General recommendations for printing processes

Tuning your HP MJF to the design

Introduction

When using HP Multi Jet Fusion (MJF) technology, there are general recommendations to follow to optimize the printing process, keep the printer in top condition, and obtain the desired results.

General considerations

General considerations to keep in mind are as follows:

Equipment

- The operating temperature of the equipment should be between 20°C and 30°C to prevent thermal fluctuations. Going beyond these limits could have adverse effects on part quality.
- The printer's operating relative humidity (RH) should be between 30% and 70% for optimal system usage and performance. Depending on the material, a different operating relative humidity might be necessary for processing. For example, HP 3D HR PA 12 requires relative humidity levels between 50% and 70%. To verify specified environmental conditions, check the material data sheet.
- Power line quality is important. If it is suspected that the power installation at the site will suffer from variability or alterations, it is recommended to install an uninterrupted power supply (UPS) system.
- The set-up altitude should be based on the location of the facility and the printer. A wrong selection could directly affect the cooling system and pressure parameters.
- Read the User Guide to master the key aspects related to cleaning, maintenance, and calibration practices.
- Make sure that the glasses that cover both fusing lamps and the thermal camera are clean.
- Ensure that the printer's thermal control is properly calibrated and meets the following parameters:

  Temperature camera calibration: This calibration is used to compensate for small misplacements of the top tem perature camera sensor. This calibration is only needed for new installations and after thermal camera replacements.

  Fusing lamps calibration: This calibration is used to correct irradiance deviations and obtain the true statuses of the lamps. It is highly recommended to perform this calibration under 40% to 60% relative humidity and to double check the printer's RH readings with an external humidity sensor. This calibration is only needed after a fusing lamp replacement or intensive cleaning of burn spots.
- Some problems may be caused by printhead issues, so it is important to make sure that the printheads are correctly maintained and aligned, and that nozzles are in good condition.
- Even if the printer is perfectly clean and calibrated, it may be necessary to fine-tune the energy provided by the lamps. To do this, the operator can modify the irradiance of the lamps depending on an assessment after printing some control parts. Each print profile requires a specified fusing lamp irradiance. The fusing lamp irradiance value can be checked on the front panel before printing.

Printing profiles and materials

HP Multi Jet Fusion technology allows for the use of different powdered materials, such as HP 3D HR PA 11 ("HP PA 11"), HP 3D HR PA 12 ("HP PA 12"), and HP 3D HR PA 12 Glass Beads ("HP PA 12 GB").

Some materials like HP PA 11 and HP PA 12 can be printed using different print profiles, which are tested sets of parameters aimed toward maximizing specific final properties such as dimensional accuracy, mechanical strength, or part appearance.

There is a relationship—maintained across different current materials—between the energy received by the parts during the printing process and the general consequence of their mechanical properties and appearance, as shown in Figure 1:

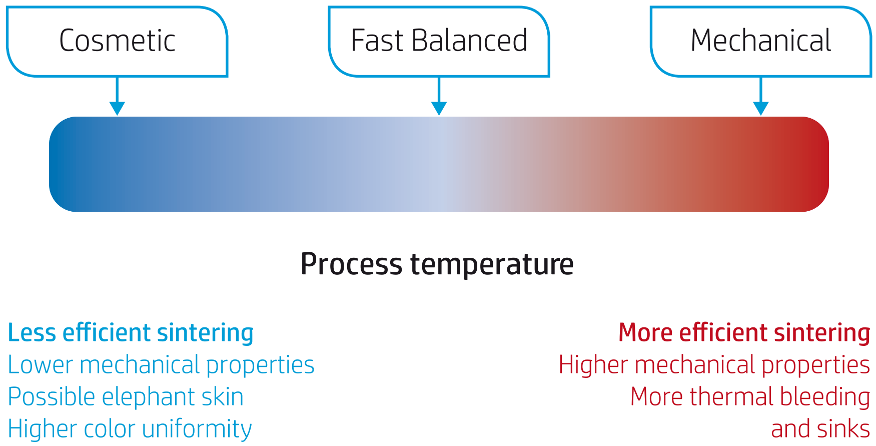


Figure 1. Relationship between process temperature and main part attributes

Thus, the hotter the part, the greater the sintering of the powder, leading to denser parts with stronger properties. However, excessive heat can result in adjacent powder sticking to the surface of the parts (thermal bleeding) and contraction-related artifacts such as sinks.

On the colder side of the spectrum, these effects are minimized, thus improving the overall look of the parts at the expense of mechanical performance and localized non-homogeneous shrinkage.

Print profiles are placed on the scale as a guideline, but their exact position would be determined by their fine-tuning potentiality. Fine-tuning is required to center these print profiles at the optimum levels according to the specific application.

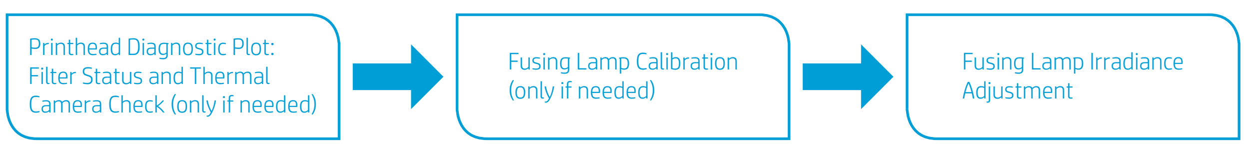


Figure 2. Fine-tuning process

- Extremely high-packing density jobs, non-recommended powder mix ratios, and poor system maintenance may lead to some part quality issues.
- It is recommended to use balanced print profiles (HP PA 11, HP PA 12, and HP PA 12 GB), which require two passes per layer, for a compromise between look and feel, dimensional accuracy, and mechanical properties. The compromise in dimensional accuracy in HP PA 11 occurs mainly in the Z-direction with respect to HP PA 12.

Balanced print profiles result in greater elongation and impact resistance for HP PA 11 compared with HP PA 12, while HP PA 12 GB provides a higher modulus with lower elongation.

HP PA 12 GB has a single print mode without a specific name, but it must be considered as balanced.

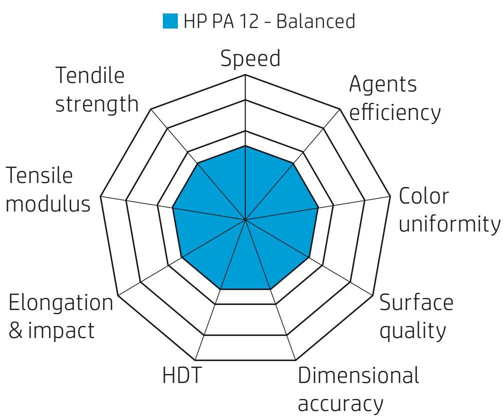
- It is recommended to use mechanical print profiles (HP PA 11 and HP PA 12), which also require two passes per layer, to achieve the best elongation at breakpoints and impact resistance results while maintaining tensile strength, which is not affected with respect to balanced print profiles.

Fast print profiles result in greater elongation and impact resistance for HP PA 11 compared with HP PA 12.

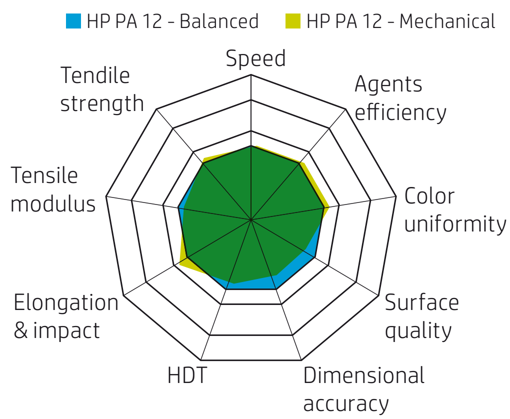
- Fast print profiles (HP PA 11 and HP PA 12) are recommended for reducing time and cost as they use half the number of printing passes as Balanced or Mechanical modes and require a lower volume of fluid agents. In both cases, tensile strength remains comparable to their respective Balanced modes but elongation at breakpoints is lowered, especially in the Z-direction. This trade-off is less pronounced for HP PA 11 than for HP PA 12, since the overall mechanical performance is higher for all HP PA 11 print profiles. Furthermore, the Fast print profile for HP PA 11 generally yields linear accuracy comparable to that of Balanced HP PA 11 but shows reduced warpage.
- The cosmetic print profile is only available for HP PA 12 and aims to reduce the occurrence of geometric artifacts such as sinks on the tops of parts. It requires two passes per layer.

To highlight the differences between the current print profiles and materials, the behavior of their general characteristics is approximated, as shown in Figure 3:

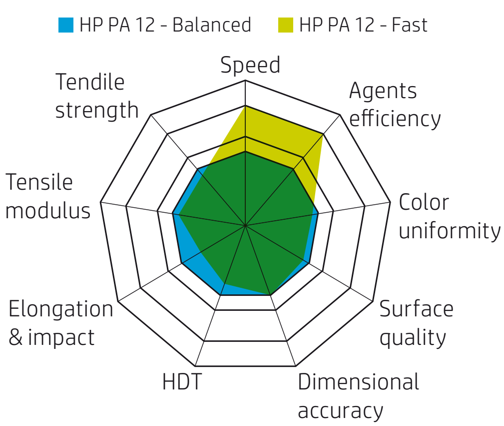
HP PA 12 Balanced print mode



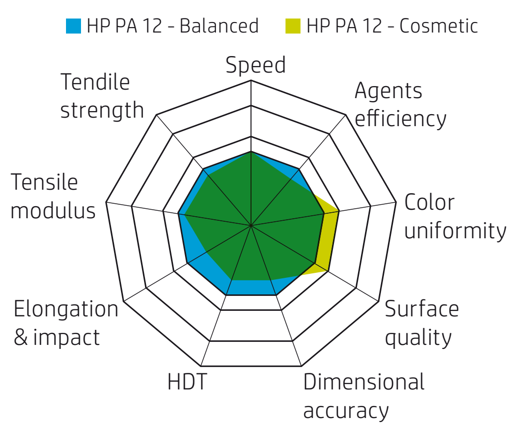
HP PA 12 Mechanical print mode



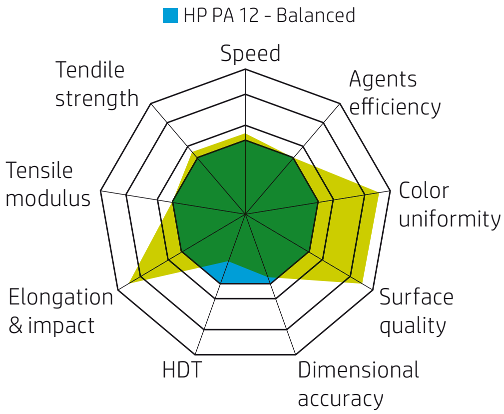
HP PA 12 Fast print mode



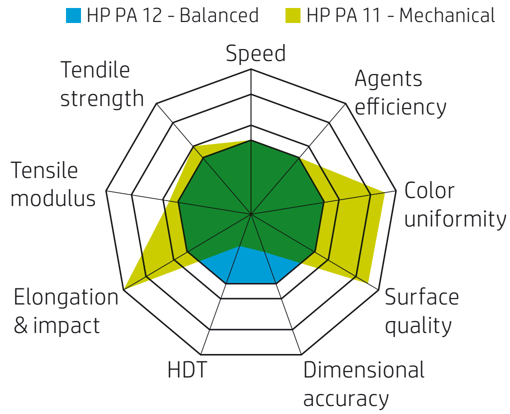
HP PA 12 Cosmetic print mode



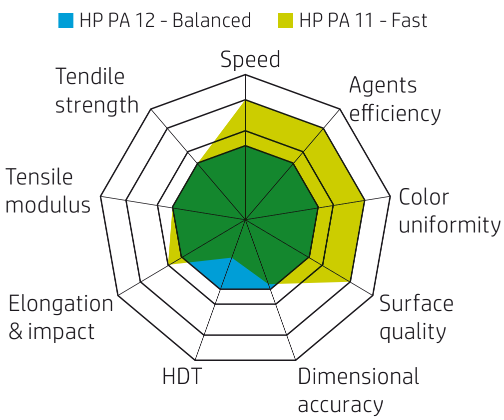
HP PA 11 Balanced print mode



HP PA 11 Mechanical print mode



HP PA 11 Fast print mode



HP PA 12 GB print mode

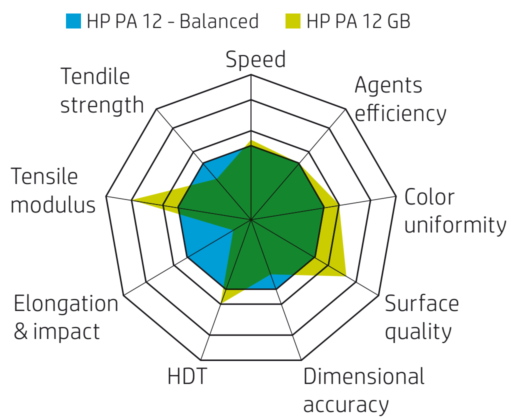


Figure 3. Comparison of the general characteristics of the available print profiles for HP 3D HR PA 11, HP 3D HR PA 12, and HP 3D HR PA 12 GB. Speed refers to the total printing time of a full bucket. Agents efficiency represents the amount of fluid agents used per bucket, with higher values meaning lower consumption. Color Uniformity and Surface Quality are based on representative parts evaluated for known artifacts (e.g., stair-stepping, thermal bleeding, etc.). Dimensional Accuracy refers to the deviation of printed parts with respect to their digital files, combining linear accuracy and shrinkage-related effects. Heat Deflection Temperature (HDT) at 1.82 MPa. Elongation at breakpoints & Impact, Tensile Modulus, and Tensile strength are measured according to international standards

For more information, please visit
hp.com/go/3DMaterials

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Process for Accuracy
Tuning your HP MJF to the design

Introduction

There are several recommendations that must be evaluated during the printing process to maximize accuracy.

Optimizing dimensional accuracy

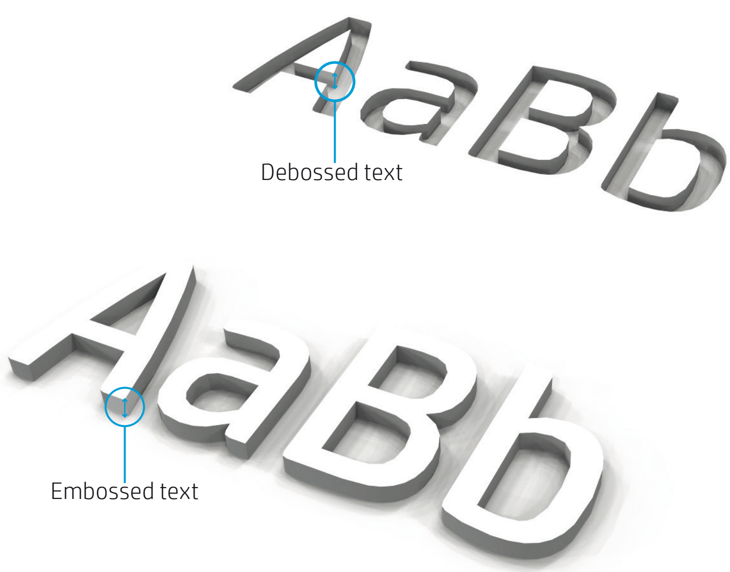
To maximize accuracy, the system needs to operate at voxel level with adequate energy delivered to properly fuse the intended sections layer by layer. To achieve this, it is recommended to bear the following in mind:

Printing profiles and materials

- In general, Balanced print profiles are recommended for optimizing dimensional accuracy. Fast modes (HP 3D HR PA 11 ["HP PA 11"] and HP 3D HR PA 12 ["HP PA 12"]) can be considered lower-cost alternatives, keeping in mind their associated mechanical trade-off.
- In the case of HP PA 11, it is also better to use the Balanced print profile, which is dimensionally similar to HP PA 12 on the XY-plane but has a higher trade-off with respect to the Z-axis.
- When warpage is the main concern, it is recommended to switch from Balanced (HP PA 11) to Fast (HP PA 11).
- With thin and long parts where flatness is critical, consider using HP PA 12 or HP 3D HR PA 12 Glass Beads ("HP PA 12 GB"), since HP PA 11 presents higher warpage potential. If HP PA 11 is the material of choice, then it is recommended to use the Fast print profile.

Build platform placement and printing process

- Orient each part by placing its critical features on the horizontal XY-plane as this will provide the highest resolution.
- Place small features such as pins, holes, and thin walls upside-down on the XY-plane to improve their look, feel, and strength. This also applies to raised texts, which should be printed on the XY-plane for maximum resolution.
- Embossed text, however, results in increased clarity when printed facing upwards.



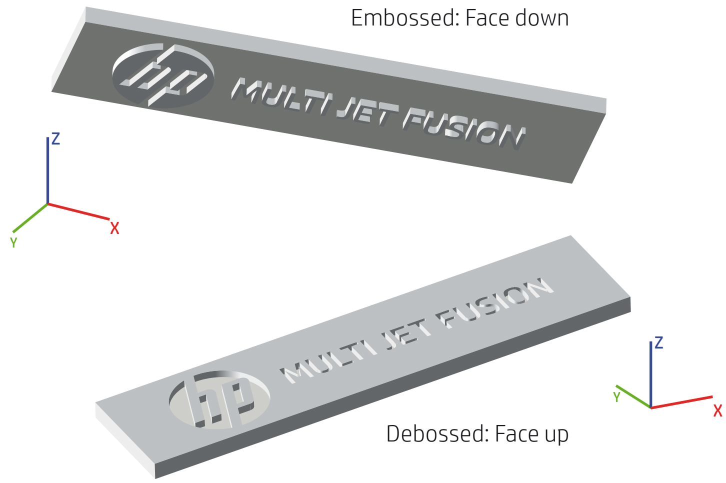


Figure 1. Recommended orientations for embossed (face down) and debossed (face up) text on HP Multi Jet Fusion parts

- The recommended minimum distance between parts is 5 mm, and the ideal distance between parts and the build volume margins is between 10 mm and 20 mm.
- It is recommended to leave enough space between dense parts, or those with a wall thickness greater than 15 mm. This distance should be more than 10 mm.

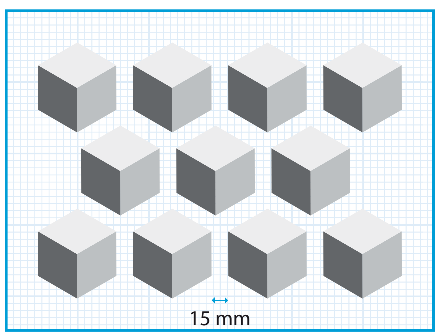


Figure 2. Recommended distance between dense parts

- It is recommended to place the parts with the highest dimensional requirements, especially on the Z-axis, as centered and as low on the printing platform as possible.
- It is recommended to distribute the parts as homogeneously as possible on the XY-plane to facilitate similar energy absorption across the printing bed.

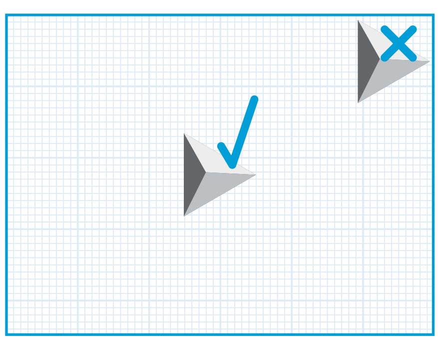
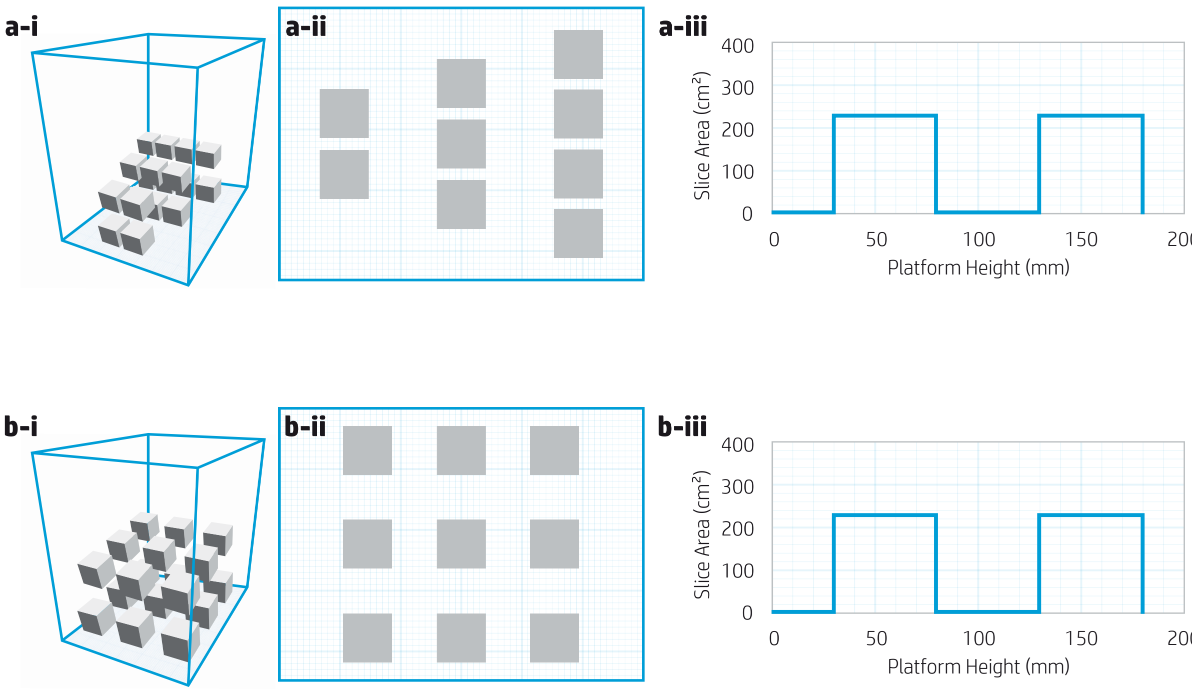


Figure 3. Recommended parts placement

- As well as in the XY-plane, it is recommended to place the parts in the bucket to prevent drastic changes in the printed areas per layer in the Z-direction.

Information about the printed area distribution is provided by some professional suites like Materialise Magics.

- A good compromise between throughput and part quality is a packing density range between 8% and 12%. However, this value can be revisited depending on application requirements.



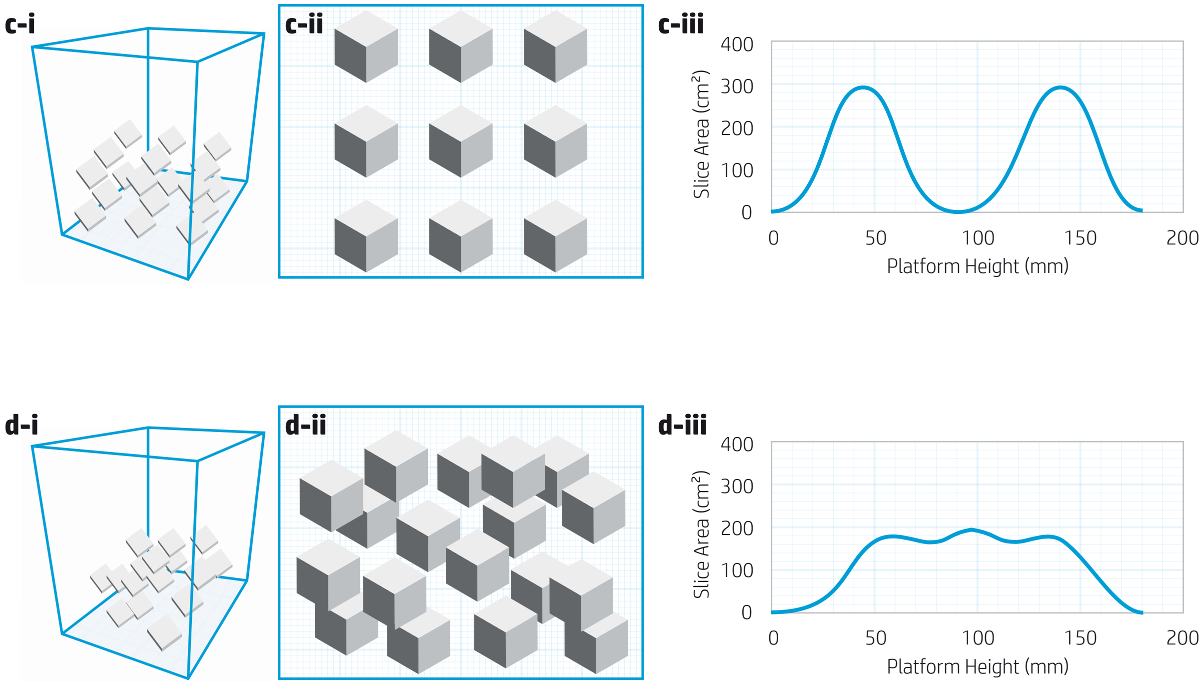


Figure 4. The printed area per layer distribution (right column) is used as an indicator of homogeneity in the Z-direction to prevent big differences in the energy absorption of parts. a) An example of a non-recommended job configuration displaying non-homogeneity in the three dimensions. b) A job that is homogeneous on the XY-plane but with a distinct and potentially problematic gap along the Z-axis. c) The gap along the Z-axis is smoother after rotating the cubes in order to prevent exposing large areas to the last layers to be printed. d) Using automatic packing, the printed area distribution is smoothed even further, minimizing adverse thermal effects. This is a recommended configuration.

Warpage concern

- When warpage is the main concern—especially for large, thin, flat parts—it is recommended to place the parts parallel to the XY-plane.
- Long parts should be placed along the Y-axis to reduce the thermal gradient even further, as this is the printing direction of the carriage.
- When printing parts prone to warpage, it is recommended to place them as centered and as low on the platform as possible. This allows them to cool more slowly, reducing the probability of warpage.
- It is recommended to print short jobs in order to minimize the Z-height—number of layers—which allows for faster printing and cooling stages.
- It is recommended to avoid fast cooling for parts prone to warpage.

Keep in mind that thin polyamide parts are not very stiff, which means that most warped parts can be effortlessly re-shaped once they are mounted in their designated place.

Thermal post-treatments can be applied to conform the material into a different shape after printing, allowing for fine-tuning of finished parts.

Dense parts

Dense parts are those with a substantial mass concentrated in a reduced volume, thus resulting in fewer cavities and walls no thicker than 15 mm to 20 mm.

- Favorable orientation is critical for parts that do not have a homogeneously distributed mass. It is recommended to print them at an angle and not along clear array patterns in order to facilitate heat distribution during printing.
- Make sure that the parts are appropriately separated (> 10-15 mm) and that the packing density does not go beyond the recommended range.

> To decrease packing density, reduce the mass of the objects by hollowing them or adding internal lattices structures.

- High packing density print jobs with dense parts may result in powder deterioration and eventually impact the powder recyclability and, thus, the cost.

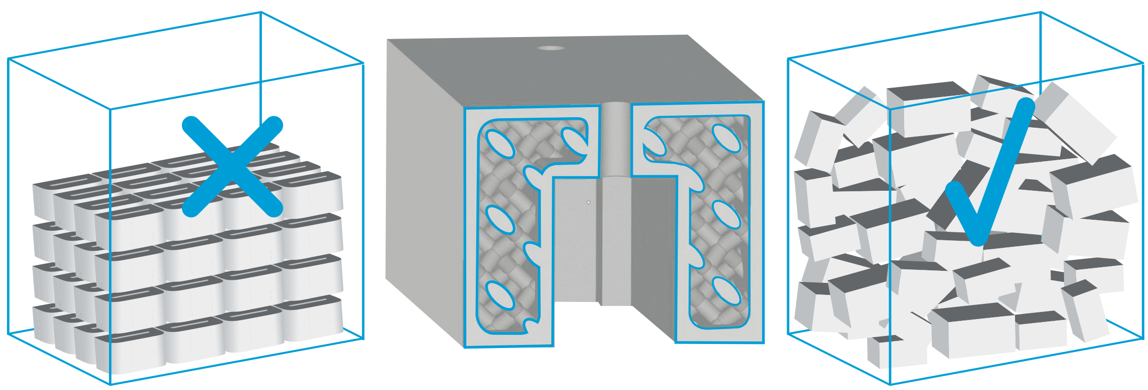


Figure 5. Left: This print job design is not recommended due to excessive packing density, dense parts, array configuration, and flat orientation. Middle: Section of a dense part that has been lightened by applying internal lattices. Right: Recommended print job configuration with lightened parts and increased part separation, tilted orientation, and more degrees of freedom during automatic packing

The recommendations are summarized in the following flowchart, which can be used as a guide for maximizing the dimensional accuracy of HP MJF–printed parts:

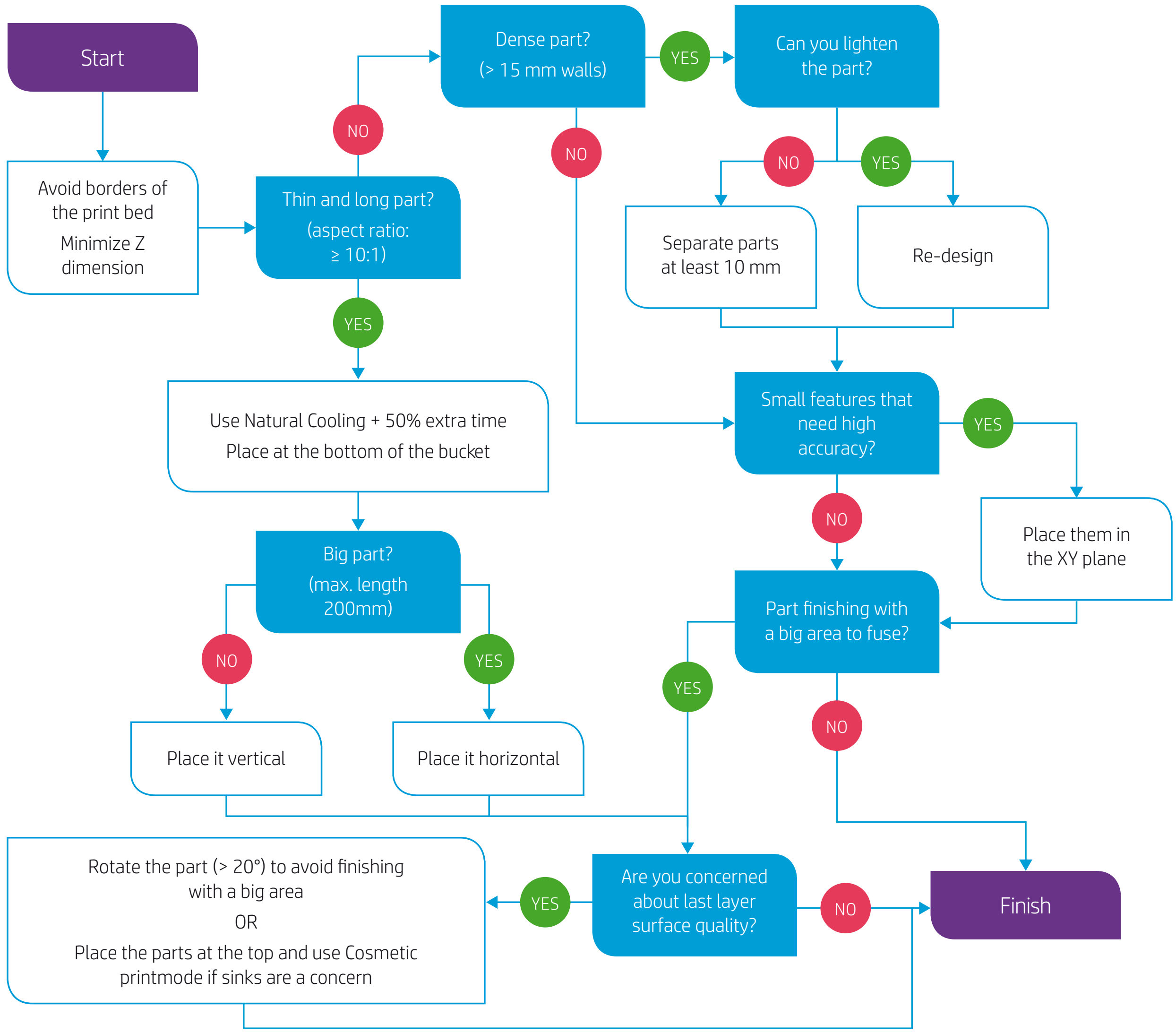


Figure 6. Dimensional accuracy flowchart

Dimensional accuracy examples

Honeycomb plate

The following example involves the printing of a honeycomb plate to maximize dimensional accuracy. This part is very similar to a big, flat plane, and therefore the object is moderately susceptible to experience warpage. However, thanks to its light honeycomb design, this deformation is not expected to be as severe as on a fully dense plate.

To maximize the accuracy and circularity of positioning holes, it is recommended to orient the part so that these features are contained on the XY-plane. This orientation minimizes the height of the part, which is compatible with the recommendations for reducing warpage and bowing.

To preserve the flatness of a part, center it as much as possible on the platform, place it in the lowest quarter, and use Slow Cooling (50% longer than the standard recommendation).

Keep in mind that placing a part flat can induce capillarity on its top face, so angle the part slightly to prevent it if this is more critical than obtaining maximum accuracy of its holes. This trade-off is reduced for HP PA 12 GB and HP PA 11 parts in Fast and Balanced print profiles, which result in similar accuracies with reduced capillarity and abraded tops.

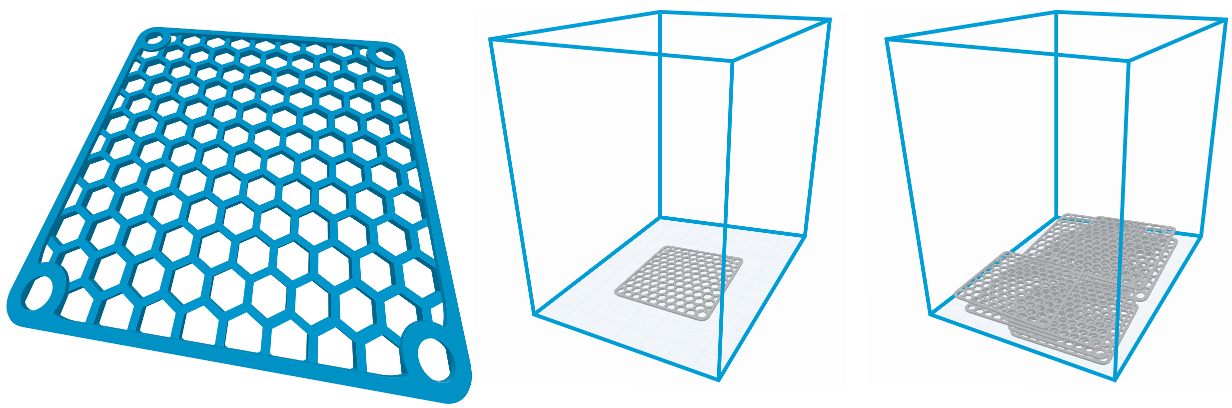


Figure 7. A honeycomb plate (left) oriented to maximize dimensional accuracy and minimize warpage. Critical features such as the positioning holes are contained on the XY-plane (middle). Right: A bucket with 10 plates in the same orientation

As shown in the figure above, in a collective scenario where several plates of this type are required, the following are recommended:

- Print short buckets (using different Build Units).
- Center the parts as much as possible.
- Make sure that a similar number of parts are being printed at each level. In the example there are either two parts or none.
- Shuffle the parts so that they do not line up along the same XY-coordinates. This allows the printing load to be shared across more printheads, extending their lifespans.
- Use extended Natural Cooling.

Phone case

The following example involves a phone case that does not require a great deal of accuracy but can potentially show warpage and bowing if not correctly oriented. This is a flat and thin part that can be considered small, and it is a good candidate for orienting perpendicularly to the XY-plane, laying on its side parallel to the Y-axis.

In this orientation, each layer is printed very quickly while the height is still short enough for the build to maintain thermal homogeneity. To minimize warpage the parts must be placed as centrally as possible, jobs should be short, and Fast Cooling should be avoided.

However, these recommendations apply mainly to HP PA 12, HP PA 12 GB, and the Fast print profile of HP PA 11, as these configurations are not significantly affected by the bowing effect if parts are printed far from the walls.

Mechanical and Balanced modes for HP PA 11 can exhibit incidences of bowing, so it is worth considering an alternative orientation. In these cases, this part should be placed flat on the XY-plane as is the case for bigger objects. The rest of the guidelines, such as using extended Natural Cooling and printing short jobs, still apply.

Figure 8. Left: A phone case to be printed. Middle: The suggested orientation for minimizing warpage when there is a low probability of bowing. Right: An alternative orientation that minimizes the bowing effect while still being a good option for reducing warpage

Process for aesthetic

Tuning your HP MJF technology to the design

Introduction

To maximize the look and feel of parts when 3D printing, it is important to consider the orientation and positioning of the parts in the build platform as well as the specific print profile and material used. It also is advisable to avoid situations wherein these elements are exposed to excessive or non-homogeneous heat during the printing process.

Optimizing look and feel

Printing profiles and materials

- If available for the intended material, consider using the Cosmetic print profile to maximize part look and feel.
- Consider also using HP 3D HR PA 11 ("HP PA 11") in Fast or Balanced print profiles as it results in far fewer part quality defects. HP 3D HR PA 12 Glass Beads ("HP PA 12 GB") also reduces the likelihood of imperfections, but the improvement with respect to HP 3D HR PA 12 (HP PA 12) is less pronounced than with HP PA 11.
- When the focus is on the appearance of the part, do not use Mechanical or non-tuned Balanced print profiles.

Figure 1. Look and feel of two identical parts printed with HP PA 12-Balanced (left) and HP PA 11-Mechanical (right)

Build platform placement and printing process

- Place small features such as pins, holes, and thin walls upside-down on the XY-plane to improve their look, feel, and strength. This also applies to raised texts, which should be printed on the XY-plane for maximum resolution.
- Embossed text, however, results in increased clarity when printed facing upwards.
- It is recommended to avoid upward-facing angles that are smaller than 20° between big, flat areas and the XY-plane.
- Downward-facing surfaces are typically exempt from stair-stepping if they are oriented using angles greater than 5° to 10°.

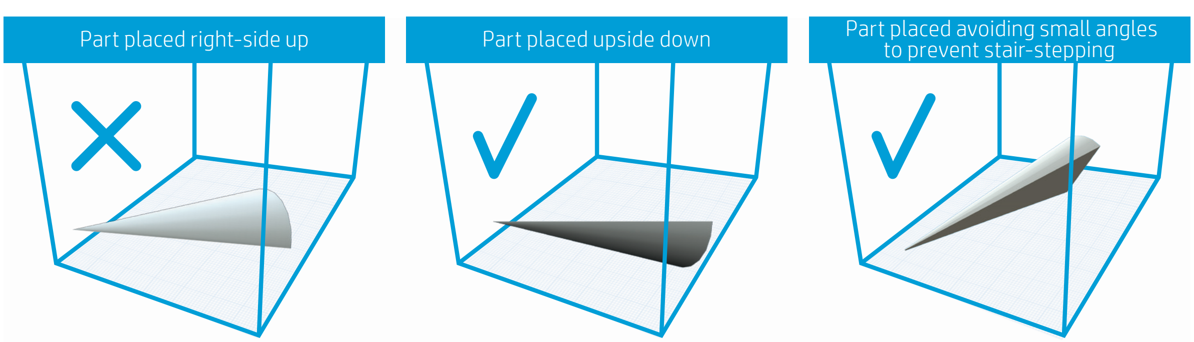


Figure 2. Orientation strategies for parts displaying curved areas to minimize the appearance of excessive layer discretization

- The recommended minimum distance between parts is 5 mm, and the ideal distance between parts and the build volume margins is between 10 mm and 20 mm.
- It is recommended to leave enough space between dense parts, or those with wall thicknesses greater than 15 mm. Normally, this distance separation should be greater than 10 mm.
- Avoid placing dense parts close to the walls of the build chamber as these artifacts mainly affect the last printed layer. Thus, it is recommended to rotate the part so that the top layers have a reduced cross-section, avoiding flat areas as much as possible.
- It is recommended to distribute the parts as homogeneously as possible on the XY-plane to facilitate similar energy absorption across the printing bed.
- Place parts in the bucket to prevent drastic changes in the printed areas per layer in the Z-direction.

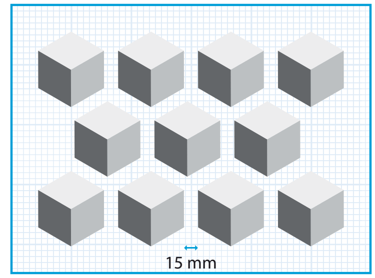


Figure 3. Recommended distance between dense parts

Information regarding the printed area distribution is presented in certain professional software programs, such as Materialise Magics.

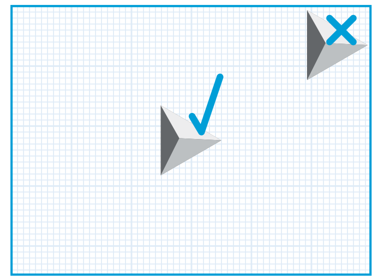


Figure 4. Recommended parts placement

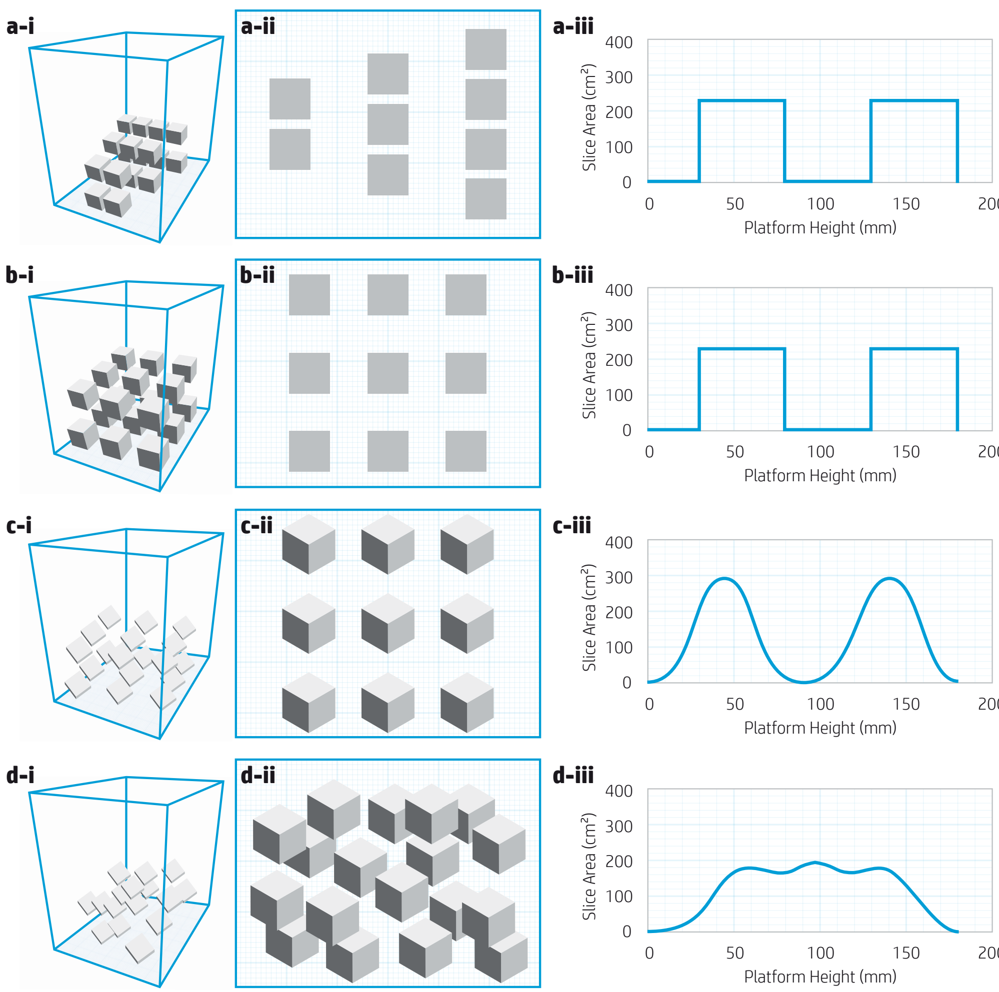


Figure 5. The printed area per layer distribution (right column) is used as an indicator of homogeneity in the Z-direction to prevent major differences in the energy absorption of parts. a) An example of a non-recommended job configuration displaying non-homogeneity in the three dimensions. b) A job that is homogeneous on the XY-plane but with a distinct and potentially problematic gap along the Z-axis. c) The gap along the Z-axis is smoother after rotating the cubes in order to prevent exposing large areas to the last layers to be printed. d) Using automatic packing, the printed area distribution is smoothened even further, minimizing adverse thermal effects. This is a recommended configuration

- Parts prone to displaying sinks or bubbles should be positioned farther away from other parts (approximately >10 mm), especially for objects directly above them (in the Z-direction). Positioning them in the top quarter of the bucket may help to reduce these effects.
- A good compromise between throughput and part quality is a packing density range between 8% and 12%. However, this value can be reassessed depending on application requirements.

The advice provided in this section is summarized in the flowchart (Figure 6), which can be used as a guide to maximize the look and feel of printed parts.

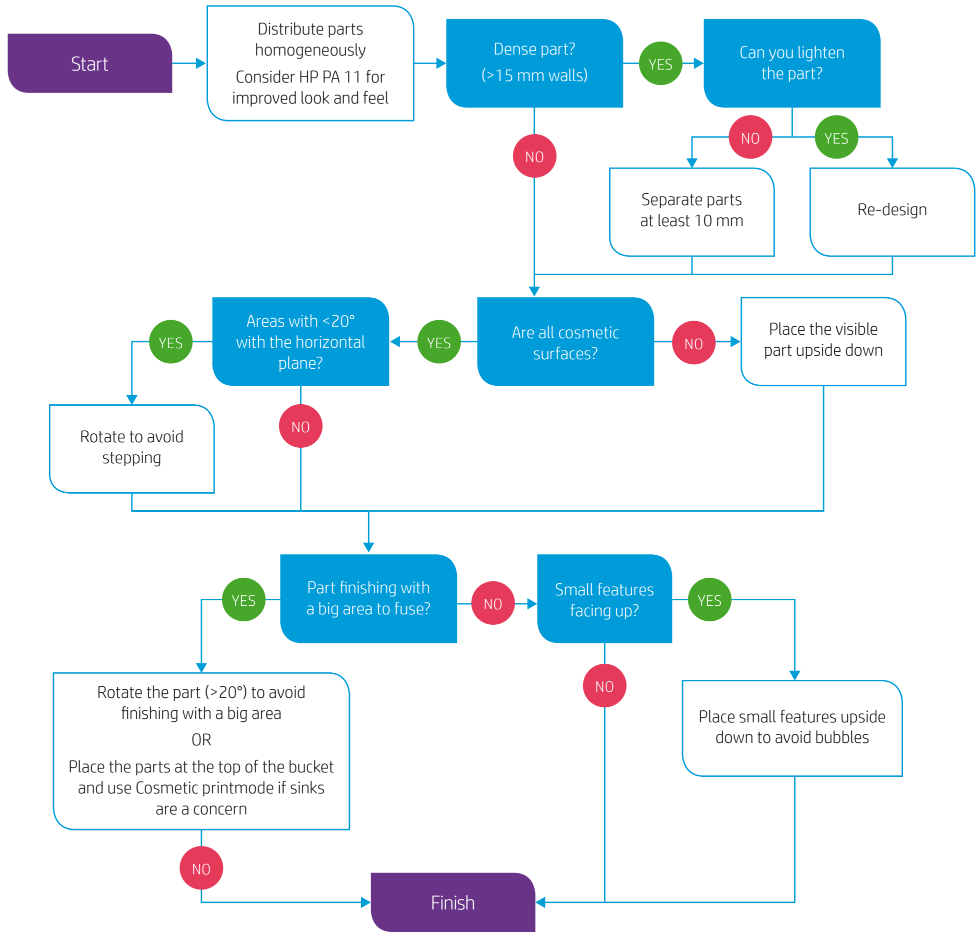
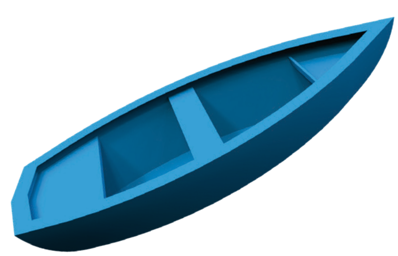


Figure 6. Flowchart for an appropriate process-parameter selection based on the geometry and functionality of a part in order to maximize its look and feel

Aesthetic example

To further illustrate the recommendations provided for cosmetic parts, below is an example involving a toy sailboat:

a



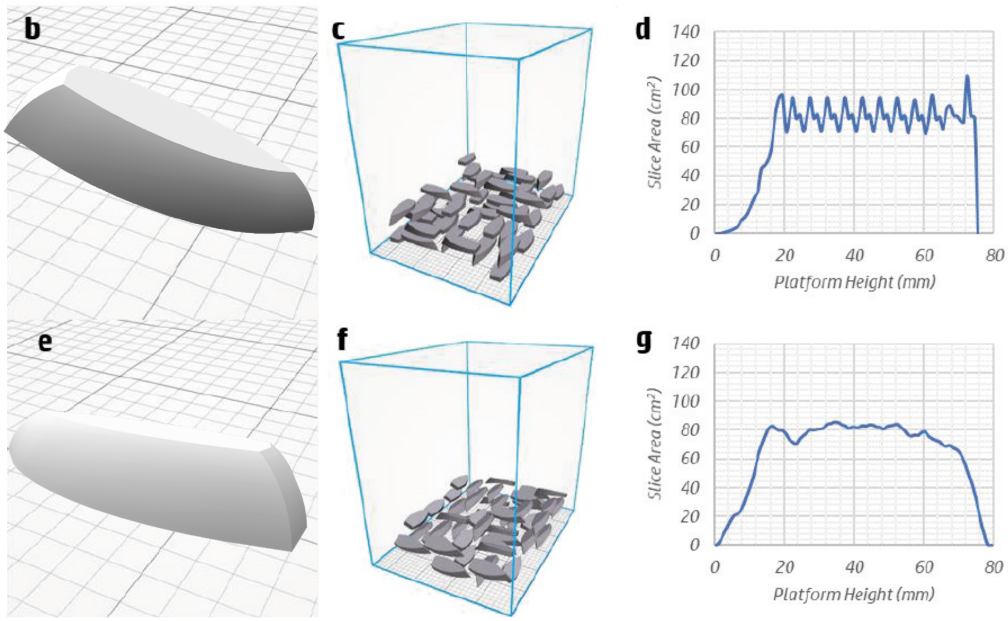


Figure 7. An example of part orientation focusing on maximizing the look and feel of a toy sailboat (a). b-d) Initial orientation stage wherein the part has a large area parallel to the XY-plane, increasing the effect of the artifacts. Fifty parts were placed, allowing rotation around the Z-axis. The area-per-layer distribution fluctuates and ends abruptly. e-g) A boat rotated 25° around its own axis in order to prevent artifacts and excessive layer-stepping. The collective area distribution with 50 boats is smoother than in the previous scenario

Since the most visible area of the object is the inside of the boat, it is clear that the part needs to be placed facing downward to provide a better finish in that section.

A first approach would be to leave it flat, but the printed area distribution of this orientation (especially in the collective case with 50 parts) ends sharply after a maximum peak, which should be avoided in order to minimize surface artifacts such as capillarity, abraded tops, and sinks.

Consequently, the boat should always be angled more than 20° in order to minimize the visibility of the individual layers. This rotation can be performed around a different axis or a combination of them. The rotation axis along the boat's length is chosen to minimize the required Z-dimension printing and smooth the printed area distributed across the many layers.

In terms of the position of the parts in the build chamber, it is best to look for the center of the platform, but there is no significant difference in the result between orienting the parts along the printing axis (X) or re-coating axis (Y). Thus, in the collective scenarios where 50 boats are printed in the same job, rotations around the Z-axis are allowed, which can increase packing density (depending on the geometry of the parts) and, more importantly, helps the required droplets to be shared across the build platform. This homogeneous distribution of the printing load is critical to prevent the over-stress of a small set of dies while leaving others idle for long periods of time.

The orientation advice for this part can be used for HP PA 12, HP PA 12 GB, and HP PA 11. However, since HP PA 11 and HP PA 12 GB typically result in reduced capillarity, a flat orientation could be applied in situations where the accuracy of some features on the XY-plane (like the hole for the sail) are critical or the height of the job is restricted.

Natural Cooling is recommended for all materials, since a faster cooling rate can lead to deviations on the flat areas with respect to their nominal shapes.

Process for mechanical properties

Tuning your HP MJF technology to the design

Introduction

Selecting the proper printing and cooling profile, printing part material, or placing the part in a specific orientation in the build platform are a few ways to maximize the mechanical properties of a 3D-printed part.

Maximizing mechanical properties

There are several considerations that must be evaluated before printing a part in order to increase its mechanical performance:

Printing profiles and materials

- Mechanical and Balanced are the print profiles that yield the best mechanical properties for both HP 3D HR PA 11 ("HP PA 11") and HP 3D HR PA 12 ("HP PA 12") materials, with the former exhibiting better results.
- HP PA 11 provides higher elongation and impact resistance[1] than HP PA 12, while HP 3D HR PA 12 Glass Beads ("HP PA 12 GB") results in higher tensile moduli while reducing elongation and tensile strength.[2]
- Using Cosmetic (HP PA 12) or Fast (HP PA 11 and HP PA 12) print profiles is not recommended for applications with high mechanical requirements.

Build platform placement and printing process

- The recommended minimum distance between parts is 5 mm, and the ideal distance between parts and the build volume margins is 10 mm to 20 mm.
- It is recommended to leave enough space between dense parts, or those with wall thicknesses larger than 15 mm. Normally, this distance should be more than 10 mm.
- In cases where many parts with the same shape are tightly packed with parallel main surfaces, treat them as dense parts and increase the distance between them.

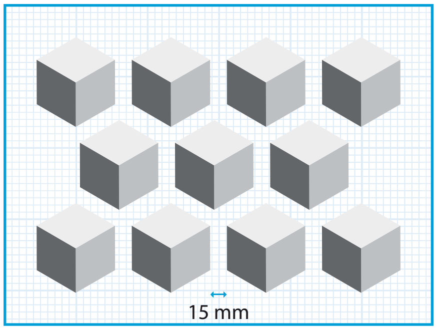


Figure 1. Recommended distance between dense parts

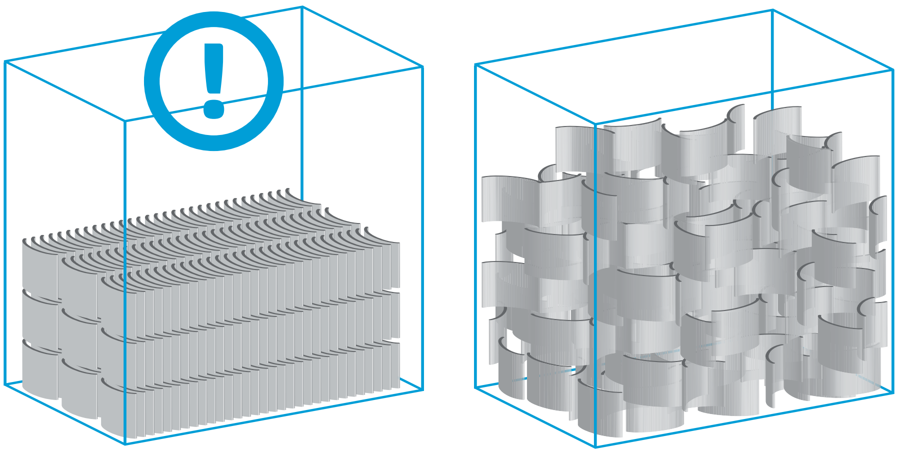


Figure 2. Left: Many parts arranged in a configuration that can result in excess heat. Right: Alternative configuration that increases heat homogeneity and facilitates dissipation, resulting in better results overall

• It is recommended to distribute the parts as homogeneously as possible on the XY-plane to facilitate similar energy absorption across the printing bed.

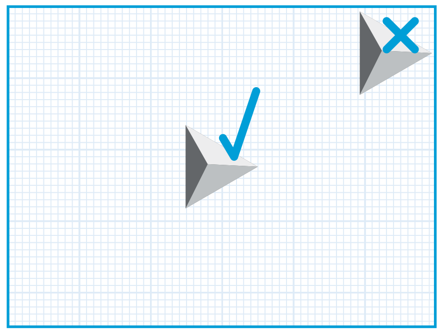


Figure 3. Recommended parts placement

• As well as in the XY-plane, it is recommended to place the parts in the bucket to prevent drastic changes in the printed areas per layer in the Z-direction.

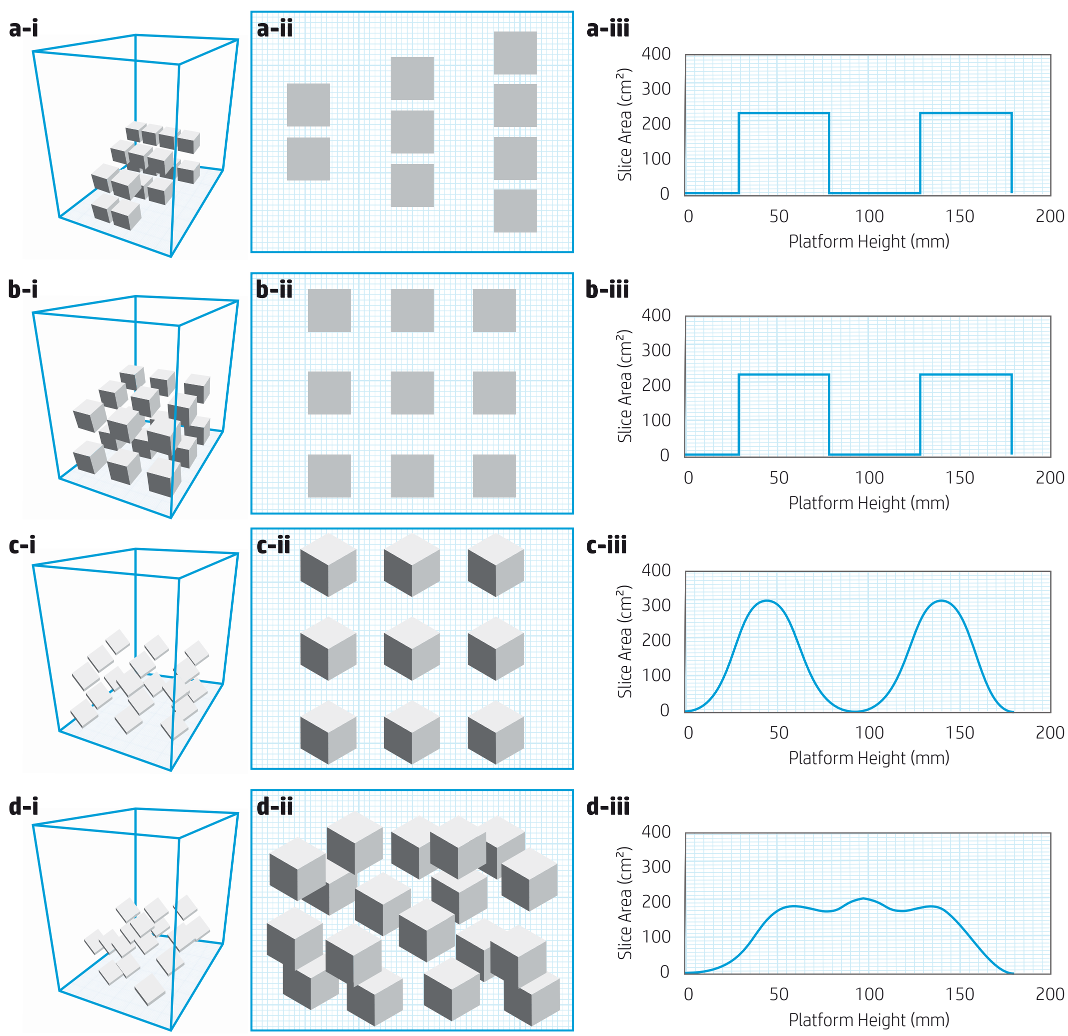


Figure 4. The printed area per layer distribution (right column) is used as an indicator of homogeneity in the Z-direction to prevent major differences in the energy absorption of parts
a) An example of a non-recommended job configuration displaying non-homogeneity in the three dimensions
b) A job that is homogeneous on the XY-plane but with a distinct and potentially problematic gap along the Z-axis
c) The gap along the Z-axis is smoother after rotating the cubes in order to avoid exposing large areas to the last layers to be printed
d) Using automatic packing, the printed area distribution is smoothed even further, minimizing adverse thermal effects. This is a recommended configuration

Information about the printed area distribution is available from professional suites like Materialise Magics.

- When optimizing mechanical properties, a good compromise between throughput and part quality is a packing density range between 8% and 10%.
- Using a low packing density improves the heat management between parts, which increases positive results through homogeneity.
- It is recommended to print short jobs in order to minimize the Z-height—number of layers—which allows for faster printing and cooling stages, and to increase the elongation at breakpoints and impact resistance of parts.
- Fast Cooling has a similar beneficial effect on elongation at breakpoints and impact resistance, but it should not be used for parts prone to warpage. This is especially critical for HP PA 11, which is more prone to warpage.

Mechanical examples

Below is an example of a part orientation for a part that requires increased elongation and impact resistance in its thinner features:

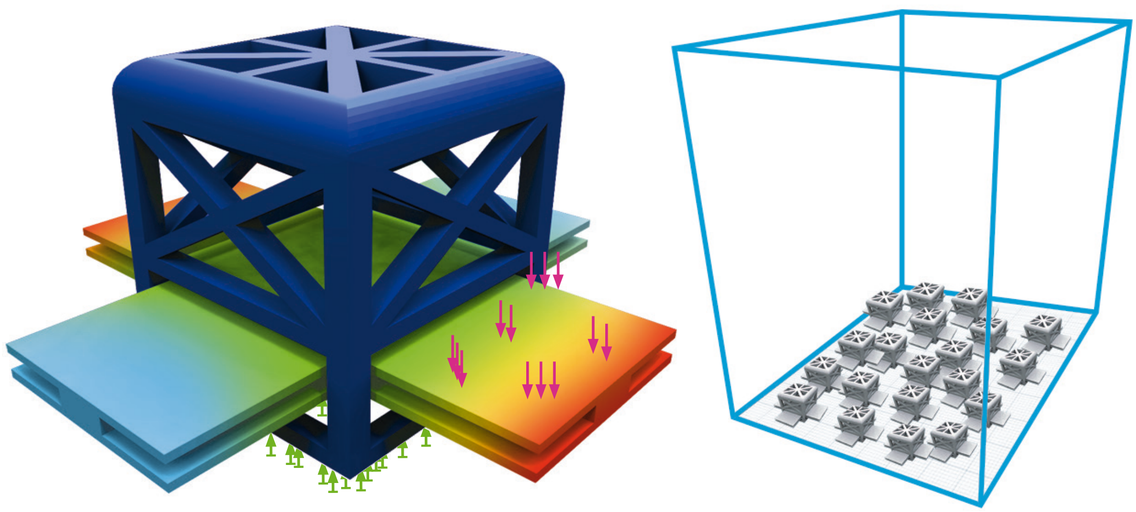


Figure 5. Left: A mechanical part with high elongation requirements on its thinner features
Right: A short bucket containing 20 iterations of the same part

As mentioned previously, process factors such as print profiles, cooling profiles, and job heights are key factors in achieving better mechanical properties.

Thus, to obtain high elongation and impact resistance values, it is recommended to use a Mechanical print profile, to cool the parts as fast as possible, and to print shorter jobs (minimizing Z-height) with low packing densities.

The choice of Mechanical print profiles for both HP PA 11 and in HP PA 12 entails a trade-off in dimensional accuracy. However, this is not an issue for the present application. Similarly, Fast Cooling would most likely induce warpage on thinner features, but their flatness in this case is not as relevant as their elongation, which would be boosted with faster cooling.

In terms of materials, the Mechanical print profile for HP PA 11 would result in higher elongation than its HP PA 12 counterpart, even without using Fast Cooling. HP PA 12 GB would not be a good choice of material for this application since it typically results in stiffer parts that tend to snap rather than bend.

1. Based on internal testing and public data for solutions on market as of April, 2016. Cost analysis based on: standard solution configuration price, supplies price, and maintenance costs recommended by manufacturer. Common cost criteria: using HP 3D High Reusability PA 11 material, and the powder reusability ratio recommended by manufacturer. HP Jet Fusion 3D 4200 Printing Solution average printing cost per part is lower than the average cost of selective laser sintering (SLS) printer solutions from $100,000 to $300,000 USD. Cost criteria: printing 1 build chamber per day/5 days per week over 1 year of 30 cm^3 parts at 10% packing density.

2. Testing according to ASTM D638, ASTM D256, and ASTM D648 using HDT at different loads with a 3D scanner for dimensional stability. Testing monitored using statistical process controls.

4AA7-4238ENW, March 2019

Machining recommendations

Tuning your HP MJF technology to the design

Introduction

HP Multi Jet Fusion (MJF) technology allows for the design and production of accurate parts with small features, complex geometries, and functional assemblies. These advantages can be enhanced by adding complementary post-processes such as machining, especially for applications where very tight tolerances are required such as small threads, bearing housings, or engineering fits.

A machining post-process can add value to the following aspects:

- **Dimensional accuracy:** A standard machining post-process can provide very tight tolerances—up to ±0.05 mm—in a particular area or for a critical feature where high function and tolerance are required.
- **Geometry references:** In addition to dimensional accuracy, a machining post-process can also improve geometric requirements like flatness, concentricity, perpendicularity, or parallelism, reaching very tight tolerances up to ±0.08 mm.
- **Small features:** A machining post-process also allows for the implementation of small features such as small threads, ensuring accurate results.
- **Surface roughness:** By default, the mean surface roughness or roughness average (Ra) of a part that is 3D printed using HP MJF technology is between 8 µm and 12 µm, depending on the face orientation. This surface roughness can be significantly improved with machining post-processes such as milling or turning, which have roughness values of up to 0.30 µm and 0.60 µm, respectively.
- **Repeatability:** A machining post-process can also decrease the variation in applications that require repeatable specs.

Please note that some plastics cannot be machined. The more rigid the plastic, the easier it is to be machined. Cutting tools used in machining rely on the rigidity of the component. Some reinforced plastics would behave better than less rigid plastics, which tend to bend and require expertise to be machined to achieve high accuracy. Softer and flexible plastics are not suitable for machining.

Design recommendations

When designing a part for HP MJF, it is important to bear in mind the requirements for the final part. Some applications may require adjustments in the design in order to machine the printed part accordingly.

Surface grinding

This abrasive post-process removes material to create very flat surfaces with fine finishes and very accurate tolerances. For this reason, the machined surface needs to be designed with additional material to achieve a suitable result. The minimum recommended thickness is 0.5 mm, bearing in mind that an excess of material will lead to increased costs as well as manufacturing and post-processing time.

Surface grinding also allows for the improvement of the part's surface roughness.

Process recommendations

When machining a part for HP MJF, it is important to select the right parameters for each post-process in order to achieve a suitable result.

Milling

When milling a part for HP MJF, the recommended machining parameters are as follows:

Operation	Through holes (direct diameter)	Through holes (large diameter)	Face grinding	Turret heights
Tool recommended	Drill of required diameter	Drill of Ø12	End mill of Ø63 with interchangeable inserts	End mill of Ø8
RPM recommended	4000	10000	6000	6000
Cutting speed recommended	200 mm/min	2000 mm/min	1000 mm/min	1000 mm/min
Depth of cut recommended	1 mm	1 mm	0.25 mm	0.25 mm
Other comments	NA	Helical interpolation	NA	Helical interpolation

Table 1: Milling recommended parameters

Using metal cutting tools can lead to high temperatures, which can worsen the surface finishing and dimensional tolerances due to the melting of the material.

Turning

When turning a part for HP MJF, the recommended machining parameters are as follows:

Operation	Facing	Cylindrical facing	Boring	Reaming
Tool recommended	Cutting tool	Cutting tool	Drill of required diam-eter	Reamer of required diameter
RPM recommended	650	650	500	150
Cutting speed recommended	50-100 mm/min	50-100 mm/min	200 mm/min	200 mm/min
Depth of cut recommended	0.5 mm	0.5 mm	NA	NA

Table 2: Turning recommended parameters

When turning big series of parts, it is recommended to use custom tools made from widia or cobalt. In addition, to achieve good results and avoid vibrations, customized chucks can also be used.

Coolant and lubrication

Although an HP MJF part can be machined without the aid of air or water cooling, it is highly recommended to use air cooling.

Cutting fluid also can be used if the part is attached with chucks and if the part is not going to be painted or the surface is not going to be treated in some way. For holes deeper than 10 mm, it is highly recommended to use the cutting fluid as the chips cannot be removed easily.

4AA7-4510ENW, March 2019

Post-Processing for HP Multi Jet Fusion

Tuning your HP MJF technology to the design

Introduction

Post-processing is the final stage in the end-to-end process for HP Multi Jet Fusion technology. It is a crucial stage in the manufacturing cycle. Finding a suitable post-processing workflow can significantly impact the look and feel of the final part, as well as its mechanical properties.

Post-processing encompasses two key stages: primary and secondary post-processing. Primary post-processing refers to cleaning processes that are required for Multi Jet Fusion printed parts. Secondary post-processing, on the other hand, refers to processes that may affect the mechanical properties of the part, provide cosmetic enhancements, or reduce surface roughness, for example.

Figure 1. E2E HP Jet Fusion 3D Printing workflow

Given the nature of HP Multi Jet Fusion technology, which injects fusing and detailing agents onto a powder-based material, primary post-processing is a mandatory stage for all parts printed with HP Jet Fusion 3D Printing Solutions. As the part is printed, it is encapsulated in unfused material, which needs to be removed to obtain the desired raw printed part.

It is important to consider this post-processing stage when designing the part. By adding drain holes, lattice structures, or a chain in duct parts, cleaning the printed parts need not be a complex task. For specific tips and recommendations on how to design parts to facilitate cleaning, see **Design for Cleaning.**

Secondary post-processing is an optional step and depends on the specific requirements of the application where the final part will be used. The techniques included in this post-processing stage can be classified as providing **cosmetic attributes** (for example, dyeing and painting), or reducing **surface roughness** (for example, vibratory tumbling or chemical polishing); however, this is not a strict classification, as some techniques such as painting or electroplating can provide both attributes.

Primary Post-processing – Cleaning

This stage involves removing excess unfused material from the surface of the printed part. If this excess is not removed correctly, it will not only affect the part's overall look and feel, but also alter the dimensional accuracy of the part.

After a job is finished, parts are "uncaked" or unpacked, either automatically or manually, in the processing station or in the printer depending on the specific HP Jet Fusion 3D Printing Solution, and unfused material is reclaimed in the system for recycling. When unpacking, printed parts must be left with a significant layer of unfused material, as it has been exposed to varying levels of fusing and detailing agents, as well as high levels of energy, altering its properties. Any unfused material left after material reclaim should not be recycled.

The layer of remaining unfused material can be removed by using different techniques:

- Bead blasting
- Air blasting (in combination with bead blasting)
- Water jet blasting (also known as water jetting)

The basic operating principle for the three techniques is identical, although the media used to expel the excess material changes. They all use pressure to dislodge the unfused material from the surface of the part so that the fused material is visible. Bead blasting and air blasting are dry techniques, whereas water-jet blasting is a wet technique.

Figure 2. Part after unpacking, uncleaned (left); Part after cleaning (right)

Bead Blasting

Bead blasting involves propelling an abrasive or blast media, usually in bead or sphere form, at high pressure against the surface of the part using compressed air. As well as dislodging the unfused material from the surface, the bead dimples the surface without affect its dimensional stability, providing a more uniform, "satin" finish.

The unpacked parts are placed in the blasting chamber. An air compressor pushes air into a pressurized hopper, where it is mixed with the blast media, and the air-blast media mix is projected into the blasting chamber onto the unpacked parts via a blast gun or nozzle.

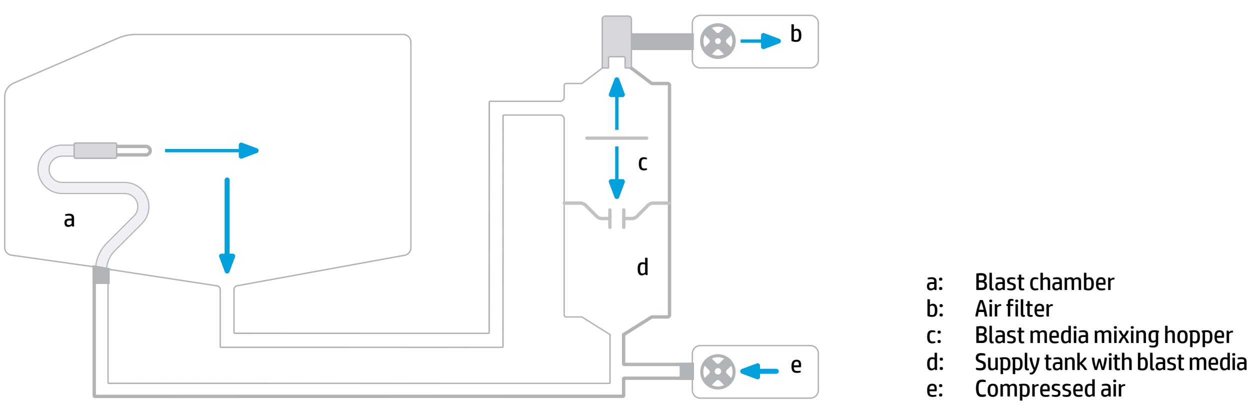


Figure 3. Functional diagram of a bead blaster

Bead blasting can be performed manually or automatically depending on the specific requirements of the part to be cleaned.

In automatic bead blasting, the parts are placed in the blasting chamber and usually moved, using a turntable, tumbler, track or conveyor, so the parts are exposed to the fixed or mobile blast nozzles. In manual blasting, an operator is responsible for controlling both the delivery of the blast media using a foot pedal and the distance from the blast nozzle to the part.

Automatic bead blasting allows multiple parts to be processed simultaneously, achieving a consistent finish on all parts. Often additional parts such as small filler balls are added to the chamber to ensure a uniform finish on all parts.

Manual bead blasting is more suited to fragile parts that require careful processing to avoid damage. However, the process is more time-intensive than automatic blasting for high production volumes, and is also susceptible to greater error as parts can be burnt more easily if they are placed too close to the blast nozzle.

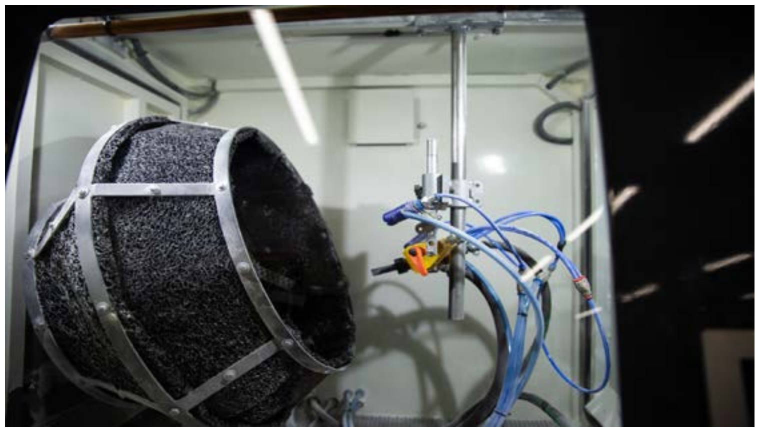


Figure 4. Automatic bead blaster

Both systems require a compressed air installation that offers a minimum air pressure of 3 bars, however more pressure may be required for better results. There are numerous solutions on the market that offer manual and automatic bead blasting, and standard equipment specifications usually satisfy the requirements for cleaning HP Multi Jet Fusion printed parts.

Regardless of whether an automatic or manual system is used, there are five key factors to consider in bead blasting:

- Blast media
- Air pressure
- Nozzle diameter
- Distance to part
- Time required

Figure 5. Made for HP Jet Fusion blasting equipment

Blast media

The size and the type of beads result in different surface finishes. There are several materials that can be used as blast media: glass, stainless steel and other metals, for example. For parts printed with HP Multi Jet Fusion technology, pure glass beads with a diameter of 70–110 µm are recommended, since they do not affect the dimensional accuracy of the part. Stainless steel beads of a similar diameter may also be used, as they provide a darkened, more uniform surface and result in a greater abrasion of the surface. Although their cost is higher, stainless steel beads are suited to high production volumes, as they are hardwearing, and cleaning the filters and the machine afterwards is easier.

The beads may be single-use or reusable depending on the blaster configuration; however, they must be replaced at least 6 to 8 hours in high production lines, for a blast media load of 12 kg, or 3 to 4 hours for a blast media load of 5 kg, to avoid the risk of polyamide contamination.

Figure 6. Printed part cleaned with glass beads (left); part cleaned with metal media (right)

Air pressure

This is a determining factor in bead blasting. If the pressure is too low, the process will be ineffective and more time will be required to clean the surface. If the pressure is too high, the bead may break and cause damage to the part's surface. Nonetheless, generally speaking, increasing the pressure decreases the cleaning time.

For automatic bead blasting, the air pressure should be set at around 4–7 bar. This value should be adjusted according to the time required, the geometry of the part, and the quality of the abrasive media.

For manual bead blasting, the air pressure should be lower, around 3–5 bar, with the recommended value for non-fragile parts being 5 bar, and 4 or 3 bar for fragile parts. A lower pressure is recommended for manual bead blasting compared to automatic bead blasting, as other factors such as operator experience and blasting angle can affect the outcome.

Nozzle diameter

The diameter of the nozzle should be taken into consideration when determining the air pressure. The abovementioned values for air pressure are based on the use of a 10 cm-diameter nozzle. If the diameter of the nozzle is less than that, the pressure value should be adjusted proportionally.

Distance to part

The distance from the blast nozzle to the part determines the effect that the blast media have on the part's surface. It is also one of the factors that can give rise to incidents during the cleaning process. For automatic bead blasting, the distance is controlled by the equipment configuration (around 15–20 cm), while for manual bead blasting this can be manually controlled, and a closer distance of 10–15 cm is recommended. To avoid damaging parts by insufficient distance, a printed cage can be used to group small parts or parts with fragile features.

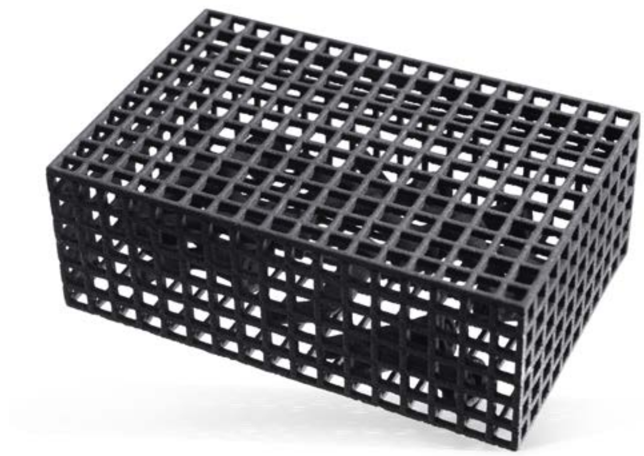


Figure 7. Cage printed with small parts inside

Time required

As mentioned before, manual bead blasting is more time-intensive, and depends on the operator's experience and judgment on whether the part is clean enough or not. The time required also depends on the geometry, size and complexity of the part. On average, 20 to 40 seconds is required to clean a part of medium size and complexity with no thin surfaces or fine detail. For fragile parts where less pressure is used, the value might be greater.

For automatic bead blasting, the time required is calculated based on the condition of the media. If the media is new, less time will be required compared to bead blasting done with reused media. On average, the process takes around 10 to 20 minutes.

It should be noted, however, that the overall look and feel of the part can be improved with less pressure and longer blasting time.

Air Blasting

Air blasting involves propelling a stream of compressed air onto the part's surface. It is usually used in conjunction with bead blasting to remove any remaining powder material and blast media dust that may have been left on the surface without affecting the dimensional or mechanical properties of the part.

The operating principle of air blasting is similar to bead blasting: an air compressor feeds air into a pressure vessel, and a trigger mechanism releases the jet of compressed air from the pressure vessel onto the surface of the part via a blast nozzle.

Air blasting requires a compressed air installation that provides a minimum air pressure of 3 bar, although greater pressure may be required for better results.

Since compressed air has a lower impact force on the surface compared to blast media, air blasting does not provide uniformity on the powder removal process and is not recommended as the sole solution for cleaning parts. It should be used only after the part has been bead-blasted.

Nonetheless, air blasting may not be necessary if the part has been blasted using a blaster that contains a deionizer. The deionizer electrically discharges the parts, meaning that any dust falls from the surface.

Some bead-blasting solutions also offer air blasting functions, in which case the same machine may be used for both processes, however ensure that the machine does not contain any abrasive media before proceeding to air-blast the parts.

Similar to bead blasting, the key factors that influence the outcome of the process are air pressure, nozzle diameter, distance to part, and time required. The values for these factors are similar to manual bead blasting. To summarize, the air pressure range should be between 3 to 5 bar, adapted according to the nozzle diameter; an optimal distance of 15 cm should be left between the part and the blast nozzle; and an average time of 10 seconds per part will be required, depending on the complexity and size of the part, as well as the operator's experience.

Water Jet Blasting

Water jet blasting or water blasting involves jetting a fluid mixture of compressed air and water via blast nozzles onto the part surface to remove powder. It can also be used for initial surface finishing by including a suspended solid (or blast media) in the fluid mixture.

The technique has usually a higher cost than bead blasting, but it provides several key advantages. It is ideal for cleaning complex geometries or ducts automatically, since the blast nozzles have different orientations, allowing the fluid to penetrate hard-to-reach areas. It also can reduce slightly the surface roughness with minimal additional processing time, much faster than using traditional vibratory system for the same initial roughness reduction.

It ensures a dust-free environment, as no subsequent processing is required to remove blast media dust. In general, the fluid can process several kg of powder before becoming saturated, moment in which the supplies would need to be replaced.

The key factors for achieving the best results with water jet blasting are similar to bead blasting:

- fluid composition
- air pressure
- nozzle diameter / distance to part
- time required

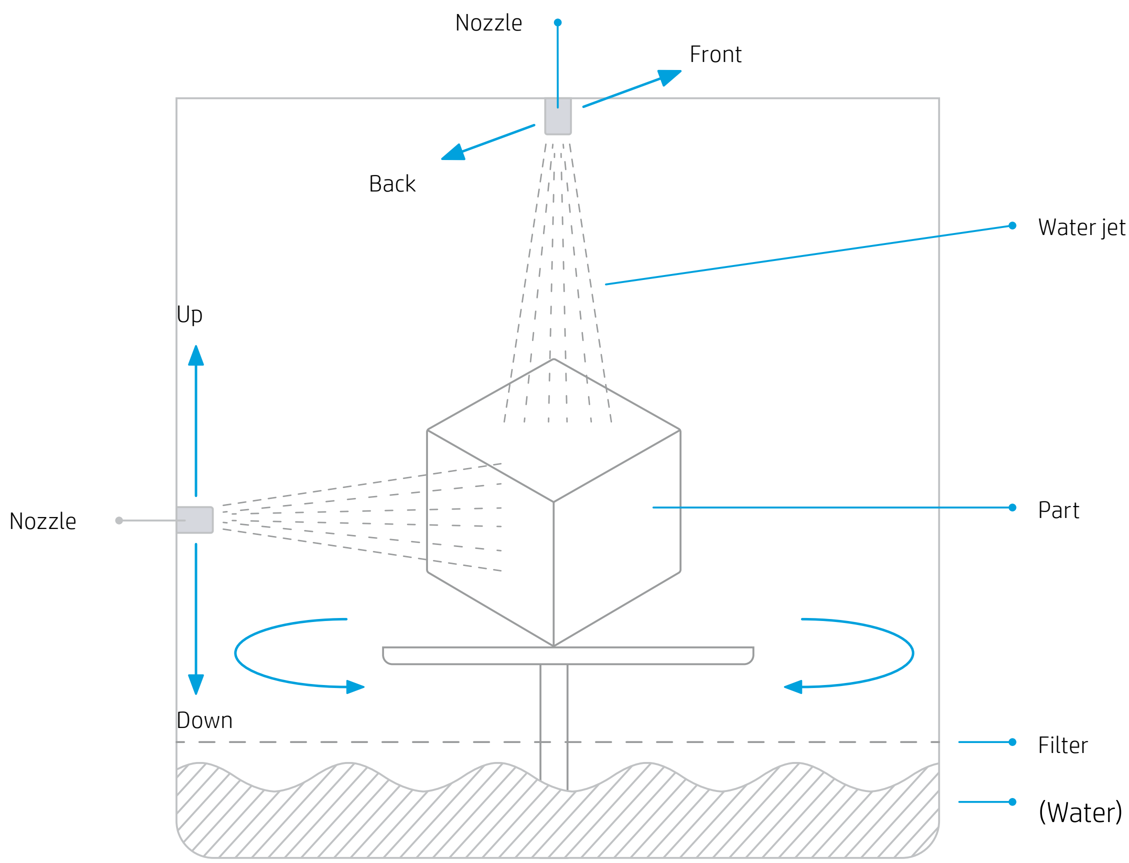


Figure 8. Water jet blasting equipment

Fluid composition

One of the key factors in water jet blasting is the fluid used as the medium. Different fluid compositions can be used according to the solution; for example, pre-treated water without any blast media, or a water-soluble detergent in which an abrasive ceramic or an abrasive ferrous metal is suspended, providing an initial surface finish.

Air pressure

The pressure value is dependent on the part geometry and the presence of fine detail, but it is usually lower than the one used in bead blasting.

Nozzle diameter / distance to part

Since water jet blasting is usually an automated solution that is performed in a sealed chamber with several nozzles pointing different directions, both the nozzle diameter and the distance to part is controlled by the equipment's configuration.

Time required

As with bead and air blasting processes, the time depends on the complexity and geometry of the part. For parts of medium size and complexity with no thin surfaces or fine detail, an average of 30 minutes or less is required for a full cleaning job.

4AA7-5263ENW, July 2019

Secondary Post-Processing for HP Multi Jet Fusion

Tuning your HP MJF technology to the design

Introduction

Secondary post-processing is an optional step in the end-to-end workflow for parts printed with Multi Jet Fusion technology. While the raw part—once it has been suitably cleaned by bead blasting or water jet blasting—can be used as is, without further treatment, the specific application of the final part may require processing to fulfill technical requirements, such as a colored finish or a smooth tactile surface.

The techniques included in this step have been classified as either providing **cosmetics**, or reducing surface roughness; however, some techniques may provide both attributes. For example, electroplating gives color and finish to the part, but also acts a functional coating, minimizing **surface roughness.**

Cosmetics

The cosmetics category can be subdivided into techniques that provide color uniformity in the raw part, such as dyeing and graphite blasting, and those that provide coloring, different to that offered by the raw part; however, since some techniques (dyeing, for example) provide both uniformity and coloring, this distinction has not been made.

The cosmetic category includes five key techniques:

- Dyeing
- Graphite blasting
- Smoothing blasting
- Painting
- Electroplating

Dyeing

Dyeing involves immersing the part in a hot dye for a prescribed period of time so that the dye penetrates the part completely, until a specific color or color homogeneity across the entire part surface is achieved.

Dyeing is currently the most commonly used secondary post-processing technique for Multi Jet Fusion 3D printed parts. It is suitable for applications where the part is visible, or subject to wear since the color penetrates the interior. The results obtained depend on the color starting point of the raw part, either gray or white printed parts depending on the HP Multi 3D Jet Printing Solution. The range of colors and tones that can be achieved is much greater when using a white raw part than a gray part.

Figure 1. Dyed grey parts- color possibilities

Figure 2. Dyed white parts-color possibilities

Manual dyeing is an inexpensive, efficient technique that uses a dye bath or vat, and a hotplate. The dye mix is made up in the dye bath and then conditioned. It is then heated to 80-100 °C and the parts immersed in the mix for approximately 8 minutes. The dyeing time will depend on the color of the raw part and the desired color intensity. The newly dyed parts are then transferred to the rinse bath containing water heated to 60 °C, in order to remove any excess dye from the parts and avoid staining. The parts are then left to dry, either naturally or by placing them in a drying oven at 50 °C.

Figure 3. Dyeing process of HP Multi Jet Fusion printed parts

Automatic dyeing solutions are a convenient and efficient alternative that requires less operator intervention. The principle is identical, but these solutions offer specific programs for dye bath mixing, conditioning, dyeing, part rinsing, dye disposal, and dye bath cleaning. In some automatic dyeing machines, the dyeing mix can be reused up from 5 to 10 times and stirring features ensure the dye solution is always homogeneous, achieving better results.

Dyes are available in powder and liquid format. The concentration of the dye mix depends on the dye specifications and the desired color intensity, with approximately 7 g/L for powder dyes, and a ratio of 0.1 L dye to 10 L water for liquid dyes. The dyeing temperature also varies according to the format used: 100 °C for powder dyes and 80 °C for liquid dyes.

For the best results when dyeing, parts must have been thoroughly cleaned to ensure they are completely free of any unfused material. Parts must be able to move freely within dye mix, so the dye bath should be adequate for the volume of parts to be dyed. Small fragile parts should be placed in a mesh bag to protect them from the effects of stirring in the dye mix.

If stains appear on the parts due to scratch marks or where the dye has become too concentrated—even after rinsing—such marks can be removed by bead-blasting the parts or by using smoothing blasting process.

Figure 4. Dyed part with scratch marks (left) that are removed by using bead blasting (right)

Furthermore, in parts prone to warpage such as large, thin and flat parts thinner than 2 mm, there may be increased warpage due to thermal shock and tension caused by the technique. There can be a slight impact on tensile strength, elongation at break, and tensile modulus in dyed parts due to a minimal water absorption

Figure 5. HP Multi Jet Fusion printed part before (left) and after dyeing (right)

Graphite Blasting

The principle of graphite blasting is similar to bead blasting, although its intent is different. While the purpose of bead blasting is to clean parts of unfused powder without coloring or impacting the part's surface roughness, graphite blasting provides color uniformity. Parts are processed in a blasting chamber, where a mix of glass bead media and graphite are blasted at parts to achieve a uniform color across the parts. Then any excess graphite and blast media dust must be removed by air blasting.

Parts processed with graphite blasting obtain a metallic-looking surface, which is highly attractive in some applications. Furthermore, the technique provides other desirable attributes such as reducing friction between moving parts, making it suitable for functional and mechanical parts where its lubricative benefit may be an advantage. Its impact on dimensional and mechanical properties, as well as surface roughness, is neutral, since any impact on the surface of the part is caused by the glass beads themselves.

Figure 6. HP Multi Jet Fusion printed part before (left) and after graphite blasting (right)

Since graphite blasting uses the same equipment as bead blasting, the factors for achieving the best results are similar in nature. The blast media mixture consists of glass beads of 70–110 µm and graphite, with graphite representing 0.7% of the total media mix. A 5 kg glass bead-graphite mixture is suitable for 1–2 full print jobs.

The settings for air pressure and distance to part are similar to manual bead blasting, being 3 bars depending on the part fragility and 10–15 cm distance to part. Since graphite blasting is necessarily a two-step process, as parts are blasted first in the bead chamber and then air-blasted to remove excess graphite, the total time required is around 2–5 minutes per part, allowing 1–5 minutes per part for bead blasting in an automatic chamber and a subsequent 5 seconds per part for air blasting. As with bead blasting, small and fragile parts can be processed in batches using a sinter box.

Graphite-blasted parts are prone to staining due to excess graphite on the surface, the degree of which varies depending on the blasting time; however, air blasting can reduce the level of staining. Graphite blasting is recommended for visual prototypes, but not for final parts that receive frequent handling, as it is not wear-resistant and fades over time.

Smoothing blasting

Smoothing blasting, also known smoothing blasting, involves propelling an abrasive media, onto the surface of the part at high pressure.

With an operating principle similar, if not identical, to bead blasting, the main purpose of smoothing blasting is to give a better surface finish, usually in combination with dyeing process. This is achieved by using a more abrasive and round formed blast media, usually plastic or ceramic rather than glass used in bead blasting, and a higher pressure.

The surface finish achieved can range from matt to glossy finish depending on the type of media used, and the processing time, and the surface becomes more resistant to scratches, dirt and liquid absorption.

As with bead blasting, the key factors that affect the result are air pressure, blast media, and time required. Since it is usually done by an automated system, both nozzle diameter and distance to part is controlled. For example, with a minimum distance to part of 200 mm and a pressure of 5 bar, a batch of parts can be cleaned in around 10 to 20 minutes, depending on the material and finish.

This process reduces slightly the surface roughness, but this effect is more noticeable when combined with other processes such as vibratory finishing.

Painting

Painting involves the application of a pigmented liquid composition to the part in thin layer, which converts to a solid film when dry. This results in improved color uniformity and surface roughness on the part. Other desirable properties such as UV resistance, wear and scratch resistance, and water tightness can also be achieved depending on the formulation of the paint used.

Both solvent and water-based paints can be applied to Multi Jet Fusion parts. Depending on the final application where the part will be used, the raw part can be painted directly or pre-processed first. As with any of the secondary post-processes, the raw part must be thoroughly cleaned and be free of any unfused material before painting. For best results, the raw part should be primed and then sanded to achieve a uniform surface, as any minor imperfections in the surface will be seen after painting. Several layers may be required according to the final application.

The surface roughness of HP Jet Fusion 3D printed parts can be improved by adding layers of paint, the greater the number of layers, the smoother the surface.

Paint can be applied manually or automatically using a spray gun.

Data courtesy of Skorpion Engineering srl

Data courtesy of SuperFeet

Figure 7. HP Multi Jet Fusion printed parts before and after painting; Color possibilities: from metallic to vivid colors

Electroplating

Electroplating and metal coating are techniques used to add a layer of metal to the surface of a printed part. This is done to improve the look and feel of the part for cosmetic applications or to improve physical properties such as conductivity, EMI/RFI shielding, mechanical strengthening, and heat conductivity, as well as other desirable attributes as a functional coating like antibacterial properties.

Electroplating can be performed on raw parts, however, given the initial roughness of the part, the look and feel required for most cosmetic applications may not be achieved. For a better, mirror-like finish, raw parts must be pre-processed to reduce surface roughness to 1 or 2 µm, using a vibratory tumbler, chemical polishing, or smoothing blasting, although small holes due to porosity may still be observed.

Figure 8. HP Multi Jet Fusion printed part after electroplating

Electroplating involves adding a thin layer of metal to a metallic object. At a basic level, it consists of dissolving one metal in a solution and subsequently attaching it to another metallic surface using an electric current. The target surface must be able to conduct electricity.

Since Multi Jet Fusion 3D parts are printed in polyamide, a semi-crystalline thermoplastic, the part must be treated to make the surface conductive before the electroplating process. There are three methods to do this:

- Electroless plating
- Gas activation technology
- Conductive coating

The method chosen to make the surface of the raw part conductive depends greatly on the application and desired attributes for the final part. The most commonly used method, however, is electroless plating.

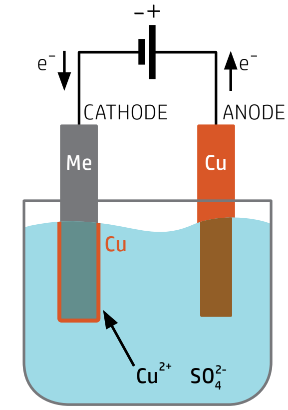


Figure 9. Functional diagram of the electroplating process

Electroless plating

Electroless plating adds small particles of palladium inside micro-cracks in the part's surface, which will create an initial layer of metal. It is a complex process, which is dependent on the geometry of the part for its effectiveness.

Electroless platting is a multi-step process in which first the part needs to be etched mechanically, i.e. sand blasting with an abrasive media, to enhance the surface-adhesive capabilities of the part. For raw or tumbled parts, processing the part with mechanical etching is sufficient; however, for parts treated with chemical polishing, chemical etching may be required. In chemical etching, the surface is attacked chemically using a chromic acid-based solution. Any excess chromic acid is then neutralized. Next, a solution consisting of palladium and tin salts is applied to the part. The part is then submerged in an electroless plating solution, which coats the surface of the material with either nickel or copper depending on the solution, creating a pre-plate layer.

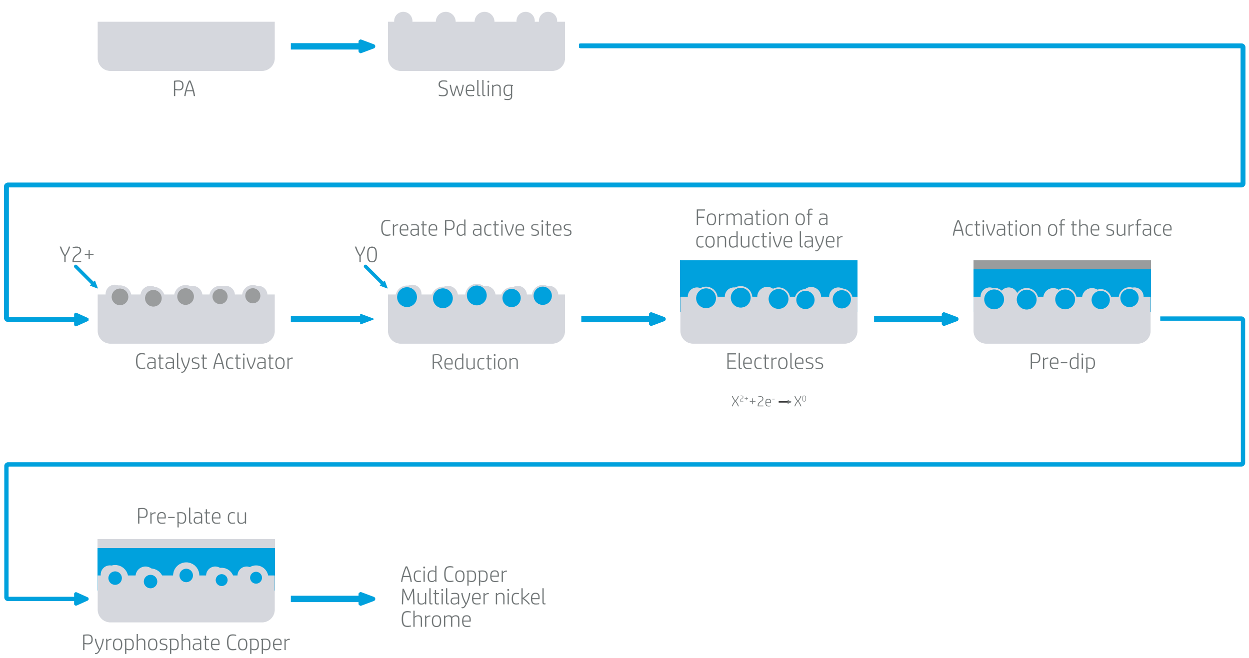


Figure 10. Swelling process

Gas activation technology

Gas activation technology uses an ionized gas to make the surface conductive. It does not require mechanical or chemical etching to prepare the surface. It is fast and gives selective metallization, however, it results in a small area where the electrode is connected without electroplating.

Conductive coatings

Coating the part is the easiest and the most economical way to make the surface conductive. However, it is not a very robust solution, as adhesion of the coating to the surface is weak, meaning it does not provide durability over time.

Once the surface has been made conductive by electroless plating, gas activation, or with a conductive coating, the standard procedure for electroplating can be done, deposing a metal coating on the surface of the part. Various metals can be used to plate the surface: notably, nickel, copper, chrome, and precious metals such as gold or silver.

To overcome possible porosity or irregularities on the surface, a priming spray paint can be applied after mechanical polishing and before electroplating for the best results.

Surface roughness

Given the nature of powder bed fusion technologies such as Multi Jet Fusion where the distribution of particles may be non-uniform, surface roughness is usually inconsistent across the part's surface. Secondary post-processing treatments help to homogenize the surface finish and reduce roughness. There are two main techniques that can smooth the printed part's surface:

- Vibratory finishing
- Chemical polishing

Vibratory finishing

Vibratory finishing, also known as tumbling, involves vibrating parts in a tumbler with an abrasive media, causing the media to rub against the parts. The abrasive media have a lapping effect on the surface of the part. It is an automatic process that requires low operator supervision. However, care should be taken when using this process, as it can cause damage to fragile parts, tends to round corners, and may affect the dimensional specifications of the part, particularly if the time is excessive or the media type and size are inadequate

Figure 11. HP Multi Jet Fusion part before (left) and after tumbling (right)

Vibratory finishing can be either a wet or a dry process, with the media being adapted accordingly. In wet vibratory finishing, coarse ceramic and plastic media are usually used, resulting in a more polished finished. The wear on the media tends to be less and the overall process is usually quieter. However, the waste resulting from the liquid-abrasive media mix needs to be filtered and treated. Dry vibratory finishing, on the other hand, is a cleaner process, resulting in easier treatment of waste output (only worn dry media). However, it tends to be more aggressive, depending on the media.

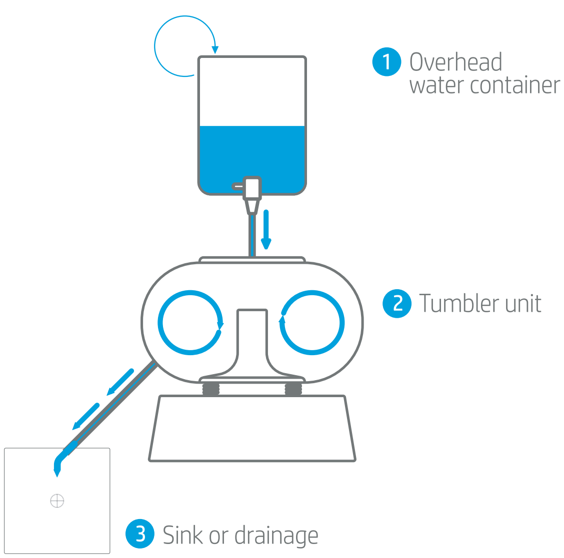


Figure 12. Functional diagram of wet tumbling equipment

Figure 13. Printed parts being processed in the tumbler

There are several key factors that influence the results achieved in vibratory tumbling: abrasive media, time, and revolutions per minute.

The abrasive media play an important role in the Ra value ultimately achieved. The media used in vibratory tumbling is usually ceramic or plastic, though other materials such as steel, synthetic and organic media may be used according to the target roughness value. With a higher density and greater hardness, ceramic media tends to be more aggressive than plastic. Plastic media remove less material during the process, allowing small details to be preserved, but require usually longer processing times. The shape of the media can vary according to the desired effect and the size and shape of the parts.

Figure 14. Different blasting media used in tumbling process: ceramic, plastic, and steel (from left to right)

Similar to sanding, the size of the media used should progress from large to small. The tumbling process should be started initially with a larger particle and then move onto a finer particle size as progress towards the desired roughness is made. If the part is small or fragile, a finer size may be more appropriate. Larger-sized media do not reach smaller areas of the part, while smaller-sized media may become lodged in smaller crevices of the part, requiring an additional cleaning step afterwards.

The revolutions per minute of the vibratory tumbler and the time required to achieve the desired result depend on the abrasive media and the manufacturer specifications. The effectiveness of the process is not constant over time, tending to be more efficient at the beginning of the process when the media is newer, losing efficiency as the process progresses. Optimal tumbling time should be studied for the desired application, but it usually lasts several hours

Chemical polishing

Chemical polishing, also known as chemical smoothing, is a physio-chemical process that smooths the surface of thermoplastic polymer parts, including internal cavities. It is a non-line-of-sight process; in other words, it acts on the surface of the part without degradation of the part's mechanical properties and can achieve a surface finish with a roughness of value of less than 1 µm and different levels of glossiness. It can be used on polyamide (PA 11 & 12), as well as other thermoplastic polymers such as TPE and TPU.

Figure 15. Surface roughness improvement after chemical polishing

Since the process can be controlled, it can result in matt, gloss or shiny surface without losing any fine detail on the part or affecting the part's dimensional accuracy to any great extent.

If chemical polishing is used on gray parts, since the process acts on the surface layer, it can cut through the partially fused outer layer to give a piano black part, avoiding the need for an additional dyeing step.

Figure 16. Image of raw part, and two chemically polished parts with varying degrees of processing

For very thin sections that are less than 1 mm, there is a risk of structural deformation with chemical polishing. Furthermore, the process is not very efficient with sharp edges.

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