Technical Newsletter

# Design Guidelines – HP 3D High Reusability PP enabled by BASF – HP Jet Fusion 5200 Series 3D Printing Solution

Printed with HP 3D High Reusability PP enabled by BASF

## Overview

This document presents design guidelines for using HP 3D High Reusability PP enabled by BASF in HP Jet Fusion 5200 Series 3D Printing Solutions.

## Contents

## Introduction and mechanical properties

Before going into specific design guidelines on recommendations and values, let's do a brief overview of the HP 3D HR PP main characteristics that are of interest for designers and mechanical engineers using this material for their applications.

The HP 3D HR PP melting temperature is about 140° Celsius, about 40° less than the other HP MJF polyamides.

HP 3D HR PP has an advantage versus PA12 from its lightweight characteristics, which is because of its lower density.

The elongation at break of HP 3D HR PP, which is between the values of PA12 and PA11, gives good ductility and toughness properties.

PP main characteristics for part designers :

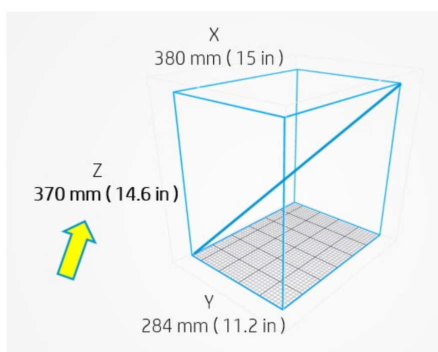
- Lightweight
- Elasticity, Ductility and Toughness
- Chemical Resistance
- Limited Moisture Absorption
- Welding Capabilities

In terms of stiffness, HP 3D HR PP also has a good modulus, just 12% lower than PA12 and PA11.

In terms of chemical resistance and moisture absorption ratio, HP 3D HR PP is one of the best plastics, significantly better than polyamides. In addition, it has very good welding capabilities. It can be welded to other injection molded HP 3D HR PP based plastics through many different techniques.

## Printable volume

The printable volume is an important piece of information for the designer. Although HP 3D HR PP uses a build unit with the same hardware as the one used for polyamides materials, the maximum Z-dimension in the build chamber is 370 mm (14.6 in), 10 mm (0.4 in) shorter due to the HP 3D HR PP higher shrink rate.

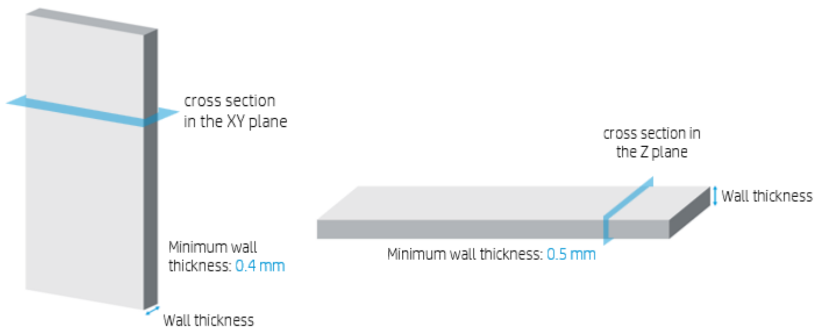



Make sure these dimensions are properly configured on the job preparation software if not using HP SmartStream 3D Build Manager.

## Wall thickness

The recommendations given are the minimal features for mechanical reasons. Whatever the resolution, leveraging our knowledge from 2D printing allows us to print as thin as 80 microns:

| Minimum wall thickness | mm |
|---|---|
| Short walls with its **SECTION** orientated on the **XY-plane** | **0.4 mm** |
| Short walls with its **SECTION** orientated on the **Z direction** | **0.5 mm** |

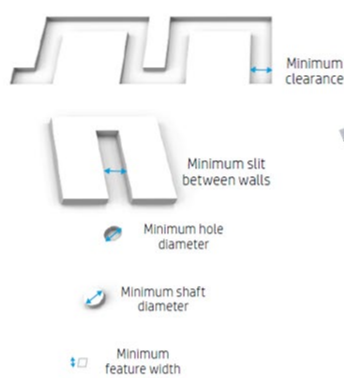


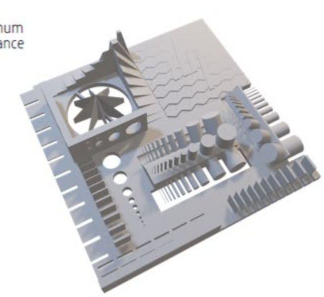

The resolution in XY is 20 microns, compared to 80 microns in Z, which is why we can achieve recommended minimum sections in the XY plane of 0.4 mm and sections of 0.5 mm in the Z direction.

## Printable features

There are some specifications to bear in mind in order to avoid issues in parts, and to achieve the best quality. The minimum printable features in planes X, Y, and Z are as follows:

| Minimum printable features | |
|---|---|
| Minimum clearance at thickness of 1 mm | 0.6 mm |
| Minimum slit between walls/embossed details | **0.6** mm |
| Minimum hole diameter at a thickness of 1 mm | 0.6 mm |
| Minimum shaft diameter at 10 mm | **0.6** mm |
| Minimum printable features or details (width) | 0.3 mm |



For letters, numbers, and labels, the recommendations are:

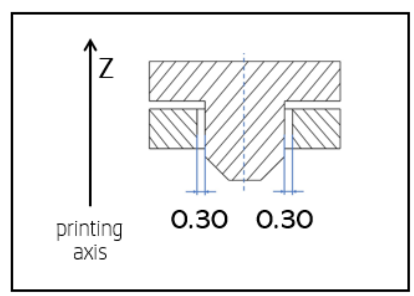
| Minimum printable features | |
|---|---|
| Minimum printable font size | 9 pt. (3.2 mm) |
| Minimum depth for deboss details | 1 mm |
| Minimum height for embossed details | 1 mm |


When preparing the job, if possible orient embossed features facing up and debossed ones facing down.

## Parts assembled after printing

When talking about features that connect with others, the value to ensure there isn't any interference between the pin and the hole is 0.3 mm. However, for parts where some interference is desired, 0.1 mm or 0.2 mm may be more suitable. We recommend doing trial and error tests with different values.

| Minimum values for clearance | mm |
|---|---|
| Clearance between **faces to avoid interference (radius)** | 0.30 mm |



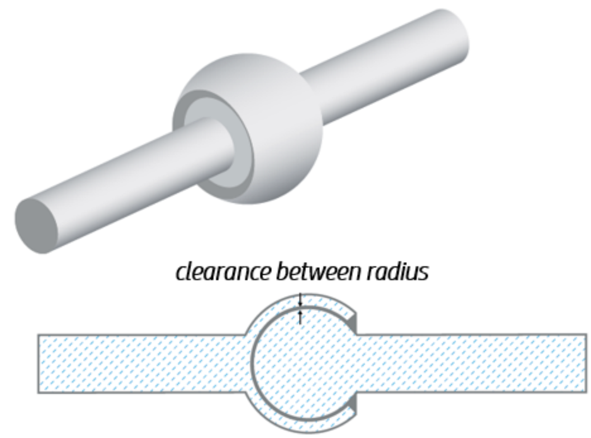

Whenever possible, orient the pin and the hole with their axis perpendicular to the XY plane as you can see in the previous sketch to achieve the best accuracy.

## Parts printed as functional assemblies

With parts that are printed as functional assemblies, like this ball and socket assembly, the minimum recommended clearance between faces (in this case between radius) is 1 mm. Obviously this is a baseline and the fit may be loose, but it is a starting point.

**Minimum printable features**

| | |
|---|---|
| Clearance between faces (radius) | 1.0 mm |
| Clearance if wall thickness is greater than 5 mm | <1.0 mm |



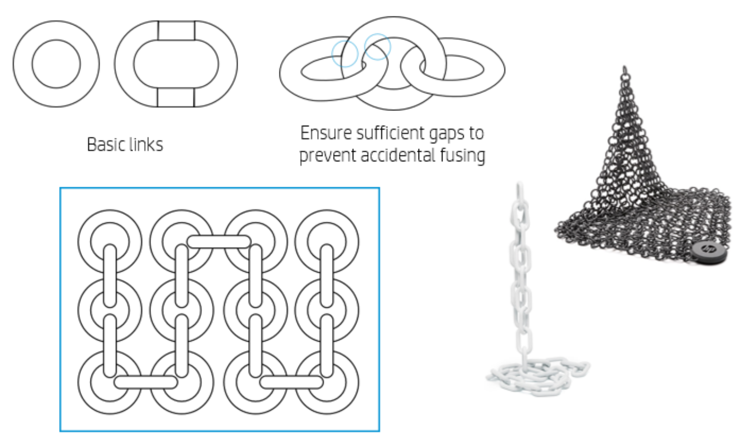

When requiring tighter fits, trial and error is again recommended, beginning for instance with a clearance of 0.3 mm.

## Interlocking parts

One of the advantages of MJF with respect to other technologies is its ability to print parts directly interlocked, such as chains and webs.

Here you can see we are able to print chains and webs with different geometries. The key to remember is to allow the recommended clearance and separation gaps between the links, to ensure one part does not fuse with another:

- Chains and webs are assemblies of interlocked links
- Minimum separation gap between interlocked components (rings): 1.5 mm
- Minimum recommended separation gap: 3.0 mm



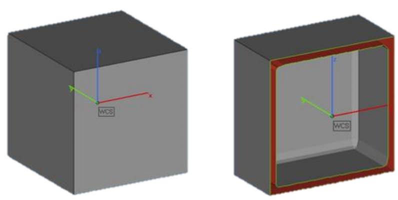

You can print these types of parts folded in the build chamber printable volume, e.g. with a zig zag position, so they can be much longer and bigger than the maximum printable volume.

## Part quality considerations: hollow parts

Heat dissipation and process temperature control becomes more difficult with parts which have bulky and massive geometries. This fact may lead to an increase in part deformations and a decrease of part quality.

With designs of massive parts, one of the simplest ways to assure part quality is to hollow them. It is the best approach for the type of components that do not have high mechanical requirements. The action of hollowing a part can be done automatically in CAD and job packing software.

- Massive parts without high mechanical requirements
- Done automatically in many softwares
- Significant cost and weight reduction



**Volume to surface ratio:**

- Calculate, for each part in the job, the following ratio:

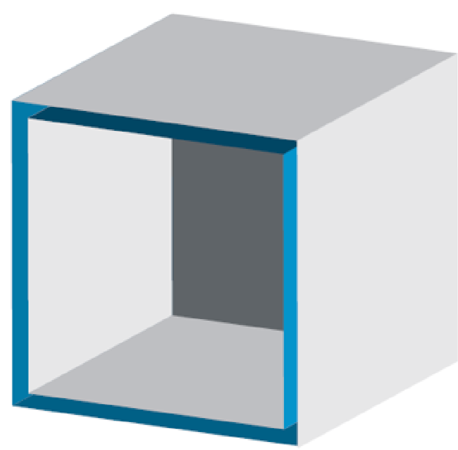
$$\frac{Volume\ (mm^3)}{Surface\ (mm^2)}$$

- Limit this ratio to a maximum of 5 mm.
- Parts with a ratio above 5 can have bad part quality or even lead to job failure. A warning message will be displayed.

Given the importance of avoiding high mass parts with HP 3D HR PP, designers have to comply with the given volume-to-surface ratio values.

Hollowing provides the added benefit of reducing the cost in agents and material. The cost reduction comes in the form of less powder and less agents consumed, which can be reduced by up to 80%.

- Minimum wall thickness: 2 mm
- Small parts: 2 mm – Large parts: 3 mm
- For wall thicknesses greater than 7 mm, consider applying an internal structure.



When hollowing parts, we recommend the minimum wall thickness of 2 mm for structural integrity. For larger parts, 3 mm is suitable.

For wall thicknesses greater than 7 mm, it might be better to reinforce the part with an internal structure, like a lattice.

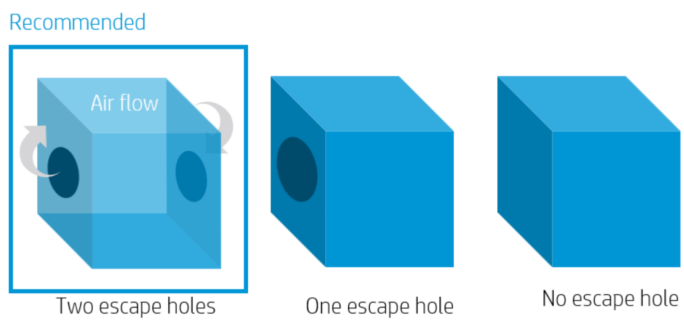
In any case, the unfused material can be left within the part, which results in heavier and more resistant parts compared with the fully hollow option.

While the part is still light, it is weaker than the non-hollowed version. The difference in weight stems from the different densities of fused and unfused material.

## Designing for cleaning hollow parts

When hollowing a part unfused material will be trapped inside, so you may want to implement drain holes to **remove the trapped unfused powder**.

- Add at least **two drain holes** on opposite faces.
- Minimum recommended diameter: **10 mm** or equivalent sections.




The recommendation is to add at least two drain holes of **10 mm** on opposite faces to facilitate cleaning if possible.

Leaving unfused powder inside a part without any hole can also be a correct strategy. It is not an issue at all, and the part is still going to be lighter than a completely solid one, since unfused material density is lower than that of fused material.

## Lattice structures

The use of lattices consists of hollowing a part and replacing the internal solid mass with a reticular, cross-linked structure that provides mechanical integrity through the collective action of many rigid cells.

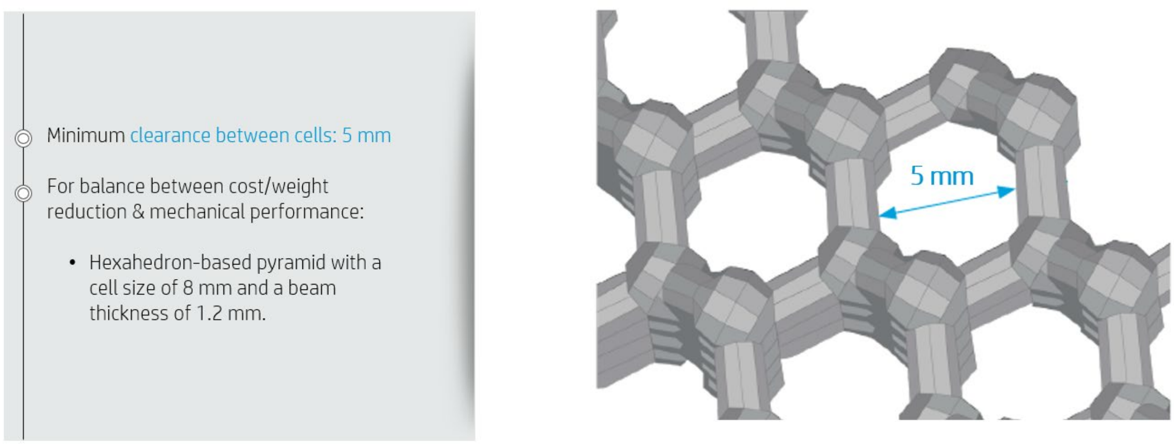
The advantage of this method is that it retains a **higher proportion of the mechanical properties of a completely dense part compared to a hollow part**, while still reducing the mass and cost of the part to a remarkable degree.

Lattices can also be used to modify the stiffness behavior in some zones of the part. The cost reduction comes in the form of **less powder and less agents consumed**, which may be reduced by 60%.

This redesign is a quick process that can be automated with different professional software.


Recommendations for applying lattices:

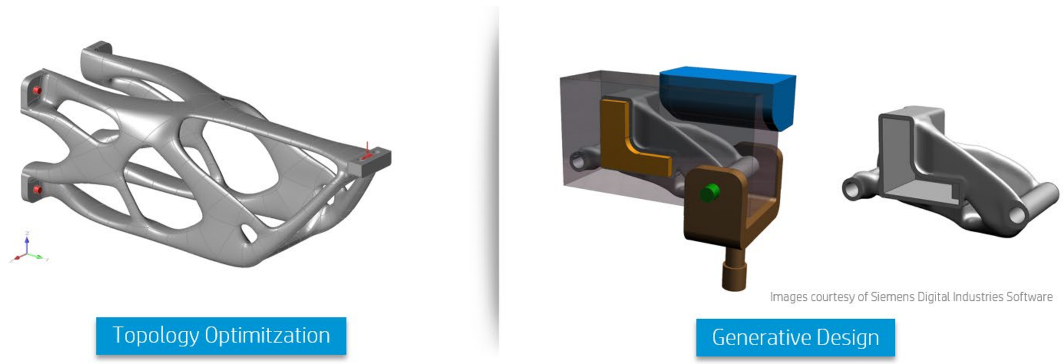
- It is hard to give a specific recommendation to facilitate cleaning, such as clearance between cells, as it will depend greatly on the type of structure and its maximum dimensions.
- 5 mm is the minimum clearance recommended. In general terms, a **hexahedron-based pyramid** with a **cell size of 8 mm** and a **beam thickness of 1.2 mm** provides a good balance between cost and weight reduction, mechanical performance, and ease of cleaning.
- It is important to remember that any unfused material can be left within the lattice structure as well.




## Topology optimization and generative design

These are two similar techniques that allow the reduction of the volume and mass of a part while maintaining mechanical specifications, therefore they are very popular and it is recommended to apply them to the design of HP 3D HR PP parts.

Most common CAD software already provide modules with this functionality.




The total mass reduction achieved in some cases can be very high, implying a significant cost reduction.

The recommendation is to consider these techniques whenever it makes sense to do so, because they may improve the part quality since they reduce the amount of fused material.

## Designing ducts

When designing internal long geometries, the removal of any unfused material can be difficult. To remove this material from narrow ducts, the design and printing of a strip or chain within the duct may facilitate internal cleaning. After printing, the chain can be pulled out to remove most of the material.

In case of ducts with small diameters, cleaning can be done with a flexible screw or steel cable (e.g. 2-3 mm thick) attached to a standard drill.

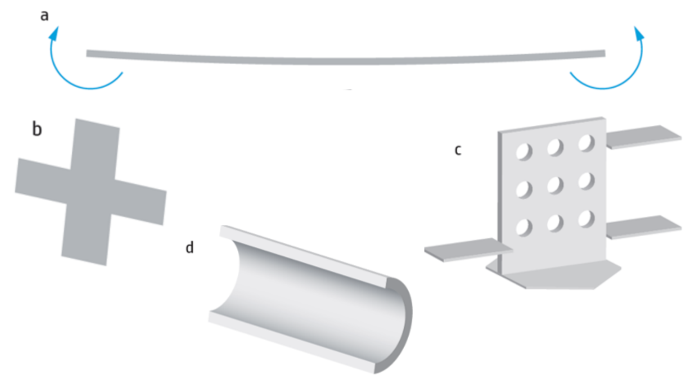

## Parts susceptible to warpage

PP is a plastic with high warpage tendency due to its characteristics. Flat and thin parts are more susceptible to deformations due to non-uniformity in cooling, which is one of the most important factors that can create warpage.

In curved open parts, you may have to reinforce them so that they do not deform, depending on the thickness and other proportions of the part.

Avoid printing:

- Long thin parts (a). Longer than 100 mm and thiner than 20 mm
- Parts with significant transversal section changes (b)
- Parts with aspect ratio higher than 10: 1 (c)
- Thin curved surfaces (d)

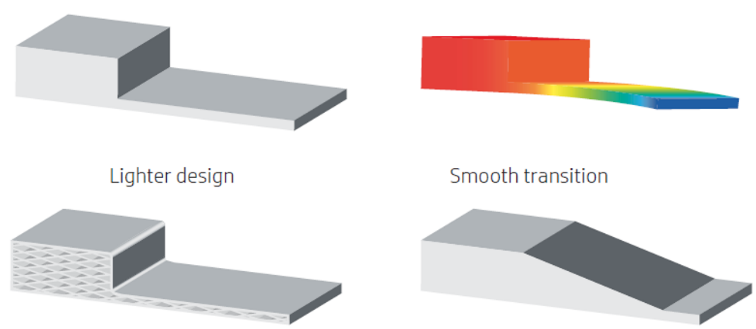



Parts with significant geometry cross-section changes may suffer uneven cooling as well. In general, areas with greater mass retain more heat, so cooling will be slower in that area. In areas where the mass is less, solidification and contraction happens earlier. Differences in contraction times in the same part create internal stresses which pull the material, producing warping.

To reduce warping, reduce abrupt cross-sectional changes as much as possible to ensure the thermal gradient is low.

Solutions:

- Design parts with a smooth cross-section transition **to reduce its thermal gradient**
- Avoid long, thin, flat parts with an aspect ratio—length vs. width—higher than 10:1.
- Lighten the parts by hollowing them or by adding internal lattices.



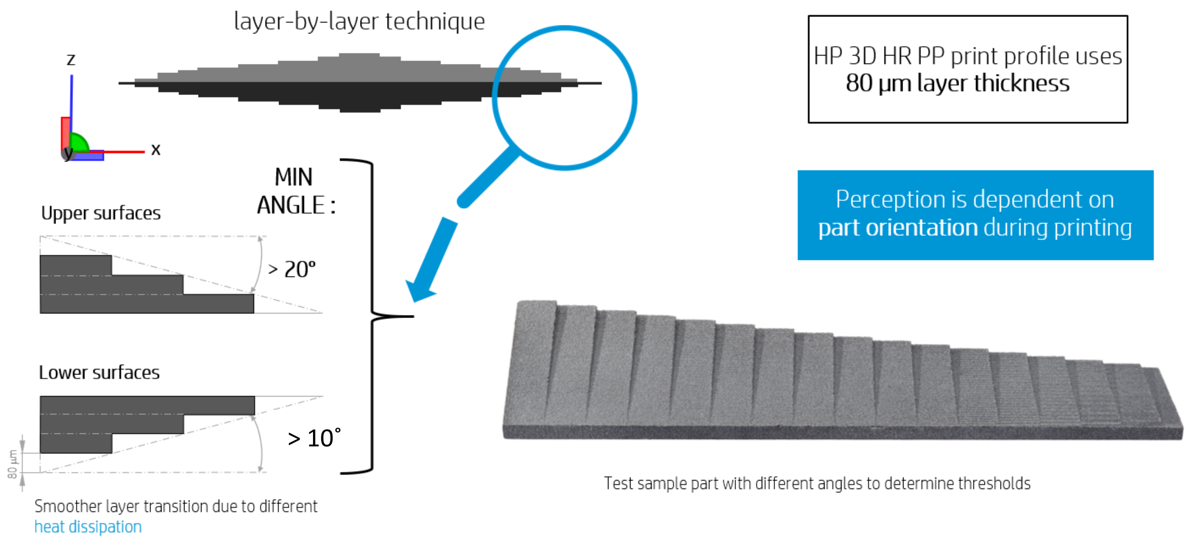

Another strategy is to reduce the mass of the part by hollowing it or adding lattice structures.

## Stair-stepping

Stair-stepping is another aspect that designers must bear in mind when the look and feel and the surface finishing of a part is important.

Multi Jet Fusion is a powder-bed fusion technology based on a layer-by-layer technique. The HP 3D HR PP current print profile creates layers 80 microns thick in the build chamber. Layers on a part can become visible to the naked eye, depending on their thickness and the printing orientation. This visibility of layers on certain part orientations is the cause of the stair-stepping perception phenomenon.

To prevent stair-stepping on curved or sloped surfaces, whenever possible you should avoid positioning key surfaces with low angles along the horizontal (XY) printing plane.



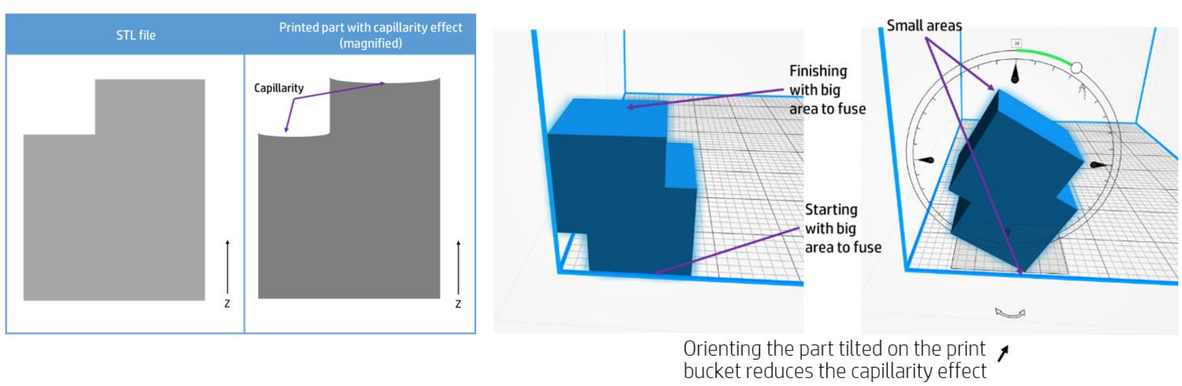

The minimum angle values recommended to avoid stair-stepping are:

- 20° for upper surfaces, and
- 10° for lower surfaces. This value is lower due to the different heat dissipation of the down-facing surfaces versus those facing up.

The idea is to design and orient the part in the build chamber in such a way that these angles are bigger, to minimize the perception of stair-stepping.

## Capillarity effect

Capillarity is another point that designers must take into consideration. When an area of fused material becomes momentarily a fluid surrounded by a bed of non-fused powder, its boundaries tend to rise due to capillarity. This may result in creating raised and sharper edges. This issue not only affects look and feel but also the dimensionals directly.



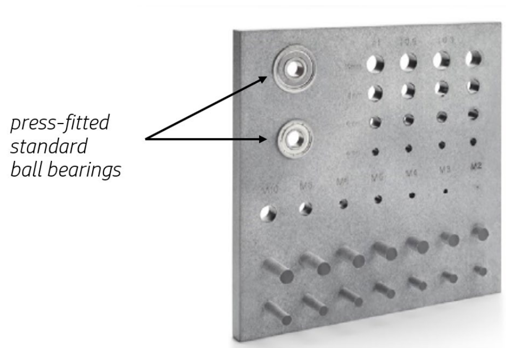
A caliper will measure greater thickness in a part with capillarity compared with a 3D scanner or CMM. This is because a caliper makes contact in the outermost section with raised edges of the parts. To reduce capillarity effects, orient the parts so that horizontal surfaces are tilted with respect to the printer's Z-axis.

# Joining HP 3D HR PP parts

Different techniques and alternatives exist to meet the needs of many applications using HP 3D HR PP.

## Press-fits

HP MJF allows users to print **mating parts**, for instance a shaft and a hole to create **functional assemblies**. Depending on the assembly's functional needs, the required **tolerances** between the mating parts **will be tighter or wider**.




The most common standard types of fit may require tight tolerances, **for instance between IT6 and IT11**. Since Multi Jet Fusion is not able to achieve tolerances this tight, it is recommended in these cases to design the part with extra material and then machine those features with tight tolerances (for instance, using a drill, a milling machine, or a lathe, depending of the final geometry).

In the case of a press-fitted ball bearing in an HP 3D HR PP printed part, design and print a pre-hole at least **1 mm smaller** than the final diameter and then drill or machine it to the bearing's required diameter.

## Threaded unions: printed threads

When needing to use bolts, screws, and nuts to join or fix your HP 3D HR PP parts, or some components on them, threaded unions could give a good solution.

For diameters equal or greater than 12 mm, you can design and print the HP 3D HR PP parts with their thread.

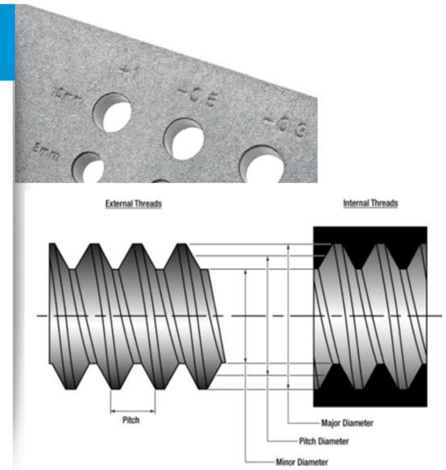
If you want to use a standard thread (e.g. ISO), draw internal threads with your CAD using the maximum allowable tolerance value from the standard given table, and draw external threads with the minimum allowable tolerance value from that table:

## Standard printed threads

- Internal threads: The maximum allowable tolerance should be used.
- External threads: The minimum allowable tolerance should be used.

| | | Internal threads - 6H | | | | | External threads - 6g | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ØD | Pitch Diameter Ø | | Minor Diameter Ø | | Major Diameter Ø | | Pitch Diameter Ø | | Minor Diameter Ø | |
| Thread | Pitch | min. | min. | max. | min. | max. | max. | min. | max. | min. | max. | min. |
| M12 | 1.75 | 12 | 10.863 | 11.063 | 10.106 | 10.441 | 11.966 | 11.701 | 10.829 | 10.679 | 9.819 | 9.602 |
| M16 | 2 | 16 | 14.701 | 14.913 | 13.835 | 14.210 | 15.962 | 15.682 | 14.663 | 14.503 | 13.508 | 13.271 |
| M20 | 2.5 | 20 | 18.376 | 18.600 | 17.294 | 17.744 | 19.958 | 19.623 | 18.334 | 18.164 | 16.891 | 16.625 |

Allowable tolerances for metric threads with general-purpose tolerances class (6H-6g) and normal engagement length under the ISO 965-2 standard



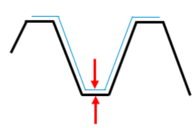

For the thread pitch value, you must respect the nominal one.

## Custom threads

In case you need to use a customized threads, take into account that they should be designed with a **clearance of 0.2 mm to 0.4 mm** between the external and internal thread, and a minimum radius of 0.15 mm on its edges:

## Customized printed threads

- Design with a clearance of 0.2 mm to 0.4 mm between the external and the internal thread.



- Remove all sharp edges and apply a minimum radius of 0.15 mm


If possible, it is highly recommended to print and test samples with different clearances, to later select the most suitable one.

## Threaded unions for sizes smaller than 12 mm

For internal threads with a smaller diameter, you can use two options:

- Self-tapping screws:

  These tap their own threads as they are driven into the part.

  The pre-formed hole design dimensions are recommended by the screw supplier.

- **Internal machined threads:**

  Print the pilot hole and then machine the thread using the required tap.

  For the Pilot hole diameter, use the **recommended drill size from the supplier or one slightly smaller**.

For External machined threads:

- Start from a solid printed cylinder and then machine the thread using the required die.
- For a solid cylinder diameter, use the **recommendations for plastic and metal**.

**Threaded unions: Self-tapping**

Self-tapping screws:

- Tap their own threads as they are driven into the part
- Hole diameter recommended by screw vendor
  - Direct printed hole typically works with nominal diameter value from the vendor
  - Other option: create smaller pilot hole and drill it later

**Threaded unions: Machined threads**

Internal machined threads:

Start from a pilot hole and then machine the thread using the required **tap**.

External machined threads:

Start from a solid printed cylinder and then machine the thread using the required **die**.

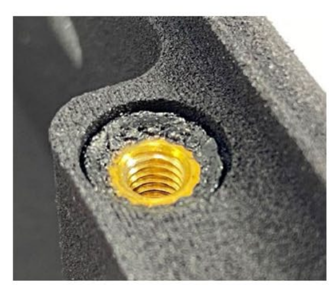
## Metal threaded inserts

In case you need for instance a threaded union that must be assembled and disassembled many times with high performance, in order not to damage the thread it may be necessary to use a metal insert.

Metal inserts are catalog parts and can be classified in 4 different groups, as seen in the following table. The best ones in terms of mechanical performance are those inserted by heat staking or ultrasonic vibrations, since the material is melted around them.

| Type of insert | | | Performance |
|---|---|---|---|
| Heat-staking and ultrasonic vibrations insert | |  | High overall performance. Not very dependent on hole size. Material is melted around the insert. |
| Press-in insert | Screw-to-expand |  | Very dependent on hole size tolerances. Recommended for non-critical applications. |
| | Hexagonal-shaped |  | Dependent on hole size tolerances. Good pull-out resistance. Recommended for non-critical applications. |
| Self-threading insert | |  | Excellence pull-out resistance. Easy to install. |

Preferred for professional applications

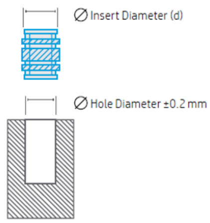


Source: Extol Inc.

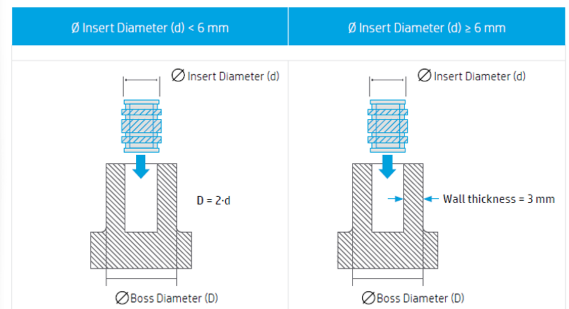
Metal insert vendors will generally specify the diameter for the pre-formed hole and the boss dimensions as well, to deliver a good performance of the union.

**Design considerations for the pre-formed hole:**

- Consider HP MJF tolerances.
- Insert vendors specify the required hole diameter size and depth.




**Design consideration for the boss diameter:**




## Helicoils

These are standard components typically used to repair holes in metal parts with damaged threads. We have tested them on our parts and they work properly. Helicoils take up less room than a normal metal insert. The tool kit sold by the vendor must be used to install them in a pre-formed hole.

**Threaded unions: HELICOILS**

| d | B |
|---|---|
| M2 | 2,1 |
| M2,5 | 2,6 |
| M3 | 3,2 |
| M3,5 | 3,7 |
| M4 | 4,2 |
| M5 | 5,2 |
| M6 | 6,3 |
| M7 | 7,3 |
| M8 | 8,4 |

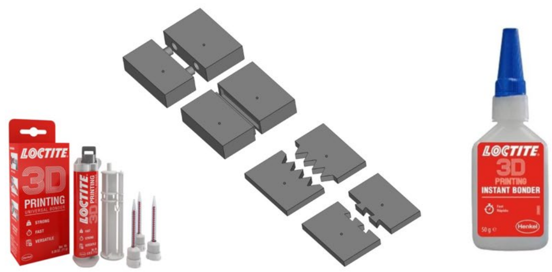
Helicoils:

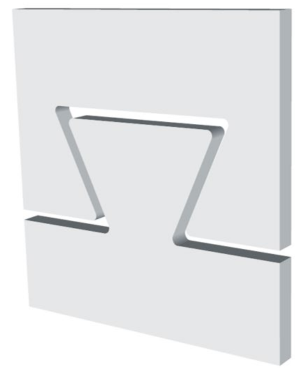
- Recommended from M2 to M8
- Hole diameter as per vendor table
  - Direct printed hole typically works with nominal diameter value
  - Other option: create smaller pilot hole and drill it later

## Bonding parts after printing

When needing to use bonders to assemble parts, the recommendation is to increase the bonding area and, if thickness allows, overlap as much as possible. You should leave a minimum clearance of 0.2 mm to 0.3 mm between interface areas, depending on the type of bonder and the printing part orientation.

| Minimum values | mm |
|---|---|
| Clearance between interface areas | 0.2-0.3 mm |

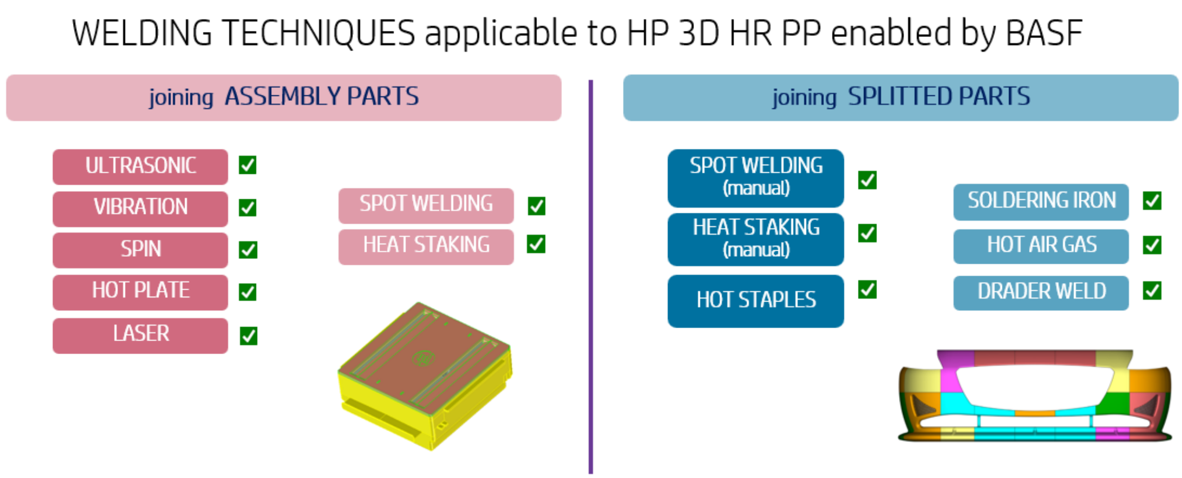


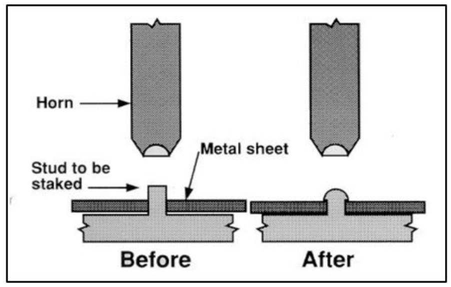
If tight accuracy on the assembly is required, trial and error with different clearances is recommended.

## Welding

HP 3D HR PP has very good welding capabilities. It can be welded to itself using many different methods, and it can also be welded properly to other injection-molded PP parts.

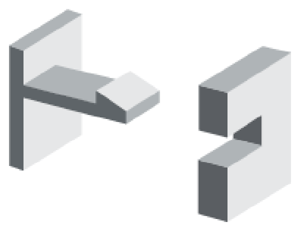


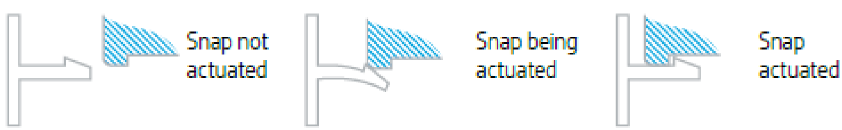
Spot welding and heat staking can be the most practical methods used for welding HP 3D HR PP parts for prototyping or final production.




## Snap-fits design

Snap-fits is another assembly method used to attach plastic parts via a protruding feature on one part, which deflects during assembly, to be inserted into a groove or a slot in the second part. They are a common mechanical joint.







$$y = \frac{P \cdot L^3}{3 \cdot E \cdot I}$$

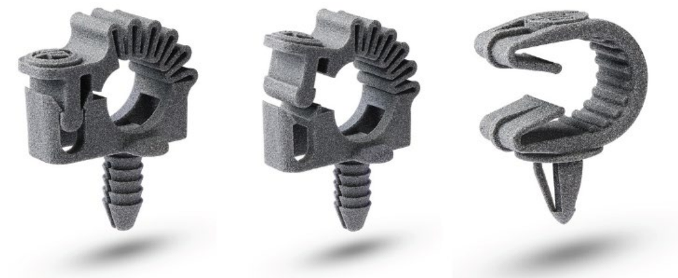
$$\sigma = \frac{P \cdot L \cdot h}{2 \cdot I}$$

$$\sigma < E \cdot \varepsilon$$

$$\text{Allowable strain } (\varepsilon) < \frac{1}{3} \cdot \textit{Material elongation at yield}$$

HP 3D HR PP elasticity and stiffness properties are suitable for creating snap-fits.

Since Multi Jet Fusion supports printing any type of geometry, snap-fits may be used and implemented easily to join printed parts while avoiding the use of other extra components, like screws and nuts.



The MJF Handbook provides a detailed guide on how to design and dimension snap-fits for your specific application. It can be downloaded at https://enable.hp.com/us-en-3dprint-mjfhandbook.



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