the operators view.
- Y: The axis on which the printheads are oriented. Front to back from the operators view.
- Z: The axis on which the layers are stacked up. Up and down from the operators view.

Bounding Box

The bounding box is the maximum part dimension on each axis, and the bounding box is always rectangular. It is possible to overlap the bounding boxes when nesting parts without the parts colliding.

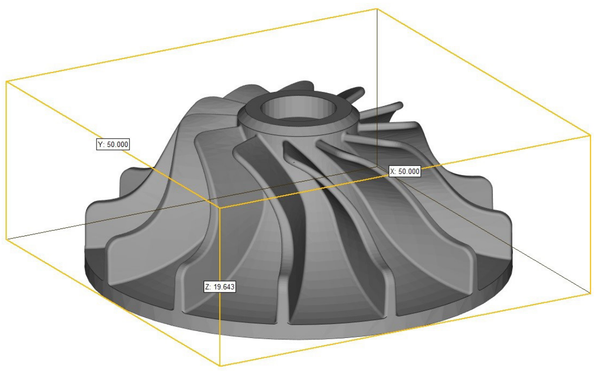


Figure 18: Bounding box

Build Density

Build density is the percentage of the build volume occupied by parts. Therefore, the nesting density is highly dependent upon the type of parts. Using single parts with the same volume as an example, a single solid part will have a higher nesting density than single a hollow part.

- Part volume: 13,435.50 mm3
- Bounding box volume: 49,107.50 mm3
- Relative to the bounding box, this part has a density of 27.4% The same principle is applied to all the parts contained in the build volume.
- Maximum Hot Bounding Box: 315 x 208 x 293 mm
- $Build\ density = \left(\frac{total\ part\ volume}{315 * 208 * build\ height}\right) * 100$

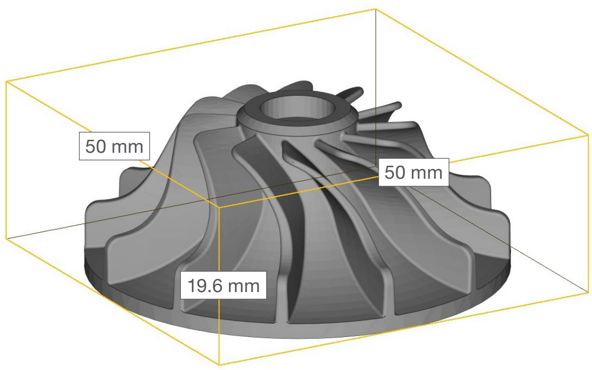


Figure 19: Build density

Preprinting Considerations

Unlike many powder bed fusions systems, the H350 layer time and, therefore, build time is consistent regardless of nesting density. This allows for more reliable processing and cost effective part production using higher nesting densities than other systems allow. Typical nesting density for the H350 is 12%, however, higher nesting can be achieved. Some geometries may not nest to efficiently and this may result in lower nesting densities. If using higher packing densities, please consider that powder recovery may be reduced.

With 180 parts nested, the percentage total of the build volume occupied by part is ~12%.

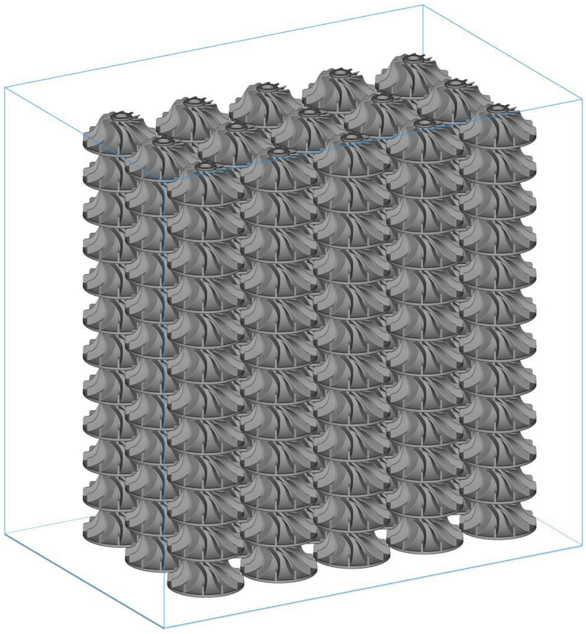


Figure 20: Build density example

Nesting

Nesting is the process of placing parts within the 3D build volume. Although the parts may be built in any orientation, the orientation will influence the aesthetic and geometric accuracy.

Therefore, depending on the part application or requirements, consideration must be given to the orientation in which parts are nested.

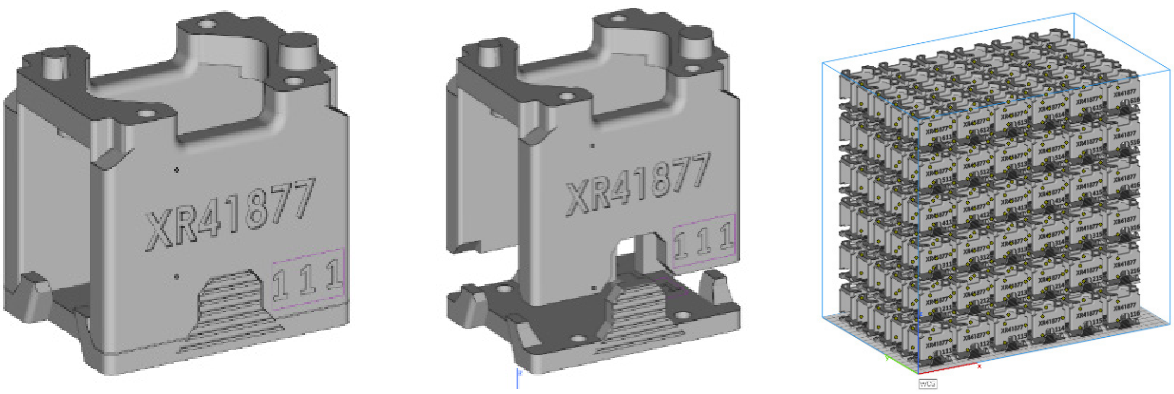


Figure 21: Nested printing

Preprinting Considerations

- Build Density

  The recommended build density is 12% (after scaling); however higher build density can be achieved if parts can be nested appropriately within the powder bed. If using higher build densities, powder recovery may be reduced.

- Gaps

  The gap between small parts should be at least 2 mm (0.08 in.) after scaling. For large, dense parts this gap should be increased as the part mass increases. Large, dense parts should be separated by 5-10 mm (0.2 - 0.4 in.) gaps depending on the part size.

Part Orientation

Aesthetics: surface finish and color uniformity

As with all powder bed fusion technologies, part orientation influences the surface finish and color uniformity. Typically:

- Upfacing: Usually darker and slightly less smooth than downfacing.
- Sidewalls: Often the least smooth and the lightest in color.
- Downfacing: Tend to be the smoothest.

To make sure parts are uniform in color as possible:

- Avoid orienting large flat surfaces in the XY plane.
- Build parts at an angle rather than flat.
- Post-processing such as bead blasting, painting, and dyeing can also be used to make the surface more uniform in color.

Curved and Sharp Features

Downward facing surfaces tend to be smoother than upward facing surfaces.

- Curved surfaces or smooth surfaces are best built oriented facing downward.
- Sharp features have the greatest definition when built oriented upward.

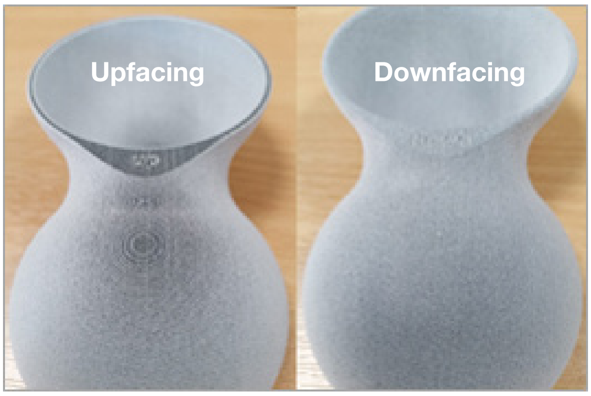


Figure 22: Orientation of features

Preprinting Considerations

Stair Stepping (Build Lines)

Stair stepping may be visible on certain features or geometries. These typically manifest on upward facing surfaces. An example is shown below with the same part built in two different orientations:

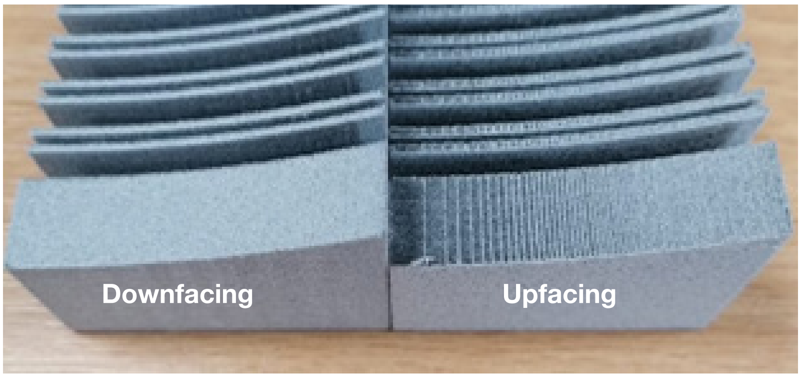


Figure 23: Stair stepping

To avoid stair stepping:

1. For large flat features, it is recommended to avoid angles below 25°.
2. Re-orienting the part often solves the problem.

Preprinting Considerations

Raised Edges

Build jobs with large, flat, upward facing surfaces may have a raised edge around the perimeter. This is due a meniscus effect caused by liquefied powder on the upper surface of the build.

To prevent this, orient the part so the last layers have a reduced cross section. This way, the last printed layer will be a small point rather than a large, flat cross section and therefore have no meniscus.

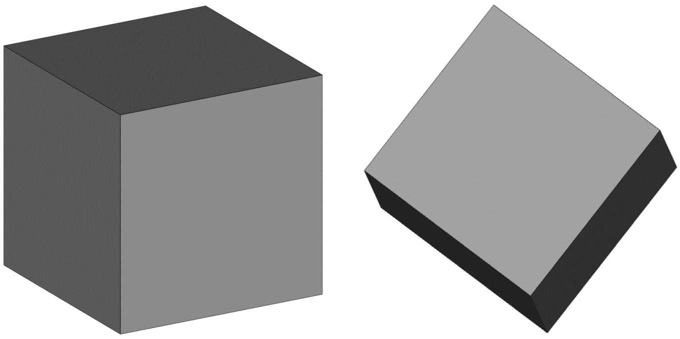


Figure 24: Raised edges (orientation)

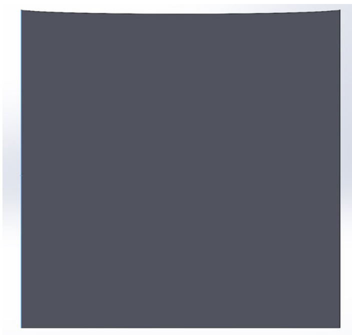


Figure 25: Raised edges (example)

Assemblies

Parts that will be assembled with a push fit, like the avionics case shown velow, should be built on top of each other. This will give the best fit once the part is assembled.

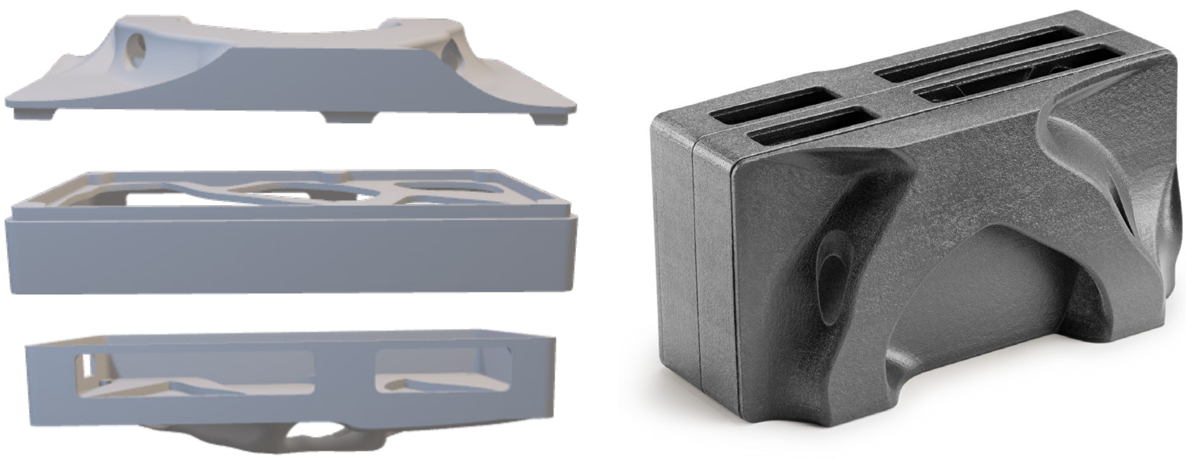


Figure 26: Push fit parts

Preprinting Considerations

Joining Parts

If possible, parts with joining features should be built on top of one another with a gap of

2 mm (0.08 in). The gap refers to the parts themselves and not the bounding box. This will give the best chance of the parts fitting together as intended.

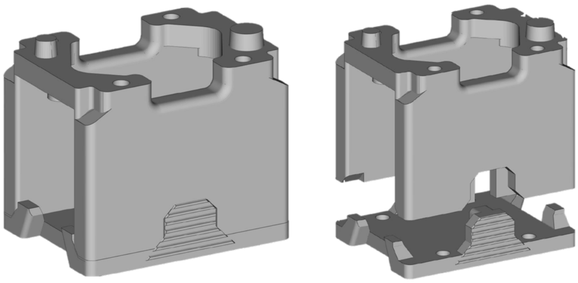


Figure 27: Joining parts

Potential for Warp

Potential for warp is dependent on the material, part geometry, and location within the build. Warp occurs as a result of non-uniform cooling or excessively rapid cooling.

- Material

  PA 11 is particularly prone to warping when compared to PA12. This must be considered when nesting parts.

- Part geometry

  To help mitigate the potential for warp:

  1. With flat/thin parts – increase the thickness of thin walls. Chunky parts are more resistant to thermal stresses induced by non-uniform cooling.
  2. Reduce part mass by hollowing or introducing honeycombs to internal structures.

- Location within the build

  To help mitigate the potential for warp:

  1. Long, flat parts built in the XY plane are particularly prone to warp. 2.Avoid placing the long edge of parts close the edges of the build chamber. 3.Place warp-prone parts towards the center of the build chamber.

Dimensional Accuracy Considerations

When powder is fused into parts, the volume occupied is reduced due to phase transition. This reduction in volume is because the bulk powder does not pack with perfect efficiency.

Therefore, when the powder becomes liquid, the small voids in the bulk powder are removed. This is referred to as shrinkage, and must be considered when preparing the build. This is done by scaling the parts up by an appropriate amount on all axes to ensure the finished part dimensions are as accurate to the CAD as possible.

When the parts are in the liquid phase, they are much hotter than the surrounding powder. This may cause a small amount of surrounding powder to stick or melt into the liquid part resulting in wall growth.

Preprinting Considerations

During this stage, two competing effects are present:

- Shrinkage, which makes the parts smaller
- Wall growth, which makes parts bigger

Both must be correctly compensated for to ensure the final parts are dimensionally accurate.

Dimensional accuracy is typically best in the XY plane. Thus critical dimensions should be built in the XY plane if possible.

1. Overall part accuracy: X and Y dimensions are typically more accurate than Z. Therefore, critical dimensions should be built in the XY plane if possible. For example, hole to hole centers will be more accurate if built flat.
2. Circularity: Holes and other circular features have a higher degree of circularity when built in the XY plane. This contrasts with orientating for optimum powder removal.

Part Hollowing

Large, blocky parts can be built as is, or may be hollowed to make the part lighter. Key considerations:

- Wall thickness (once the part is hollowed) should be at least 2 mm (0.08 in.).
- Powder removal:

A hole should be added so powder from inside the walls can be removed. A single hole will restrict airflow and make powder removal more difficult, so two holes are recommended:

- First: inlet.
- Second: outlet.

Air or glass beads can now be blown into the inlet hole and out of the second.

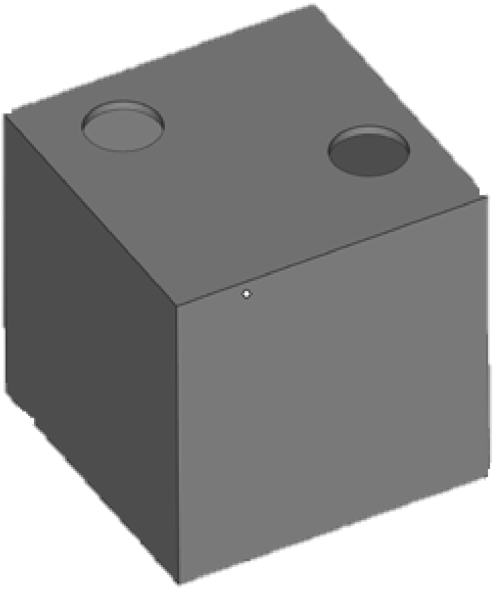


Figure 28: Hollow part

Preprinting Considerations

Using Honeycombs

Honeycombs may be used for large, thick parts as a way to make the part lighter and more material efficient. Reducing surface area may also help reduce warp. As with hollowing, before beginning the build job ensure:

- The honeycombs are large enough so powder can be easily removed.
- An exit hole is present in solid structures.

Using a Fusing Box

When printing many small parts, or parts that comprise an assembly, it may be useful to ensure that these parts are kept together during unpacking and powder removal.

A fusing box can be used to keep parts together or avoid losing small parts during powder removal. The thickness of the box walls and size of the holes can be customized. The box may also be labeled automatically in Magics to identify the parts within.

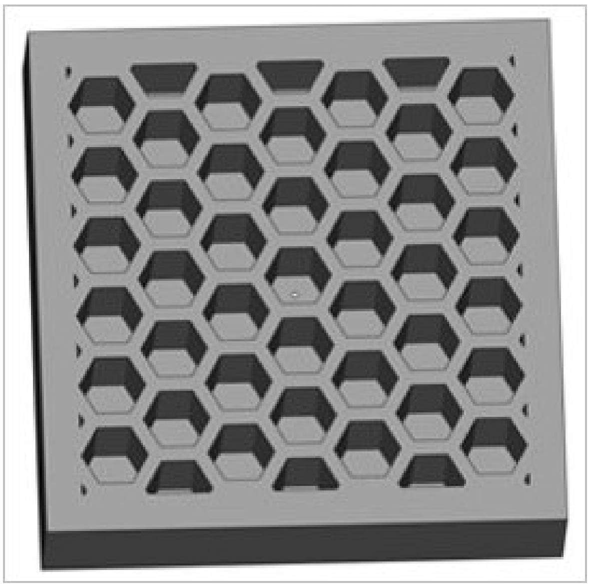


Figure 29: Part using honeycomb exit holes

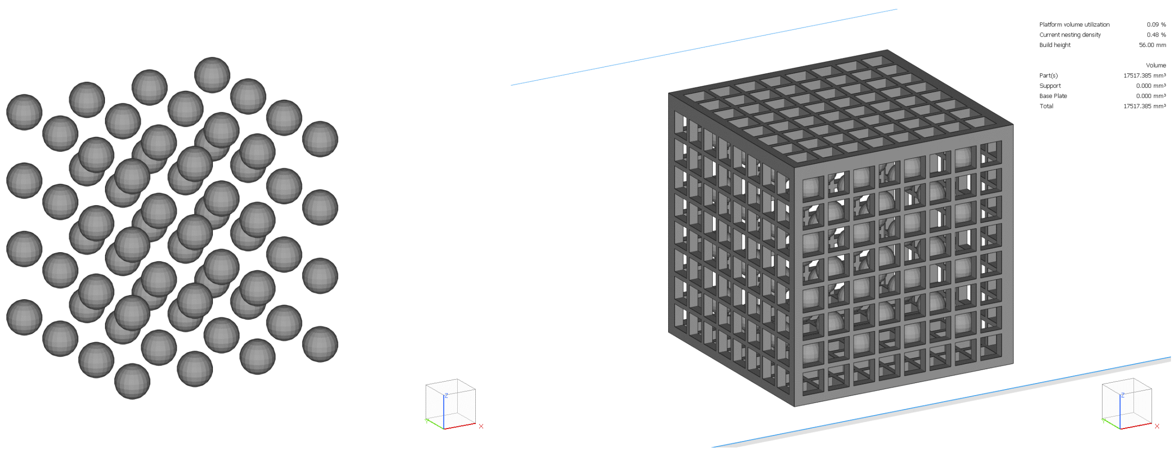


Figure 30: Sinterbox use

Preprinting Considerations

Adjusting Bed Temperature

General Considerations

Surface temperature is a critical process parameter. It plays an important role in determining part properties, aesthetics, and the ease with which the part can be depowdered. Upon installation, a nominal surface temperature is set. The initial setting is intended to give the best balance of mechanical performance, dimensional accuracy, and part aesthetics. As dimensional accuracy compensations are temperature dependent, the default compensations apply to the nominal bed temperature. For optimized dimensional accuracy, build at nominal temperature.

When to adjust surface temperature

If aesthetics or mechanical performance are a higher priority than dimensional accuracy, the temperature may be adjusted within the predetermined range. A small temperature adjustment of only 1° to 2° Celsius can have a significant impact on aesthetics.

It is important to understand the trade-off between aesthetics and mechanical performance. To increase mechanical performance, increase the temperature. For improved aesthetics, decrease temperature.

The table below depicts the benefits and disadvantages:

Lower Temperature Benefits	Higher Temperature Benefits
Improved aesthetics	Improved mechanical performance
Softer part cake	
Lower Temperature Disadvantages	**Higher Temperature Disadvantages**
Reduced mechanical performance	Sub-optimum aesthetics
	Harder part cake

Finishing

Finishing a part depends on the application in which the part will be used. Many parts will not require any further finishing. For the parts that require further finishing, many options are available. Finishing can turn a good part in to a great one.

Figure 31: Various finishes (general image)

Media Blasting

Smoothing the surface with media propelled by compressed air achieves a more homogeneous surface quality. This can be done using a manual bead blaster or in an automated system such as the DyeMansion Powershot S.

Tumbling and Vibratory Finishing

Parts can be tumbled or vibrated with media such as ceramic, plastic, porcelain, or sand. Both tumbling and vibrating give a very smooth surface finish. However, sharp features my become rounded and fine details may be reduced.

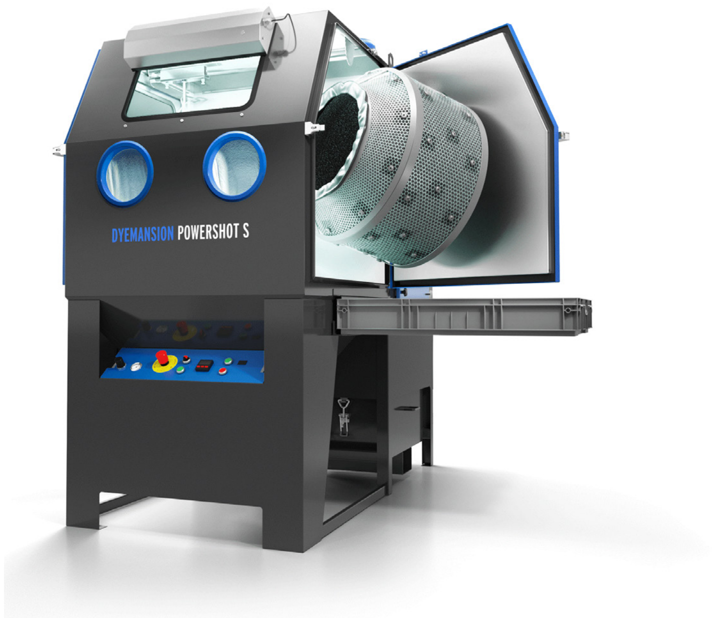


Figure 32: DyeMansion Powershot S

Finishing

Dyeing

Parts may be dyed using commercially available equipment, or they may be dyed using improvised equipment such as a hot water urn or a pressure cooker. If an unfinished part that has not been smoothed is dyed, the final surface will be matte rather than glossy. If a glossy surface is required, the part should be smoothed before dyeing.

A hot a water urn similar to the one in the following image, can be an excellent improvised dyeing tank.

Immerse the parts in the boiling liquid for 30 minutes. After this, the parts can be rinsed and dried. After rinsing, dye residue may be left on the surface of the parts. Remove the residue by wiping with an alcohol wipe.

When dyeing parts, it is important that the part surfaces are clean of any unfused powder, debris, grease, oil, or fingerprints.

Figure 33: Dyeing parts

Figure 34: Hot water urn

Finishing

Another method of dyeing parts is to place the parts in a pressure cooker rather than a hot water urn. This helps the dye penetrate the part surface more effectively. An added benefit is that the resultant color is deeper than the hot water urn method. For example, parts will come out black rather than a dark grey.

When parts are exposed to heat, the process often releases mechanical stresses contained within the part. This can cause parts to warp. Small, boxy parts are more resistant to warping, but big, flat parts are less resistant.

In addition to the manual method described above, off-the-shelf industrial equipment is also available. An example of this is DM60 from DyeMansion:

Figure 35: Dye machine and dyed parts

Finishing

Physio-Chemical Smoothing

Vapor smoothing may be used to prepare the part surface for dyeing or further finishing. Smoothing may reduce the surface roughness Ra value to around 1 micron. This seals the surface, can double elongation at break, and increase impact resistance.

Parts may be smoothed using a physio-chemical processes. Several off-the-shelf commercial products are available.

The PostPro®3D by Additive Manufacturing Technologies™ is a physio-chemical processor that works very well with SAF technology. A physio-chemical non-line-of-sight processor will smooth all part surfaces including the complex internal cavities of polymer parts.

PostPro3D

Unfinished

Smoothed and dyed

Figure 36: Smoothing with a physio-chemical smoother

Smoothing the surfaces of the part is an excellent way to prepare the part for dyeing. Best results are obtained when parts are smoothed before they are dyed.

Unfinished

Dyed

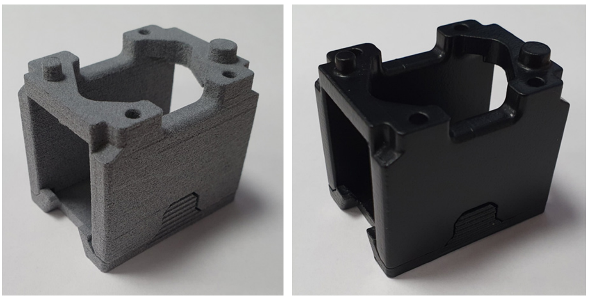
Smoothed and dyed

Figure 37: Smoothing and dyeing

Finishing

Example Applications

- Industrial printhead protective case: This is used in a clean room environment. The surface must be sealed to ensure there is no loose powder.



Natural **Smoothed and Dyed**

Figure 38: Example parts 1

- Hands-free door opener: The surface must be wiped clean before sanding and dying.

Natural **Smoothed and Dyed**

Figure 39: Example parts 2

Finishing

Sanding

If surface texture is rougher than desired, the parts may be smoothed using fine-grit, wet or dry sand paper (or abrasive pads), and lightly sanding the surface.

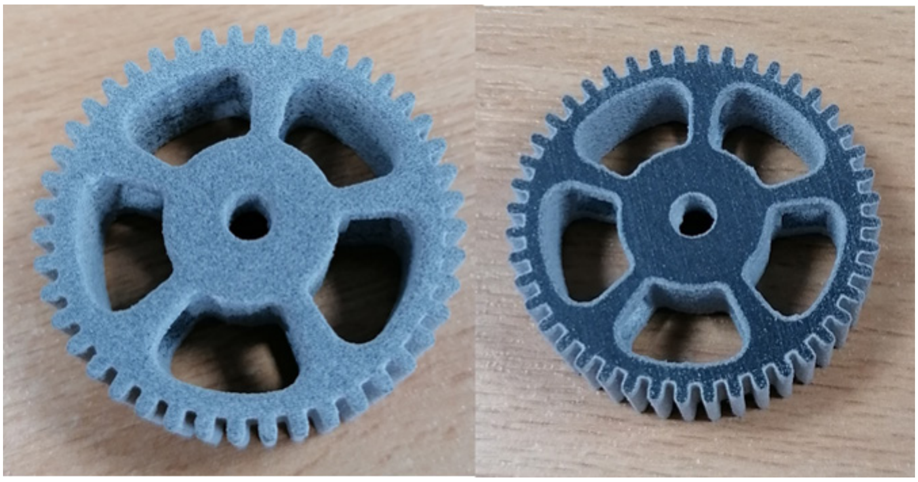


Figure 40: Unsanded vs sanded part

Drilling

If the diameter of a hole is too narrow, increase the diameter by drilling through the current hole with a larger drill bit. Drilling may also be helpful in removing powder from a negative feature.

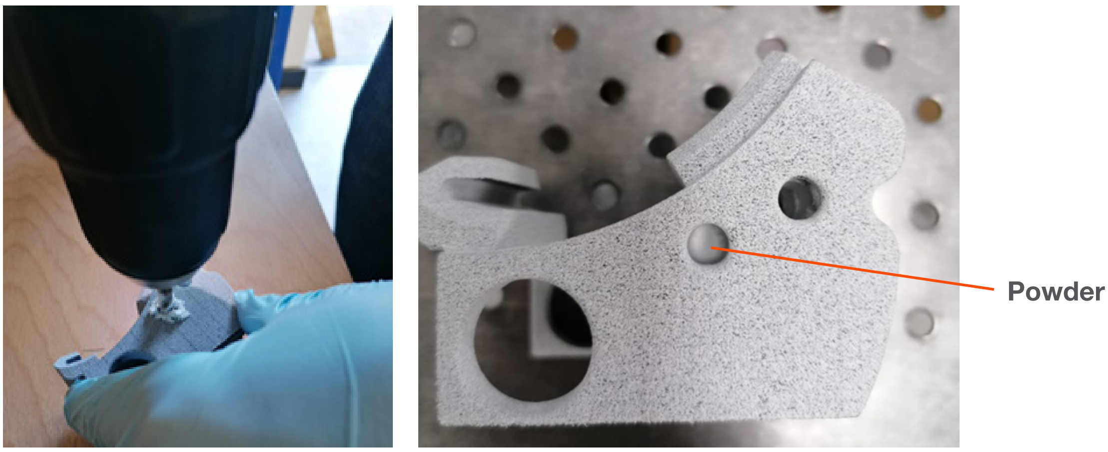


Figure 41: Drilling parts to increase hole diameter and remove powder

Finishing

Painting

Parts may be painted, if required. The example below shows an improvised cardboard spray booth within a well ventilated area.

For complete part coverage, spray paint is a good option. The parts can be suspended on a wire and spray painted.

A primer is not essential but a primed part creates a better bond between the printed part and the paint for a longer lasting finish that is less prone to wear.

For smooth finish, lightly sand the parts between coats.

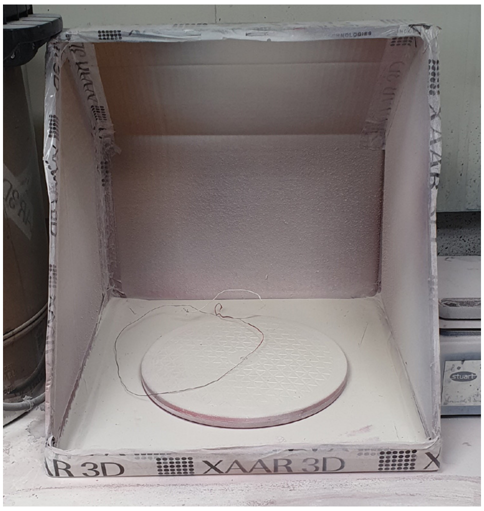


Figure 42: Improvised paint booth

Figure 43: Painted parts

Finishing

Gluing

Parts that are too big to be printed whole may be broken down into smaller sections and printed as pieces. These pieces may then be glued together to create the whole part as originally designed.

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1. Customer acknowledges the contents of this document and that Stratasys parts, materials, and supplies are subject to its standard terms and conditions, available on http://www.stratasys.com/legal/terms-and-conditions-of-sale, which are incorporated herein by reference.

2. The specifications and/or information on which this document is based are subject to change without notice.

3. The information in this guide is merely presented as an aid to the user in understanding how to improve parts. Specific implementations will be dependent on the user requirements as regards part design and materials. The user is responsible for ensuring any third party patent rights in relation to user-developed implementations are respected, and Xaar3d does not provide any form of indemnity or license to any of the techniques described herein.

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