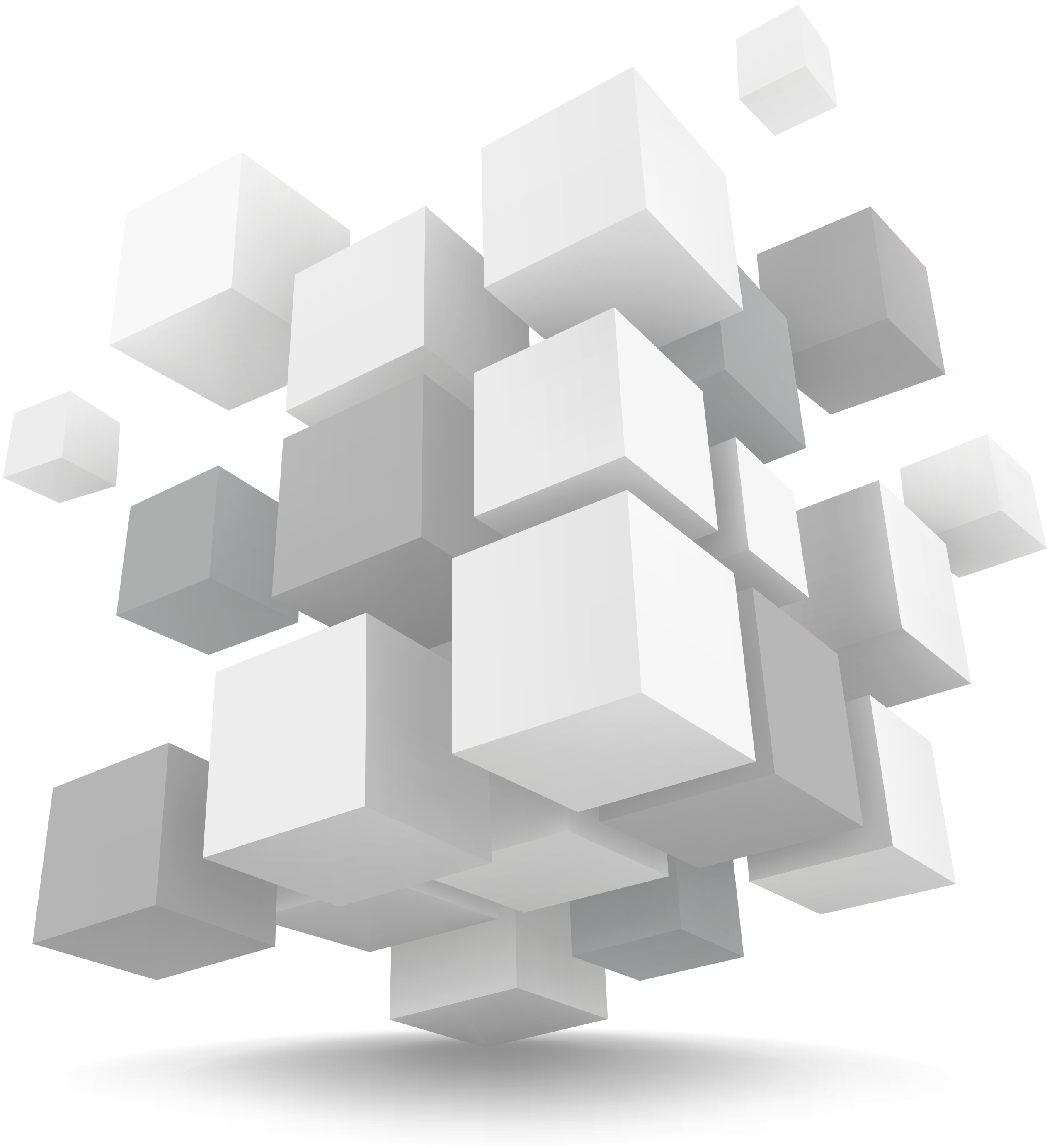
HP Multi Jet Fusion Handbook

Special edition



Best practices
Design for HP MJF: Design guidelines

Introduction

As with other 3D printing technologies, there is a set of recommendations to follow when designing for HP Multi Jet Fusion technology to ensure parts and features are printed to specification.

Wall thickness

In general, the minimum recommended wall thickness is 0.3 mm for short walls oriented in the XY plane, and 0.5 mm for short walls oriented in the Z direction.

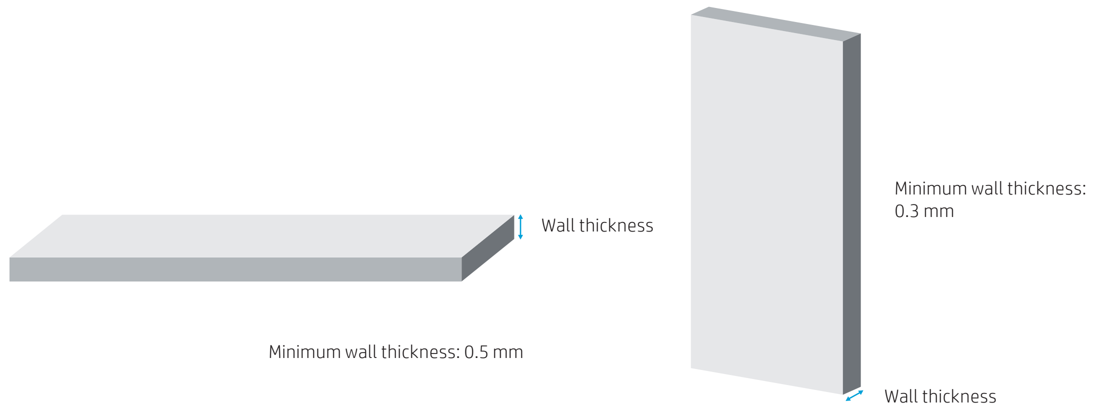


Figure 1. Minimum wall thickness

Cantilevers

When printing a cantilever, the minimum wall thickness depends on the aspect ratio, which is the length divided by the width. For a cantilever with a width of less than 1 mm, the aspect ratio should be less than 1. There are no specific recommendations for widths of 1 mm or larger. For parts with a high aspect ratio, it is recommended to increase the wall thickness or to add ribs or fillets to reinforce the part.

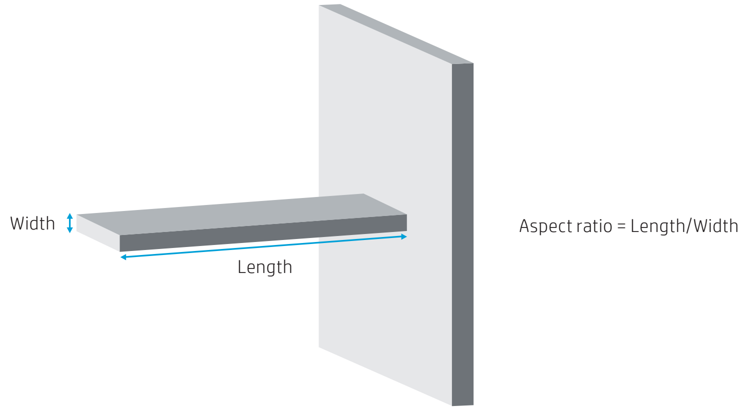


Figure 2. Cantilevers

Connecting parts

Sometimes a pair of printed parts need to fit together to form the final application. To ensure correct assembly, the minimum gap between the interface areas of these parts should be at least 0.4 mm (±0.2 mm of tolerance for each part).

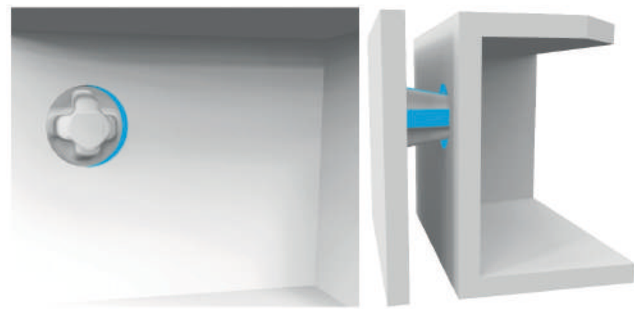


Figure 3. Minimum gap between connecting parts

Moving parts

As a general rule, spacing and clearance between faces of printed as assemblies should be a minimum of 0.7 mm.

Parts with walls with a minimum thickness of 30 mm should have a larger gap between each side to ensure proper performance.

For parts with walls that are thinner than 3 mm, the clearance between parts printed as assemblies can be as low as 0.3 mm, but this fully depends on the design, and iterations with the manufacturer may be necessary to ensure quality performance.

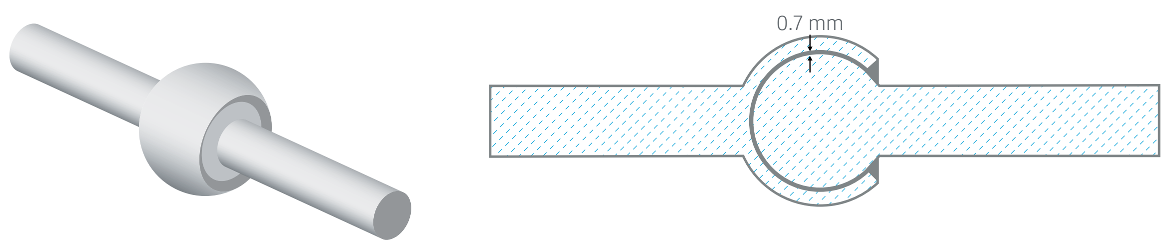


Figure 4. Minimum gap between moving parts

Thin and long parts

Thin and long parts are susceptible to non-uniform cooling, which may cause uneven shrinkage along the printed part, creating a distortion in a certain direction that deviates from the nominal shape.

As a rule of thumb, any part with an aspect ratio—length vs. width—higher than 10:1, or any part with an abrupt change in its cross-section or a predominantly long and thin curved segment is susceptible to exhibiting warpage as shown in the image below:

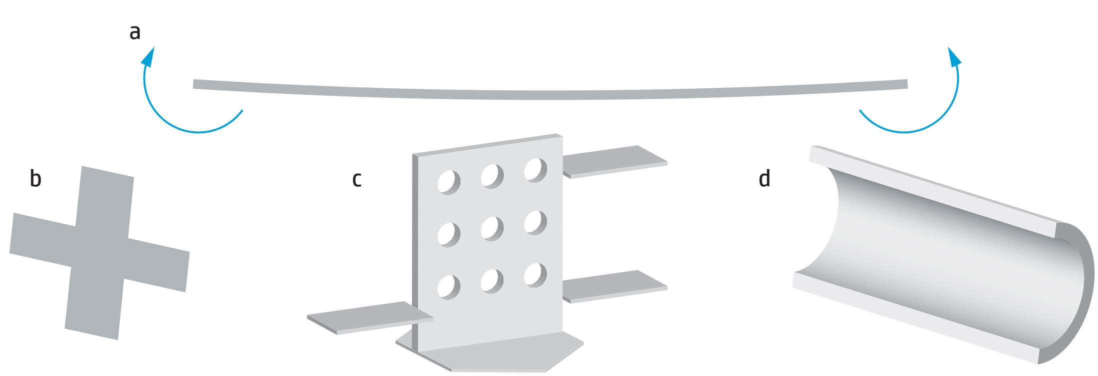


Figure 5. Part categories susceptible to shrinkage-induced warpage (a) include: thin and long parts (b), parts with abrupt changes in cross-sections (c), and thin curved surfaces (d)

To minimize the possibility of this deformation, there are several recommendations to keep in mind when designing the part:

- Increase the thickness of long walls to reduce their aspect ratios.
- Avoid ridges and ribs on large, flat areas.
- Re-design parts with high potential stresses and smoothen their cross-section transitions.
- Lighten the parts by hollowing them or by adding internal lattices.

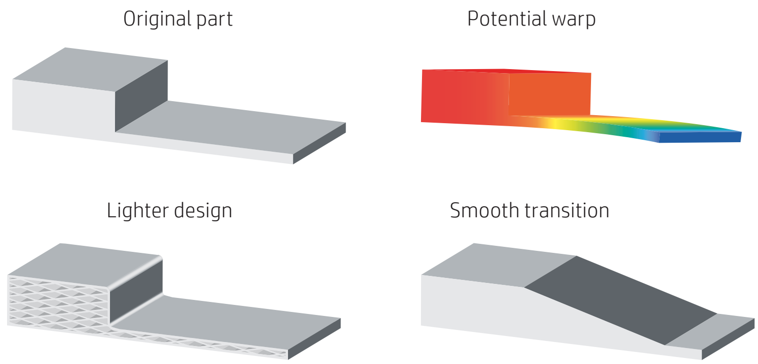


Figure 6. Warpage mitigation strategies

Design optimization strategies: Solid part or structural fill

HP Multi Jet Fusion technology allows for the printing of topology-optimized, generative designs or even small lattice structures. This kind of design allows for the creation of thinner sections, which accumulate and re-radiate less heat, improving the dimensional accuracy and general look and feel of the parts.

It also helps to reduce the weight of the part, the quantity of material, and the fluid agent used compared with fully solid designs, which not only reduces the cost of the part but also helps reduce the operating cost in applications that are very weight-sensitive.

Hollow parts

This design optimization strategy involves hollowing the model through an automatic process. (Professional software such as SolidWorks, Materialise Magics with Materialise Build Processor for HP Multi Jet Fusion technology, and Autodesk® Netfabb® have this built in.)

The minimum recommended wall thickness is 2 mm, but higher mechanical properties are achieved with thicker walls. The optimum choice is dependent upon the application.

Once the model has been printed, drain holes can be implemented in the hollow part to remove the trapped unfused powder. Otherwise, trapped unfused powder can remain 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.

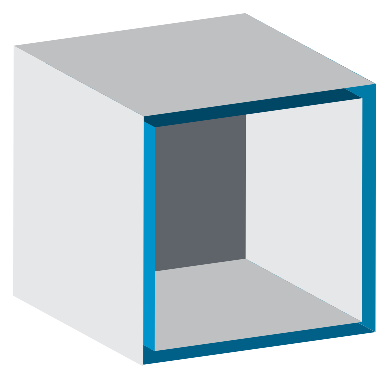


Figure 7. Example of hollow part

Leaving the powder trapped within a part also saves post-processing time since powder extraction is not required.

Lattice structures

This design optimization strategy involves hollowing a part and replacing the internal solid mass with a lattice structure that provides mechanical integrity via the collective action of many rigid cells while still noticeably reducing the part's mass and cost.

This re-design is also a fast process that can be automated with professional software such as Materialise Magics or nTopology.

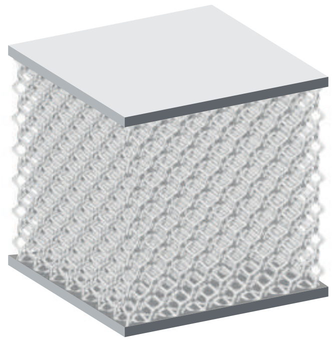


Figure 8. Example of lattice structure

Topology optimization

Topology optimization is a finite element method (FEM)–based process that finds the best distribution of material given an optimization goal and a set of constraints. Typical optimization goals are mass reduction and creating specific mechanical properties. This process requires the designer to know the part's function and load distribution in depth but provides the most optimized method of reducing weight and cost from the original design.

HP part optimized by Autodesk with Netfabb

Figure 9. Example of topology optimization

4AA7-4072ENW, February 2019

Design for accuracy
Design for HP MJF: Design guidelines

Introduction

To avoid issues with parts and to achieve maximum accuracy when designing with HP Multi Jet Fusion (MJF) technology, there are certain specifications to bear in mind.

Minimum specifications for parts

The minimum printable features in planes X, Y, and Z are as follows:

Minimum hole diameter at a thickness of 1 mm	0.5 mm
Minimum shaft diameter at a height of 10 mm	0.5 mm
Minimum printable font size for embossed or debossed letters or numbers	6 pt
Minimum printable features or details (width)	0.1 mm
Minimum clearance at thickness of 1 mm	0.5 mm
Minimum slit between walls/embossed details	0.5 mm

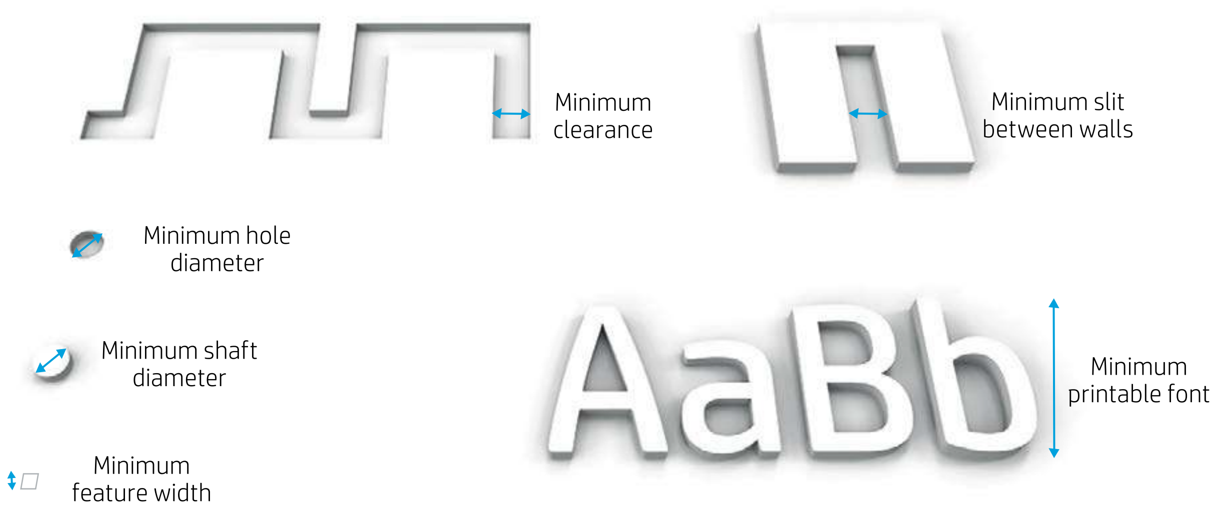


Figure 1. Minimum specification for parts

Embossed and engraved details

HP Multi Jet Fusion technology allows users to print embossed and engraved details such as letters and drawings with very high resolutions and definitions.

For the best possible output, any text, number, or drawing included in a part should have a depth or height of at least 1 mm.

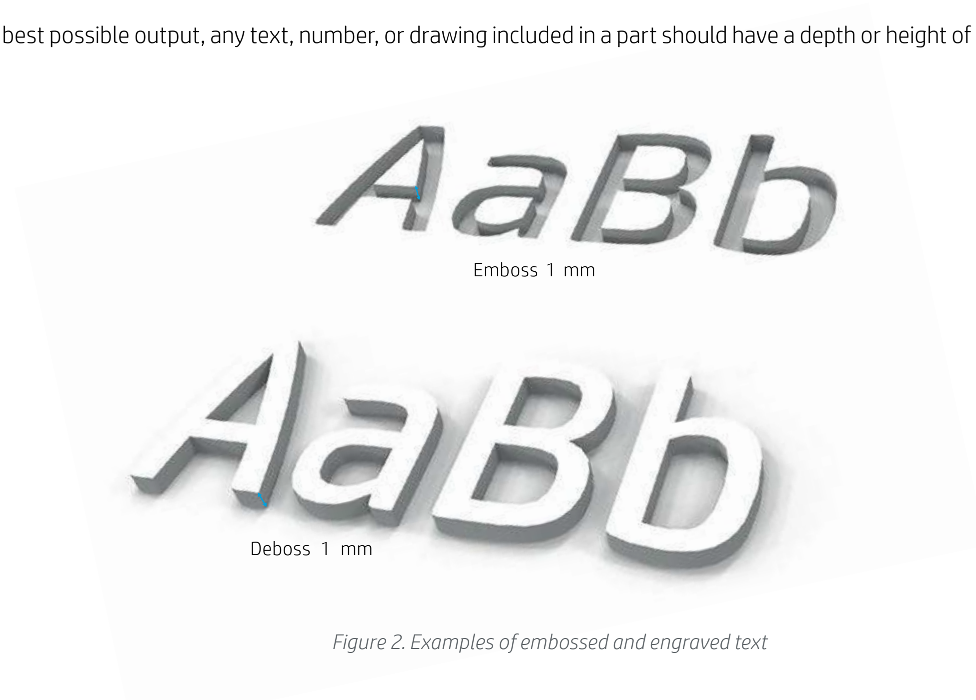


Figure 2. Examples of embossed and engraved text

Designing for accuracy guidelines

- When possible, place small features with critical dimensions—such as pins, holes, and raised texts—in the same plane.
- Design parts with a smooth cross-section transition.
- When possible, design lighter parts by hollowing them or adding internal lattices.
- Avoid long, thin, flat parts with an aspect ratio—length vs. width—higher than 10:1.
- Avoid design parts with predominantly long and thin curved segments.
- Avoid ridges and ribs on large, flat areas.

4AA7-4107ENW, October 2019

Design for aesthetics
Design for HP MJF: Design guidelines

Introduction

To print parts with optimal appearance and material properties, there are certain specifications to bear in mind.

Stair-stepping effect

All layer-by-layer manufacturing technologies require a discretization of their Z dimensions according to the layer thickness. The visibility of these layers depends mainly on their thicknesses and printing angles.

HP Multi Jet Fusion (MJF) technology uses layers of only 80 µm (0.080 mm), which are difficult to see with the naked eye in most situations. However, for small angles in the part, layered steps could become visible.

Thus, when designing parts with protruding features, it is recommended to keep angles above 20° between big, flat areas and the XY plane if they will be facing upward. Surfaces that face downward are typically exempt from stepping as long as they are oriented and avoid angles less than 5° to 10°.

These values, however, are general indications and ultimately depend on the application. For optimum results, the best solution is to try several options and choose the one that yields the better look and feel.

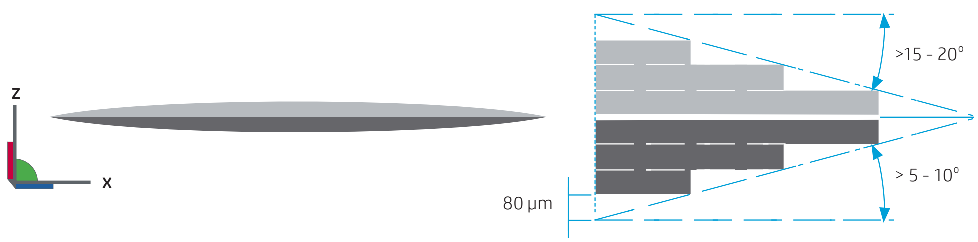


Figure 1: Stair-stepping effect

Designing for aesthetics guidelines

- When possible, place small features with critical dimensions—such as pins, holes, and raised texts—in the same plane, taking into account that areas printed facing downward would have a better look and feel than those that face upward.
- Design parts with a smooth cross-section transition.
- When possible, add internal lattices or hollow the parts to achieve a lighter design.
- Avoid long, thin, flat parts with an aspect ratio—length vs. width—higher than 10:1.
- Avoid designing parts with a predominantly long and thin curved segment.
- Avoid ridges and ribs on large, flat areas.

4AA7-4108ENW, February 2019

Design for sound
Innovative designs

Acoustic interactivity

An often-overlooked aspect of a 3D printed part is the sound it makes. We can deliberately design parts to achieve particular sounds.

Figure 1: For example, thin mobile pieces that contact each other when shaken can create a soft, silvery sound

Figure 2: Large hollow parts with reasonably thin walls and holes can create a nice resonance. In the example above, the cut-out "tongues" on the drum act like cantilevers. The tone they generate is a function of the mass of the cantilever and is therefore controlled by thickness, length, shape, and cross section

Figure 3: You can also 3D print percussive membranes, like the tambourine pictured above. Printing the tambourine with the membrane side down at a 30-degree angle helps avoid warpage of the membrane

Case study: pneumatic instruments

Designing in sections

By combining a bellow structure with other components, it is possible to make 3D printed pneumatic devices and musical instruments. The bellow parts demonstrated here are robust and flexible enough to survive sandblasting, and generate air pressure when compressed.

The prototypes consist of more than one part so that excess powder can be removed from the air chambers. They are then assembled into functional objects. The air channels in the parts are also designed to be a reasonable size to ensure that all excess powder can be released through them.

- This air pump is composed of two parts: a bellow and air valve. It blows air out when the bellow is pressed.

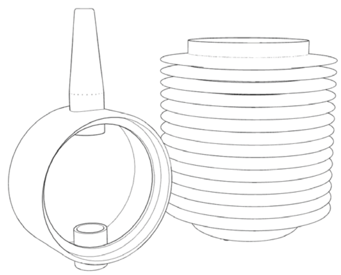


Figure 4: Air pump design

Figure 5: 3D printed air pump

Figure 6: Bellow being pressed

- This musical instrument makes a funny sound when played. A 3D printed whistle also can be attached to make a more tuned sound.

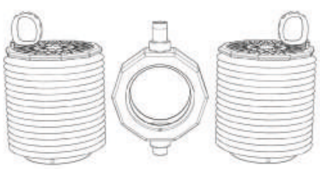


Figure 7: Musical instrument design

Figure 8: 3D printed musical instrument

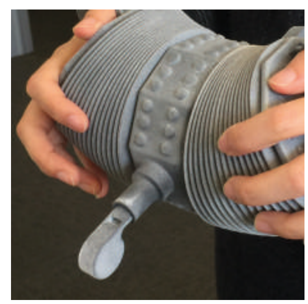


Figure 9: 3D printed musical instrument being played

- This pneumatic device can be controlled with an electronic pump. When the bellow is inflated by the pump, it expands and pushes the flexible mesh panel upward. To prevent air leakage, a pressure washer and O-ring are attached to the screw joint parts of the bellow and cap.

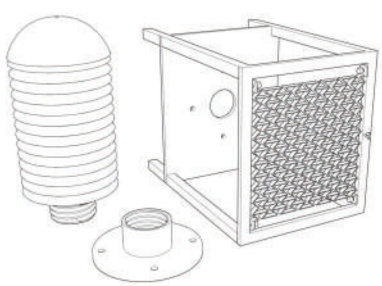


Figure 10: Pneumatic device design

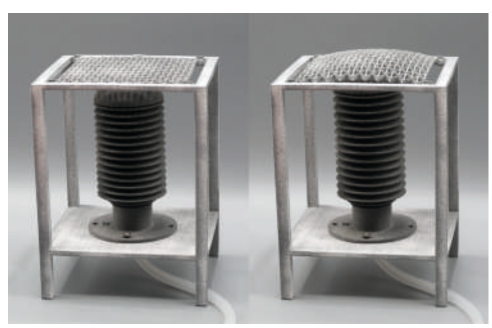


Figure 11: 3D printed pneumatic device

4AA7-5187ENW, April 2019

Design for interlocking parts
Innovative designs

Introduction

This chapter is intended as a design-oriented tool that combines reference, instruction, and inspiration, and should remain relevant as digital manufacturing processes and technologies continue to evolve. Expect to find answers to specific questions and needs, or stumble across something new to try in your digital manufacturing journey.

Chains

Basics

Chains are assemblies of interlocked links. With powder-based 3D printing, these interlocking assemblies can be printed in one go, as long as they are designed with sufficient gaps.

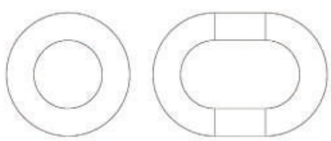


Figure 1: Example of basic links

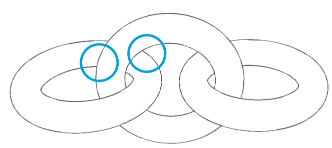


Figure 2: Ensure sufficient gaps to prevent accidental fusing

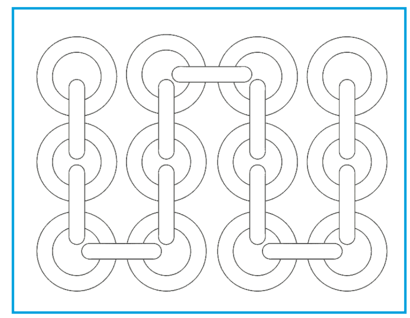


Figure 3: You can also design chains folded for compact packing and for printing parts that are longer than the print bed's dimensions.

Modifications

Thanks to 3D printing, links can be infinitely complex. They can be differently shaped, adorned, and even have additional moving parts. You can also blend different kinds of links or change scales.

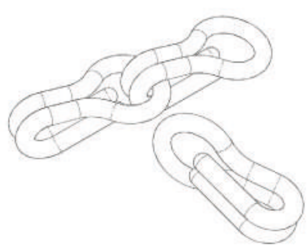


Figure 4: This chain link features an opening , which allows the chain to be re-configured after printing, as needed.

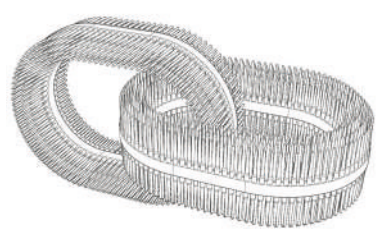


Figure 5: Textures can be added, such as the fur-like surface on the links above.

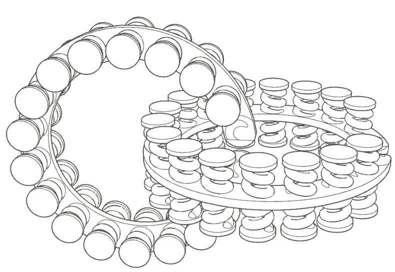


Figure 6: These rings feature both springs for texture and openings for re-configurability.

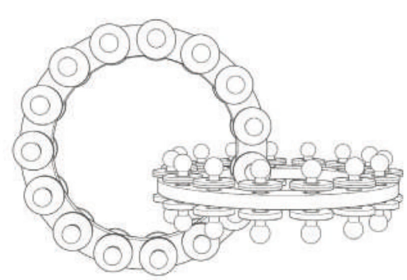


Figure 7: The disks "riveted" on these links add both acoustic and tactile properties.

Packing chains

Orientation

To avoid vertical and horizontal links, which can be cosmetically (and perhaps mechanically) different, print the chain with each link at a 45-degree angle to the print bed, alternating between -45 and +45 degrees with respect to the vertical direction.

Figure 8: Chain links oriented at 0 and 90 degrees to the print bed

Figure 9: Chain links oriented at -45 and +45 degrees to the print bed

Packing

Some chains are too long to fit in one layer of the print bed. One option is to print them in layers and then use one or more vertical links to connect the last link of a layer to the start of the one above. However, to avoid having any links (the vertical links) that look different from the others, print the chains in coiled cylinders, as shown to the left.

Start with the links at 45 degrees to the print bed and then angle each link slightly in vertical and horizontal directions. This is more easily achieved via scripting than laying out the chain by hand, but it can be done either way.

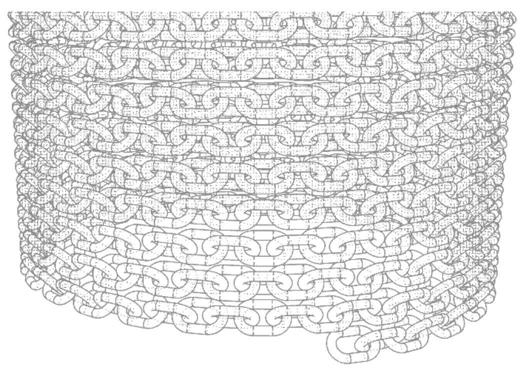


Figure 10: The bottom of a cylinder containing a chain more than 40 feet long

Measuring printed length

Note that the printed length of the chain will be longer than its apparent length in the model to be printed since the links must not touch each other while printing. The length of the final chain can be calculated as shown below. Designers may need to take this kind of expansion into account for more complicated interlocking designs like chainmail.

$$\text{Printed Length} = (\text{number}_{\text{of links}} \times \text{length}_{\text{of link}}) - (\text{number}_{\text{of links}} - 1) \times (2 \times \text{thickness}_{\text{of links}})$$

If the chain is attached to something using its first and last links, subtract another two more thicknesses of link.

Chainmail

Basics

Chainmail is a basic textile-like structure that can be made from interlocked chain links. With 3D printing, entire sheets can be printed at once. They can also be printed and folded to be larger than the print bed.

A basic four-in-one chainmail features four rings interlocking into every one, but there are many different varieties of chainmail.
An excellent resource for further tutorials is http://www.mailleartisans.org/.

How-to

For every individual ring, four other rings intersect. Ensure there are sufficient gaps, so that none of the four rings intersect with either the base ring or each other.

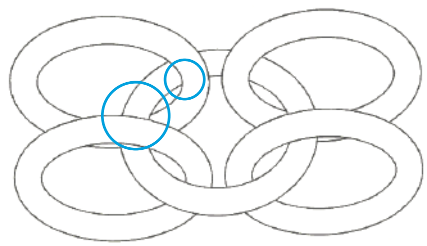


Figure 11: Ensure sufficient gaps to prevent accidental fusing

These units can be repeated in rows. In this particular example, the rings are rotated to create a 90-degree angle with one another, as each row is alternatively rotated 45 degrees clockwise or counterclockwise. However, this angle can be increased or decreased according to the design.

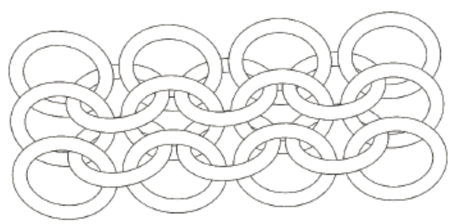


Figure 12: Chainmail design example

Modifications

Figure 13: The "riveted" disks from the chains example also work well for chainmail.

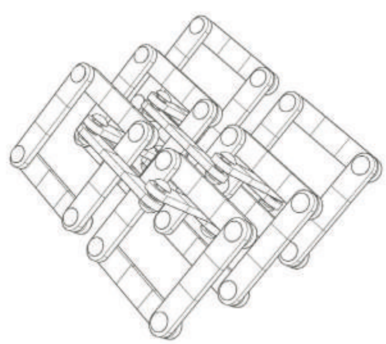


Figure 14: These hinged diamonds result in a chainmail with additional expanding properties at the link level.

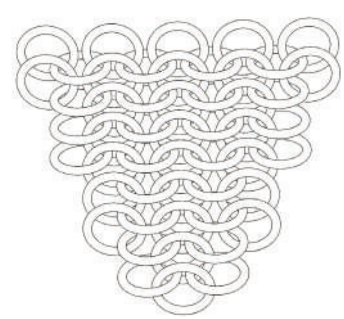


Figure 15: Chainmail pieces can also be trimmed and shaped in CAD, prior to printing.

Beyond four-in-one

3D printing makes it easier to create interlocking pieces that use more than just circles or ellipses. The following example interlocks flowers with ellipses, but you can create intricate fabrics of unlimited designs.

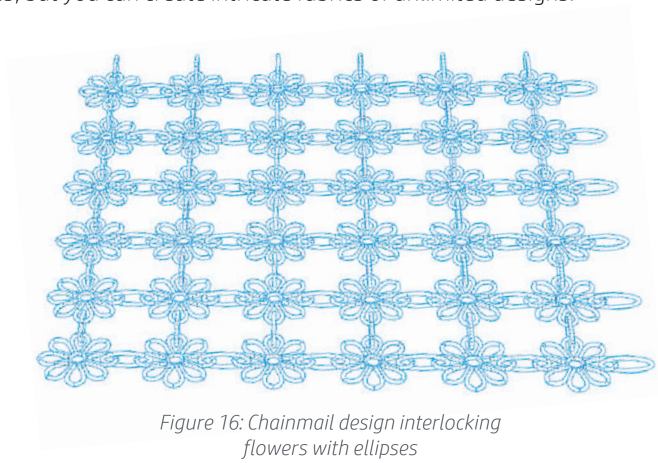


Figure 16: Chainmail design interlocking flowers with ellipses

The chainmail to the right consists of stars and two sizes of circles. The small circles connect the stars to the big circles. Note that the big circles are laid out below the stars for a more compact print job and to avoid accidental fusing. This uses a hexagonal linking pattern.

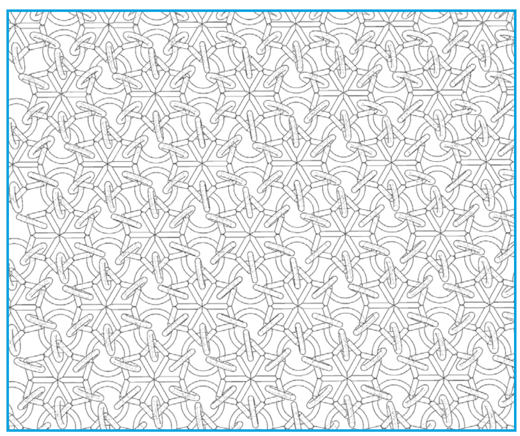


Figure 17: Chainmail design interlocking stars with circles of two different sizes

Printed examples

Figure 18: Starry chainmail

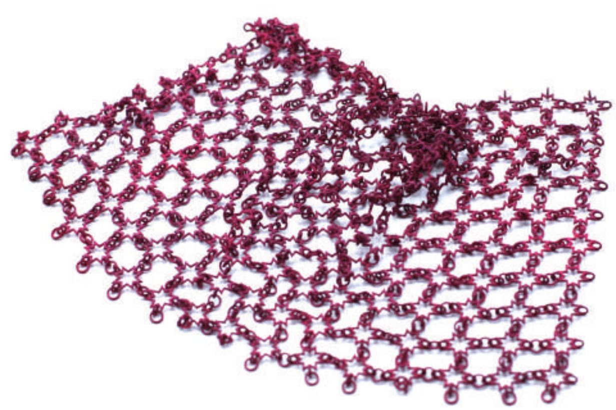


Figure 19: Star fabric

Quad-based “fabric”

Base elements

This design draws inspiration from metal fabrics, like those found in some vintage handbags. There are two base elements to this structure:

- A ring (can be a torus, extruded circle, or even octagon)
- A platform unit with four “legs.” In the example shown, the legs taper inward and emerge from a flat octagonal base.

Make sure there is a large enough gap between elements on all sides to prevent them from fusing together.

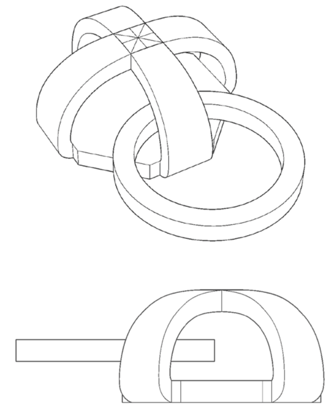


Figure 20: If your elements are too thin, they may print successfully but will fall apart in sandblasting!

Scaling

Each ring connects to four platform units, and each platform unit holds four rings. The swatch can be repeated as much as you want (or as much as will fit in your print bed). The design can also be printed folded over.

Make sure there is sufficient spacing between the elements. The proportion of ring size to platform unit size will also dictate the visual quality of the mesh and warrants experimentation.

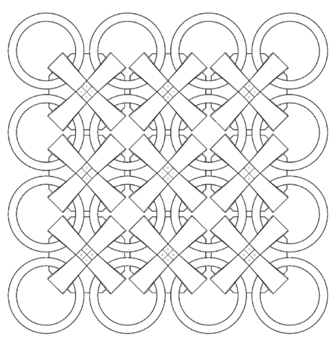


Figure 21: Conneection between quad-based "fabric" elements

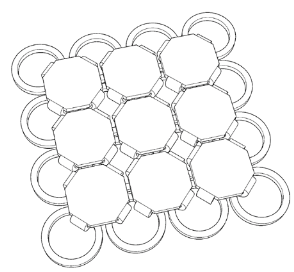


Figure 22: A quad-based "fabric" example

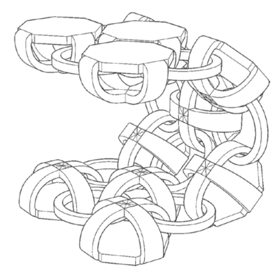


Figure 23: The folded elements shown here are bent 45, 90, and 135 degrees.

Variations

3D printing means there’s no reason the platform unit has to be flat. Here are some examples of alternative surfaces.

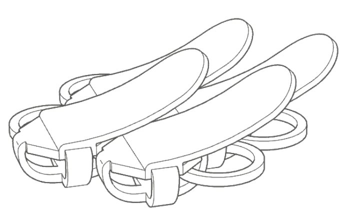


Figure 24: A layered wave pattern obscures the gaps between units.

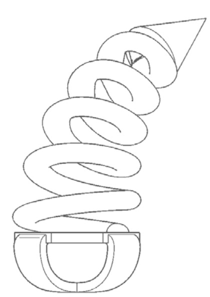


Figure 25: Springs result in novel textures.

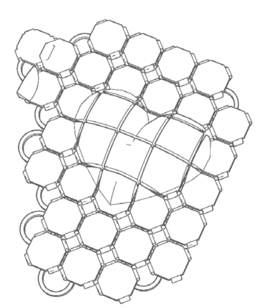


Figure 26: Create “pixellated” 3D images along the surface.

Single link mesh

How-to

3D printing allows for the combination and simplification of forms.

For example, a singular unit of angled rings can result in a single shape that can be arrayed to create a mesh.

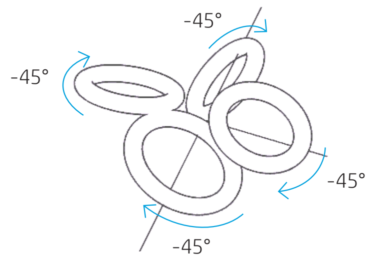


Figure 27: Angled rings resulting in a single shape

However, the shape also can be combined and reduced, only retaining the critical angles for proper interlocking.

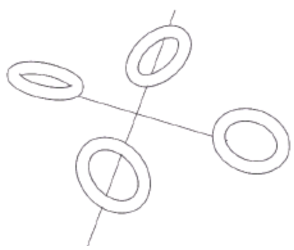


Figure 28: Angled and reduced rings

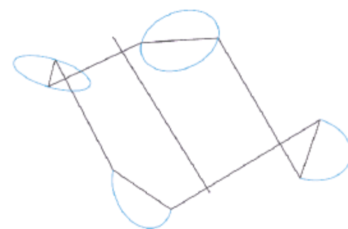


Figure 29: Angled and reduced rings resulting in a single shape

The optimized unit uses less material and looks more continuous.

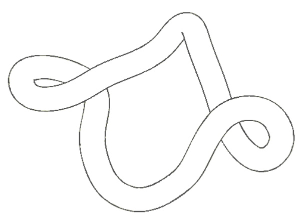


Figure 30: Optimized unit from angled and reduced rings

Example results

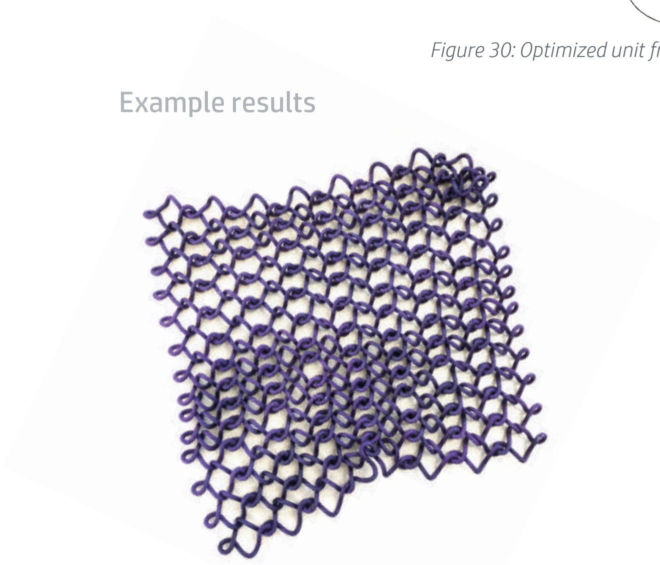


Figure 31: This design also allows for tighter vertical compression, allowing larger sheets to be printed.

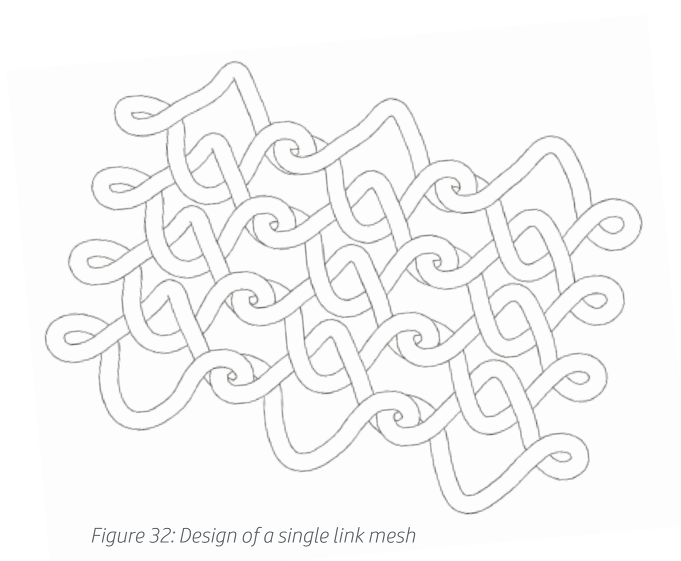


Figure 32: Design of a single link mesh

Six-in-one weave chainmail

Basics

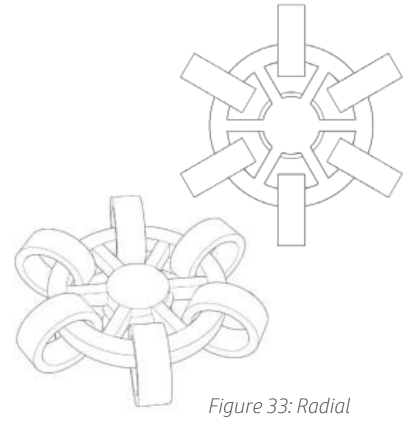


Figure 33: Radial growth design

A six-in-one weave is slightly stiffer than a four-in-one weave, and grows in a radial fashion more easily than the preceding quad-based chainmails and meshes. Generally, this weave is made of two sizes of rings, with six smaller rings fitting into one larger one.

The rings do not necessarily have to be circular. Also, the example link shown features six spokes separating the rings. However, this is a stylistic and optional choice.

Each smaller ring connects two larger ones. The increased number of connection links causes the structure to somewhat resist folding, though it is still flexible and movable.

You can also experiment with this type of interlocking design with more or fewer connection links, instead of six, to modify stiffness.

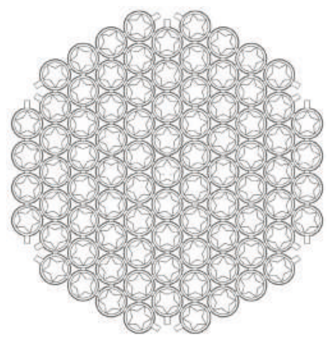


Figure 34: An example of a six-in-one weave chainmail

Modifications and applications

The flat plane provided by the larger rings provides an opportunity for developing more advanced structures.

In this example link, the spokes support a decorative panel on a flexible spring. The decorative panel gives the weave a more solid look, while the spring provides texture.

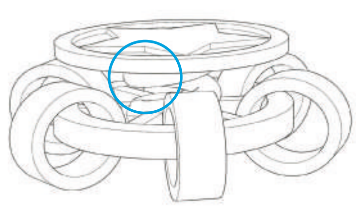


Figure 35: Make sure that any additional structures have sufficient clearance from the rings.

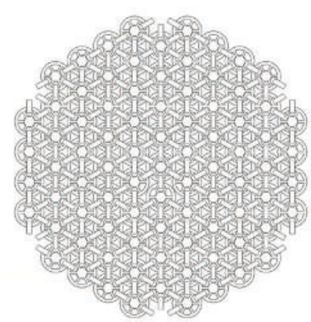


Figure 36: An advanced six-in-one weave chainmail

One example application benefiting from this structure's radial nature is a bucket hat.

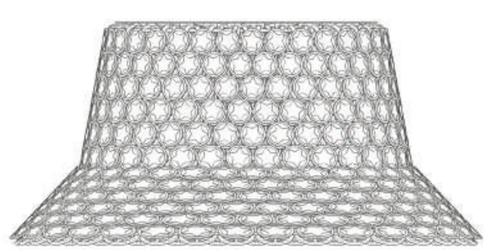


Figure 37: Bucket hat design

Hexagon-based "fabric"

A different kind of drape

As long as the elements can be easily tiled, different types of grids like this one are possible. This example uses a "sandwich" of hexagons connected by posts and linked together with triangles that circle around posts. This creates a fabric with no "wrong" side.

Hexagonal grids provide more degrees of freedom for draping compared to the quad fabrics shown before, but the use of posts here instead of the arches in the quad example can lead to a stiffer fabric if the posts are not tall enough to provide much movement.

We can easily adjust the flexibility, drape, sturdiness, weight, and other parameters of the fabric by varying the thickness of the hexagons, the height of the posts connecting the hexagons, the size of the triangle connectors, and so forth. The example fabric shown also has holes in the center of the hexagons to make it easier to clean via sandblasting.

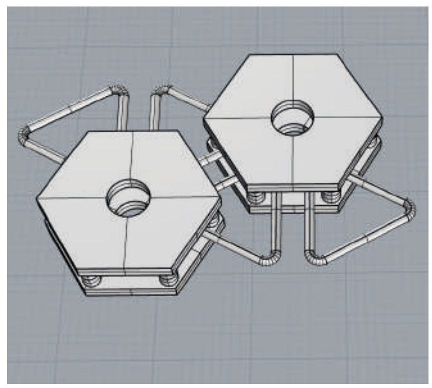


Figure 38: More information on these hexagonal units is available on the next page.

Creating larger sheets

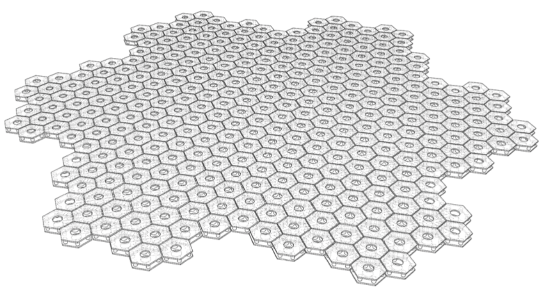


Figure 39: Hexagonal fabrics can be thought of as polar arrays instead of grids, leading to snowflake-like shapes.

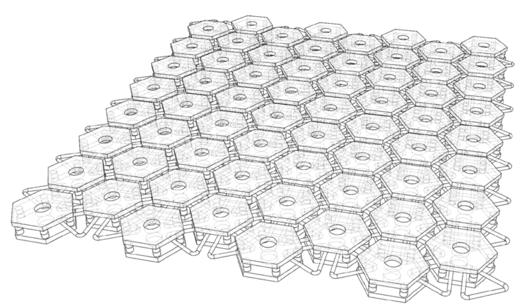


Figure 40: The easiest tiling unit to use, which is mentioned on the next page, naturally leads to offset rows and columns.

Tiling units

General considerations

For chainmail and fabric swatches, and even 3D cuboid structures, we design a "tiling unit" to lay out along one (as in a chain), two, or three dimensions. The tiling unit has connectors at the edges for the directions along which we want to tile it.

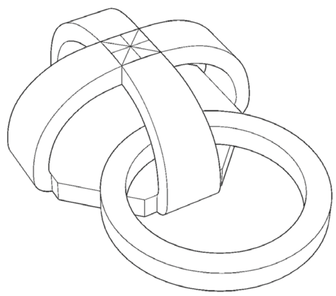


Figure 41: The quad fabric's tiling unit consists of a square with legs and a connector on the bottom right edge.

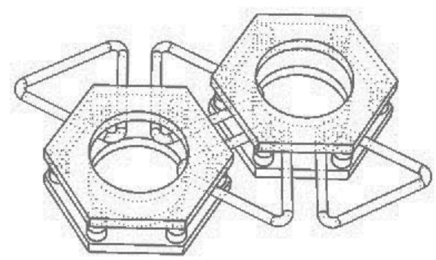


Figure 42: The hexagonal fabric uses a tiling unit consisting of a base hexagon with another one rotated to its upper right side. There are two connectors on the top of the base hexagon, and two on the bottom of the rotated hexagon.

Tiling units lend themselves to an array of functions in CAD design tools, and especially to scripting. We just determine the space we want between the units so they connect well and do not accidentally fuse. The other parameter is the number of units along the dimensions we want to tile.

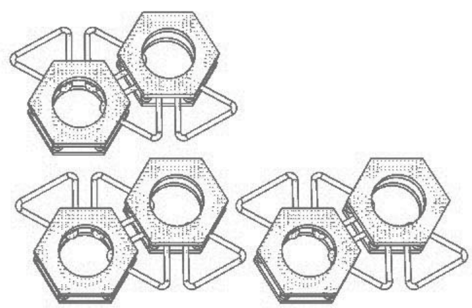


Figure 43: This example shows the hexagonal tiles in X and Y directions pulled away from each other so we can see how they connect.

Layering

3D printing allows us to combine techniques and create fabrics with several layers. This offers a great deal of room for experimentation.

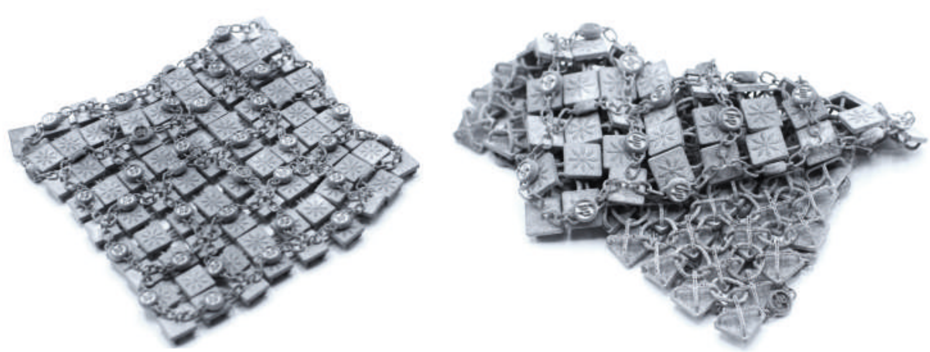


Figure 44: This example uses a quad fabric with embossed flowers and a second layer of chains and logos.

Applying interlocking swatches

Trimming

Sheets can be trimmed in CAD prior to printing to create the desired final outcomes. This is much less wasteful than printing full sheets and editing them after.

Sheets can also be folded to create larger parts, like in this shirt example.

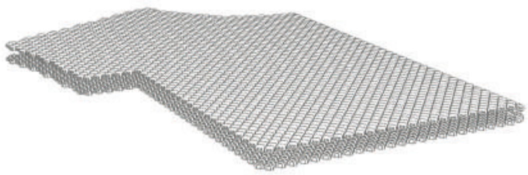


Figure 45: A shirt designed from folded sheets

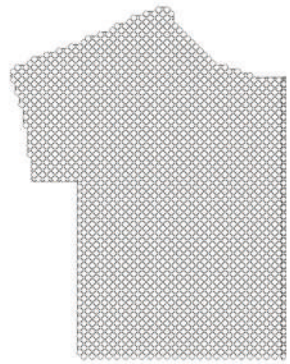


Figure 46: Top view of a shirt design

Seaming

You can design in edges to your interlocking structures by combining sheet-like structures with chain structures. Adding this border cleans up the edges.

Doing so also creates an easier, more aesthetically pleasing way to connect separate parts. For example, the skirt panel on the left can be combined with four others, with ribbon woven through the chain trim, to make a final design.

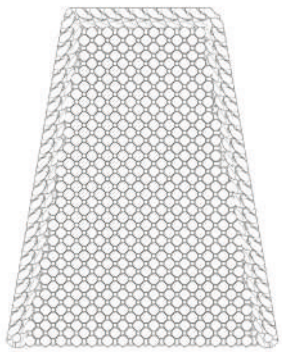


Figure 47: Sheet-like structures combined with chain structures

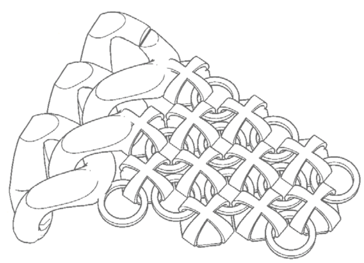


Figure 48: Edge detail

Stretching

Interlocking structure designs can also be stretched and deformed to fill in the desired shape. However, be sure to double check that the transformation does not reduce the clearance between parts too much for successful printing.

Figure 47: Bucket hat design with stretched and deformed interlocking structures

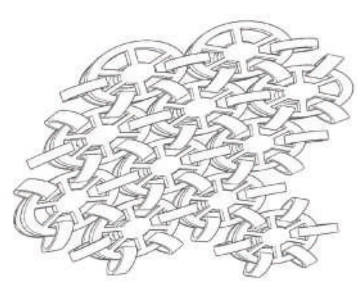


Figure 48: Design detail

Case study : 3D printed skirt

Context

Textiles have been refined over centuries of innovation, so 3D printing will likely not replace our standard daily clothing. However, in certain contexts, like the fashion-forward, open desert music festival of Coachella, an easy-to-clean plastic skirt fits right in and makes good sense.

Overall design

This skirt uses a large-grain version of the Quad-Based Mesh structure. The larger size, with 1.2 mm–thick rings holding 10 mm–wide platform units together, is robust enough to hold up, even when coming into contact with a rough dusty field. The mesh is still fine enough to create natural and comfortable movement.

Design optimization

Given HP MJF's efficient XY speed, connecting flat panels is the most efficient approach to creating the skirt. The panels were tapered to create a basic, flattering, five-panel skirt. Each panel was then lined with a thicker, twisted chain to create smooth edges and easy attachment points for final assembly.

Ribbons are woven through the chains to stitch the panels to each other. One final ribbon is threaded along the top edges. Due to the chains' compressive qualities, this ribbon helps create an adjustable waistband.

After days of wear at Coachella, the skirt was simply rinsed off with a hose and brought back to HP Labs, where it now resides in the Immersive Experiences Lab's Living Room Lab.

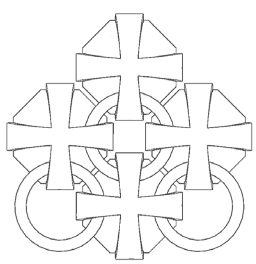


Figure 49: Design detail

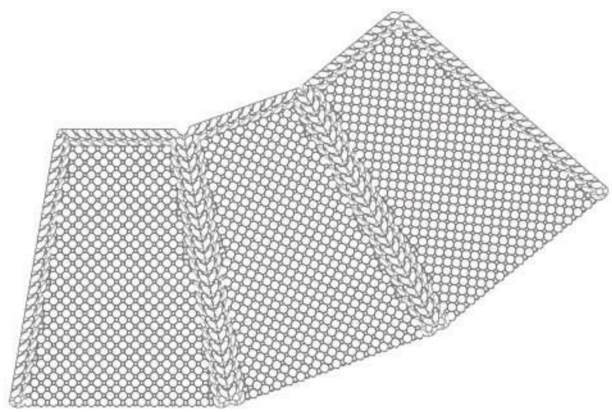


Figure 50: 3D printed skirt design

4AA7-5119ENW, April 2019

Types of fits

Design for HP MJF: Union joints design

Introduction

HP Multi Jet Fusion technology allows for the design and printing of parts that can be assembled between the parts or to other manufactured parts, such as metal parts, to create final products and functional assemblies. The mating parts can be joined by union joints such as fits, self-tapping screws, printed threads, threaded inserts, snap-fits, etc.

Fits are used to establish tolerances between inner and outer features of bearings, bushings, shafts, or drilled holes, and are often represented as a shaft and a hole, although they include other parts that are not only cylindrical.

There are two types of fits based on the allowable limits for shaft and hole size:

Clearance fit

A clearance fit leaves a space or clearance between mating parts: The hole diameter is larger than the shaft diameter. The shaft can slide and/or rotate in the hole when assembled, requiring no force.

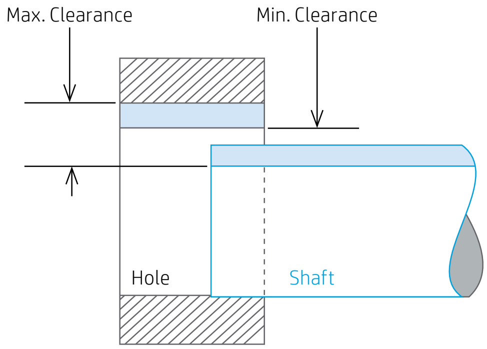


Figure 1: Clearance fit

In this type of fit, the maximum clearance is the difference between the maximum size of the hole and the minimum size of the shaft, while the minimum clearance is the difference between the minimum size of the hole and the maximum size of the shaft.

Interference fit

In an interference fit the hole diameter is smaller than the shaft diameter. This type of fit does not allow relative motion between mating parts, providing a strong connection and requiring strong force in assembly and disassembly.

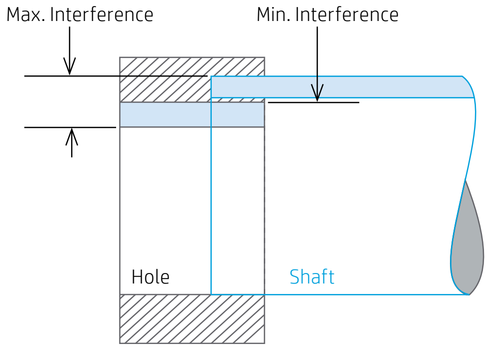


Figure 2: Interference fit

In this type of fit the maximum interference is the difference between the maximum size of the shaft and the minimum size of the hole, while the minimum interference is the difference between the minimum size of the shaft and the maximum size of the hole.

Design guidelines

Depending on how the mating parts must fit to achieve the assembly's functional needs, the required tolerances will be tighter or wider, which will determine whether additional post-processes, such as machining, are required to achieve suitable accuracy.

Standard fits

There are international standards in the metric system—ISO 286 and ANSI B4.2—and the imperial system—ANSI B4.1—that define the allowable tolerance limits that should be used depending on the type of fit required.

For example, when designing standard fits, it is common to use the International Tolerance Grades defined in ISO 286.

Each standard tolerance grade in ISO 286 establishes the allowable tolerance limits for a given dimension. As shown in the following table, a smaller IT grade provides tighter tolerances:

Standard tolerance grades	Values of standard tolerance (mm)								
	from: 1 to: 3	3 6	6 10	10 18	18 30	30 50	50 80	80 120	Nominal size (mm)
1	0,0015	0,0015	0,0015	0,0015	0,0015	0,002	0,002	0,003	Measuring tools
2	0,002	0,002	0,002	0,002	0,002	0,003	0,003	0,004	
3	0,003	0,003	0,003	0,003	0,004	0,004	0,005	0,006	
4	0,004	0,004	0,004	0,005	0,006	0,007	0,008	0,010	
5	0,005	0,005	0,006	0,008	0,009	0,011	0,013	0,015	Engineering fits, bearings, machining processes (grinding, turning)
6	0,007	0,008	0,009	0,011	0,013	0,016	0,019	0,022	
7	0,009	0,012	0,015	0,018	0,021	0,025	0,030	0,035	
8	0,014	0,018	0,022	0,027	0,033	0,039	0,046	0,054	
9	0,025	0,030	0,036	0,043	0,052	0,062	0,074	0,087	
10	0,040	0,048	0,058	0,070	0,084	0,100	0,120	0,140	
11	0,060	0,075	0,090	0,110	0,130	0,160	0,190	0,220	
12	0,090	0,120	0,150	0,180	0,210	0,250	0,300	0,350	Large manufacturing, die casting, stamping, sand casting
13	0,140	0,180	0,220	0,270	0,330	0,390	0,460	0,540	
14	0,250	0,300	0,360	0,430	0,520	0,620	0,740	0,870	
15	0,400	0,480	0,580	0,700	0,840	1,000	1,200	1,400	
16	0,600	0,750	0,900	1,100	1,300	1,600	1,900	2,200	
17	0,900	1,200	1,500	1,800	2,100	2,500	3,000	3,500	
18	1,400	1,800	2,200	2,700	3,300	3,900	4,600	5,400	

Table 1 Standard tolerance grades

Usually, the most common types of fits require very tight tolerances that cannot be achieved by designing and printing the part directly, and additional post-processes, such as machining, are required to achieve suitable accuracy.

Thus, there are some recommendations for designing a part that will need to be machined after printing to achieve the tight tolerances required. These recommendations include accurate holes and bearing housings.

Accurate holes

Depending on how the hole is machined, a pre-hole or pilot hole can be designed into the part to guide the drill bit to the appropriated location. If the part is machined directly with a drill bit size equal to the final required hole diameter, it is recommended to machine the part without a designed pre-hole, letting the CNC Machine create the pre-hole to ensure proper positioning of the drill.

When it is necessary to machine a hole with a larger diameter than the available drill head, it will need to be machined by interpolating. In this case, a pre-hole or pilot hole can be designed into the part, where the required diameter must be at least 1 mm smaller than the final hole diameter.

Bearing housing

In applications where fitting a bearing is required, it is recommended to machine it, interpolating with a smaller drill and then adjusting it to the required tolerance. Like the case mentioned above, a pre-hole can be designed to save material, where the required diameter must be at least 1 mm smaller than the final diameter to ensure a proper finish.

Figure 3: Bearings inserted into an HP MJF part

Customized fits

When designing mating parts to create functional assemblies with a non-required standard fit, it is recommended to consider the following design guidelines:

- To print a clearance fit: When inserting a metal shaft into an HP MJF part hole, the minimum clearance must be as follows:

  Clearance between mating parts >maximum size of the metal shaft + minimum size of the HP MJF part hole

- To print an interference fit: When inserting a metal pin into an HP MJF part hole, the minimum interference must be as follows:

  Interference between mating parts >minimum size of metal pin+ maximum size of the HP MJF part hole

4AA7-4113ENW, October 2019

Inserts

Design for HP MJF: Union joints design

Introduction

Threaded inserts provide a strong, reusable, and permanent thread in plastic parts, and they are typically used when frequent assembly and disassembly are required for service or repair. Threaded inserts are often available in brass, stainless steel, and aluminum, and can be installed using various techniques (e.g., heat-staking, ultrasonic vibrations, or press-in).

Recommended inserts for HP Multi Jet Fusion

Selecting the best threaded insert type and installation technique depends on a few factors, such as part application, plastic part material, and strength requirements.

HP Multi Jet Fusion parts are made of thermoplastic materials and can be re-melted and re-formed once printed. For this reason, inserts that are installed by heat-staking and ultrasonic vibrations are recommended for thermoplastic materials due to their high overall performance; however, press-in (screw-to-expand or hexagonal-shaped) and self-threading inserts may also be used in some applications.

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.

Table 1: Types of inserts

Design guidelines

Hole diameter

A pre-formed hole is necessary to install a threaded insert, so the hole diameter is a very important element in achieving the desired strength: Oversized holes will result in a reduction of the joint strength and undersized holes can potentially crack the part. Usually, suppliers of threaded inserts specify the hole diameter size and depth needed to install an insert.

The hole size is dependent upon the part orientation, and for this reason it is recommended to always print the part using the same orientation.

For this reason, it is important to take into account the insert supplier specifications and select a type of insert that is compliant with HP Multi Jet Fusion capabilities.

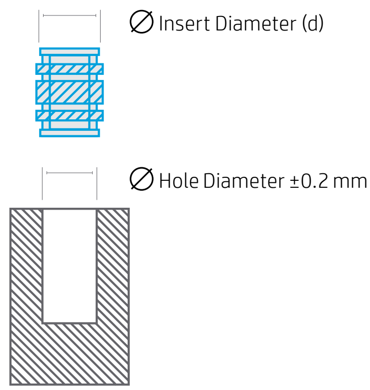


Figure 1: Hole diameter

Bosses

Bosses are typically used for mounting purposes such as attaching fasteners or as a receptacle for threaded inserts. Traditionally a boss diameter is twice the size of the external diameter of inserts that are less than 6 mm, while a 3-mm wall thickness applies to all larger inserts.

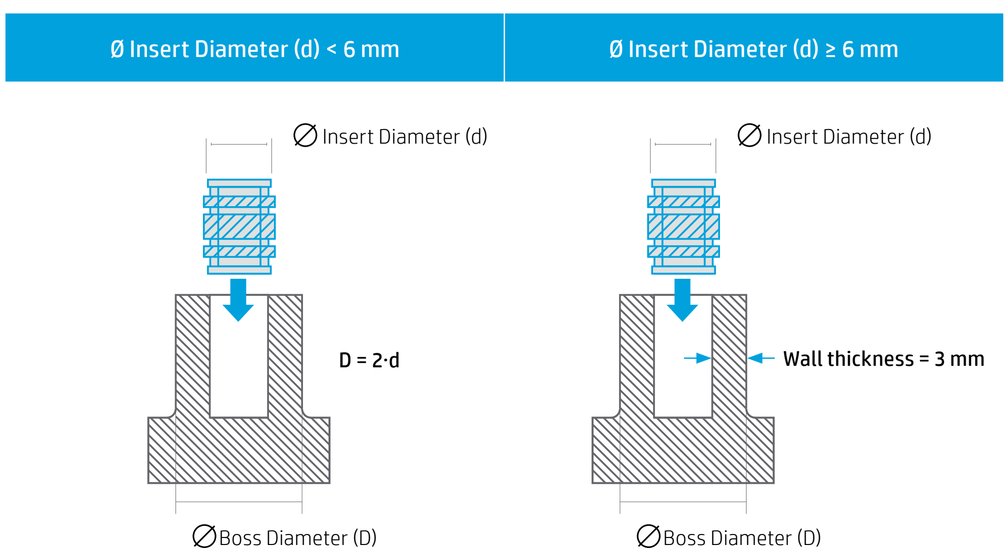


Figure 2: Boss diameter

Special consideration should be given to cold-press installations where increased stress may require larger boss diameters.

Mating part

The threaded insert—not the plastic part—should bear the load. For this reason, the diameter of the mating part hole is also important to keep the insert from being pulled through the hole.

Thus, the diameter of the mating part hole must be larger than the outside diameter of the assembly bolt but smaller than the diameter of the insert, as shown below:

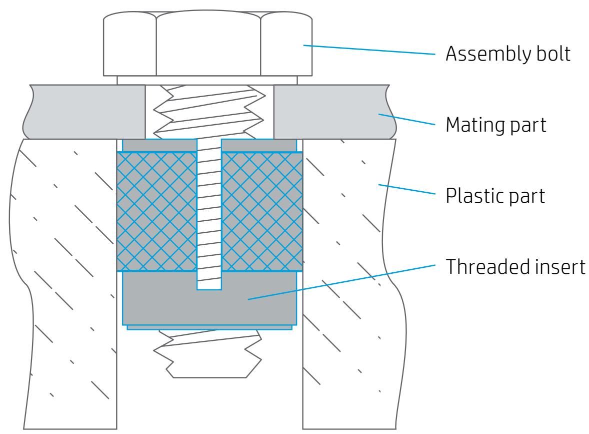


Figure 3: Threaded joint assembly

The mating part must also withstand the stress generated by the clamping force. In instances where the mating part will also be plastic, the use of a collar or a washer between the assembly bolt and the mating part should be considered.

4AA7-4111ENW, October 2019

Snap-fits

Design for HP MJF: Union joints design

Introduction

A snap-fit is an efficient assembly method used to attach plastic parts via a protruding feature on one part (e.g., a hook), which deflects during assembly to be inserted into a groove or a slot in the second part. After the assembly, the protruding feature returns to its initial position.

Snap-fits provide a simple and economical way to assemble plastic parts by drastically reducing assembly time. The way a snap-fit is designed determines whether it can be disassembled and reassembled several times and the force required to do so. This assembly method is suited to thermoplastic materials for their flexibility, high elongation, and ability to be printed into complex shapes.

HP Multi Jet Fusion technology allows for the designing and printing of parts with specific design features integrated, such as snap-fits, in order to connect them.

Types of snap-fits

The various types of snap-fits are listed below.

Cantilever snap-fit

The cantilever snap-fit is the most commonly used type of snap-fit. It consists of a cantilever beam with an overhang at the end. In this type of snap-fit there is a direct relationship between the robustness of the assembly and the strength of the snap-fit.

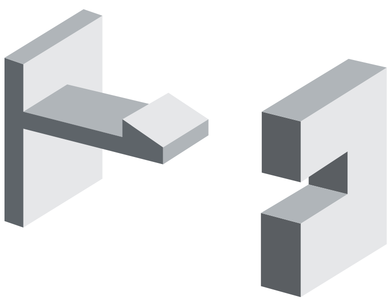


Figure 1. Cantilever snap-fit

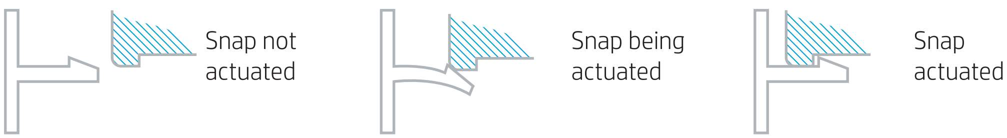


Figure 2. Cantilever snap-fit assembly operation

L-shaped snap-fit

When it is not possible to design a cantilever snap-fit without compromising the robustness of the assembly and the strength of the snap-fit due to material or geometrical constraints, an L-shaped snap-fit can be an alternative. Adding a groove to the base of the snap-fit increases its flexibility while reducing the strain on the beam, compared with a cantilever snap-fit.

Figure 3. L-shaped snap-fit

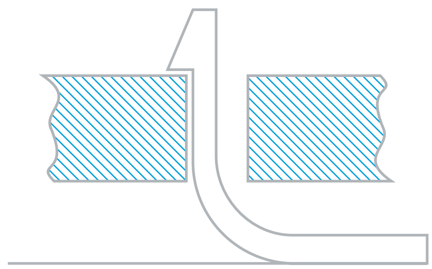


Figure 4. L-shaped snap-fit assembly operation

U-shaped snap-fit

The U-shaped snap-fit is another alternative to the cantilever snap-fit when it is necessary to increase the snap-fit flexibility within a reduced space. This U-shaped alternative is extremely flexible, and thus easier to remove. This type of snap-fit is usually used in cases where the parts need to be pulled apart repeatedly or when two parts don't require a lot of force to stay in position (e.g., in a battery compartment lid).

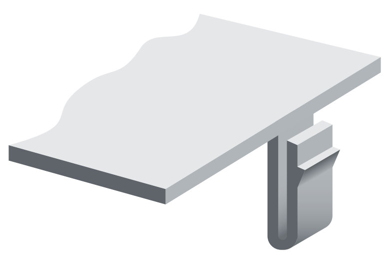


Figure 5. U-shaped snap-fit

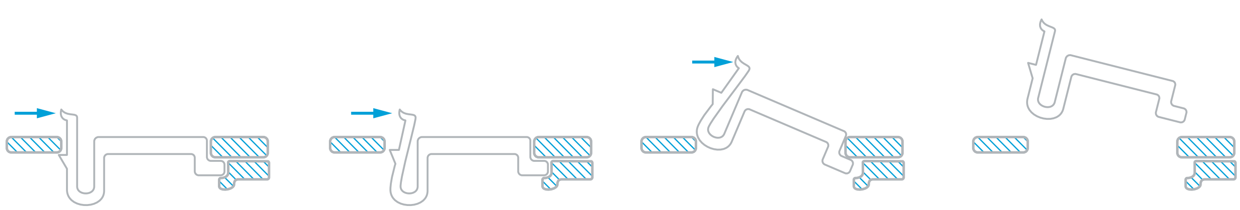


Figure 6. U-shaped snap-fit assembly operation

Annular snap-fit

The annular snap-fit is an assembly method usually used between two cylindrical or ring-shaped parts or between two rotationally symmetric parts, where the deformation required to assemble or disassemble the snap-fit is made in a 360º direction at the same time.

With this assembly method, one part is designed with an undercut and the other is designed with a mating lip. The joint occurs through the interference between both parts during the assembly operation.

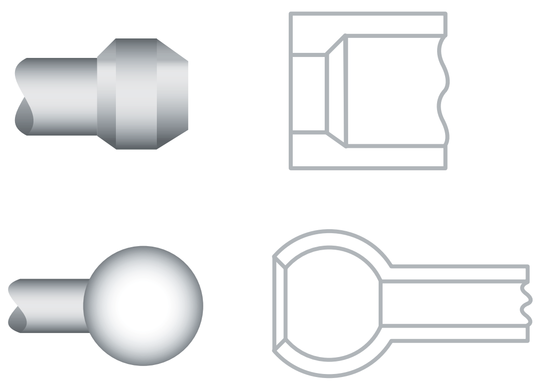


Figure 7. Annular snap-fit

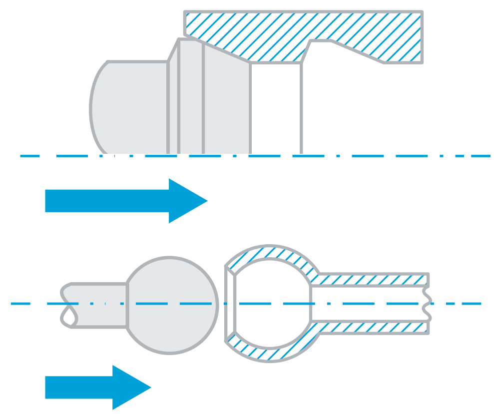


Figure 8. Annular snap-fit assembly operation

Torsional snap-fit

The torsional snap-fit is an assembly method where the flexible point is in a torsional bar instead of the self–snap-fit body. When the torsional bar is pushed down, it turns slightly and opens the joint.

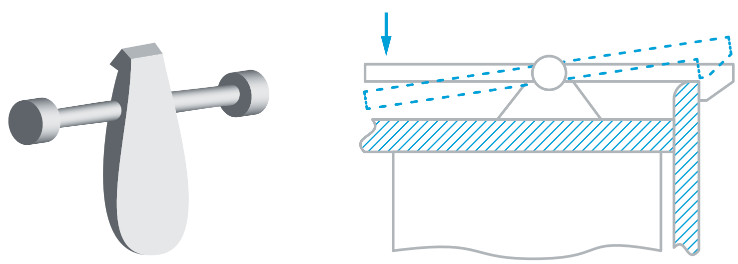


Figure 9. Torsional snap-fit

Design considerations

As mentioned previously, the most commonly used type of snap-fit is the cantilever snap-fit. When designing this type of snap-fit, it is important to design a balanced solution between the robustness of the assembly and the strength of the snap-fit cantilever beam.

This type of snap-fit can be approximated using a simplification of the general beam bending theory, which allows for the inspection of the snap-fit design feasibility. This approach models the cantilever snap-fit by a fixed-free beam with a point-applied end load:

Figure 10. Cantilever beam with a point-applied end load

Mating force and beam stress

The robustness of the assembly will be defined by the force (P) required to assemble and disassemble it. A weak force required to deflect the snap-fit beam will lead to a weak assembly that is unable to maintain the connection between both parts. Otherwise, a strong force will lead to an extremely robust assembly, which will be difficult to assemble and disassemble when required.

Moreover, the design of the snap-fit must be strong enough to resist the stress (σ) suffered by the beam when it deflects due to the mating force (P) applied, without compromising the snap-fit integrity and performance.

For this reason, the mating force (P) and the beam stress (σ) must be the main considerations when designing a cantilever snap-fit, and according to the beam bending theory, they are dependent upon the snap-fit geometry and the material used to make it.

Material and geometry dependence

Because of their direct relationship with the assembly robustness and snap-fit strength, the snap-fit material and geometry are considered the most critical design parameters, and they are often dependent upon the available design space.

For this reason, geometry and material choice are usually the first steps when designing a snap-fit.

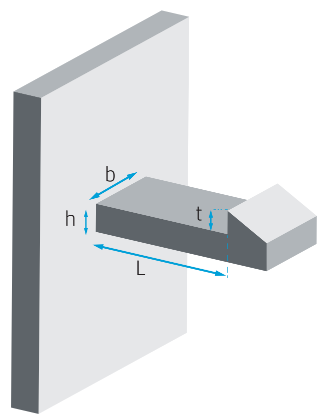


Figure 11. Snap-fit geometry

When choosing the snap-fit material and geometry (h, b, L, t), other dependent factors are clearly defined:

- Choosing the snap-fit cross-section geometry (h, b) allows the designer to calculate its moment of inertia (I), which, for a cantilever beam with a rectangular cross-section, is as follows:

$$I = \frac{b \cdot h^3}{12}$$

- Once the printing material is selected, the modulus of elasticity (E) is made clear since it is often provided in the material datasheet.

The product of the moment of inertia (I) and the modulus of elasticity (E) is known as the beam flexural rigidity (EI).

According to the beam bending theory, these dependent parameters, along with the snap-fit material and geometry, have a direct relationship with the required mating force (P) and the beam stress (σ), as shown below:

- Deflection (y) at the end of a cantilever beam with a point-applied end load:

$$y = \frac{P \cdot L^3}{3 \cdot E \cdot I} \quad (1)$$

- Maximum stress (σ) in a cantilever beam with a uniform rectangular cross-section:

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

The minimum amount of deflection (y) at the end of the cantilever beam required to assemble and disassemble the snap-fit is usually a known parameter dependent upon the geometric constraints and the available design space. In fact, it is defined by the depth (t) of the snap-fit overhang:

- The minimum amount of deflection (y) must be at least equal to the depth (t) of the snap-fit overhang to allow a proper assembly and disassembly operation.

$$y \geq t$$

- A deeper overhang will lead to a strong assembly, but it will mean that the beam must deflect further and, as a consequence, it will require a greater matting force (P)—as shown in equation (1) —and the beam stress (σ) will also increase—as shown in equation (2)-.

Design calculations

The first step in checking the snap-fit design feasibility is to calculate the resultant mating force (P) and to check whether it is suitable. This calculation can be done by solving the equation (1) for P:

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

Based on the equation (3), the force (P) is dependent upon how much farther the snap-fit beam must deflect (y), but it also will depend on the material resistance against the bending deformation, which is known as beam bending stiffness (k), and its function of the beam flexural rigidity (EI), the length (L) of the beam, and beam boundary condition:

$$P = k \cdot y \quad (4)$$

The suitable mating force (P) value should not be greater than 50N to 100N, which is considered an ergonomic value for an estimated finger strength average.

Once the mating force (P) has been calculated and it results in a suitable value, the second step to check the snap-fit feasibility is to calculate the stress (σ) in the cantilever beam based on the equation (2).

If the beam stress (σ) is above the yield strength of the material, the snap-fit will deform, and some part of the deformation will be permanent and non-reversible, thus compromising the snap-fit performance and strength up to rupture.

$$\text{Beam stress } (\sigma) < \text{Material yield strength} \quad (5)$$

Considering that the yield strength is not a common property specified in technical datasheets when producing plastic parts, the best option to calculate the snap-fit strength is to use the material allowable strain (ε) and modulus of elasticity (E):

$$\text{Beam stress } (\sigma) < E \cdot \varepsilon \quad (6)$$

In order to obtain the allowable strain (ε) value, designers can refer to usual recommendations for other plastic manufacturing processes such as Injection Molding:

$$\text{Allowable strain } (\varepsilon) < \frac{1}{3} \cdot \text{Material elongation at yield} \quad (7)$$

All design considerations are shown in the following flowchart:

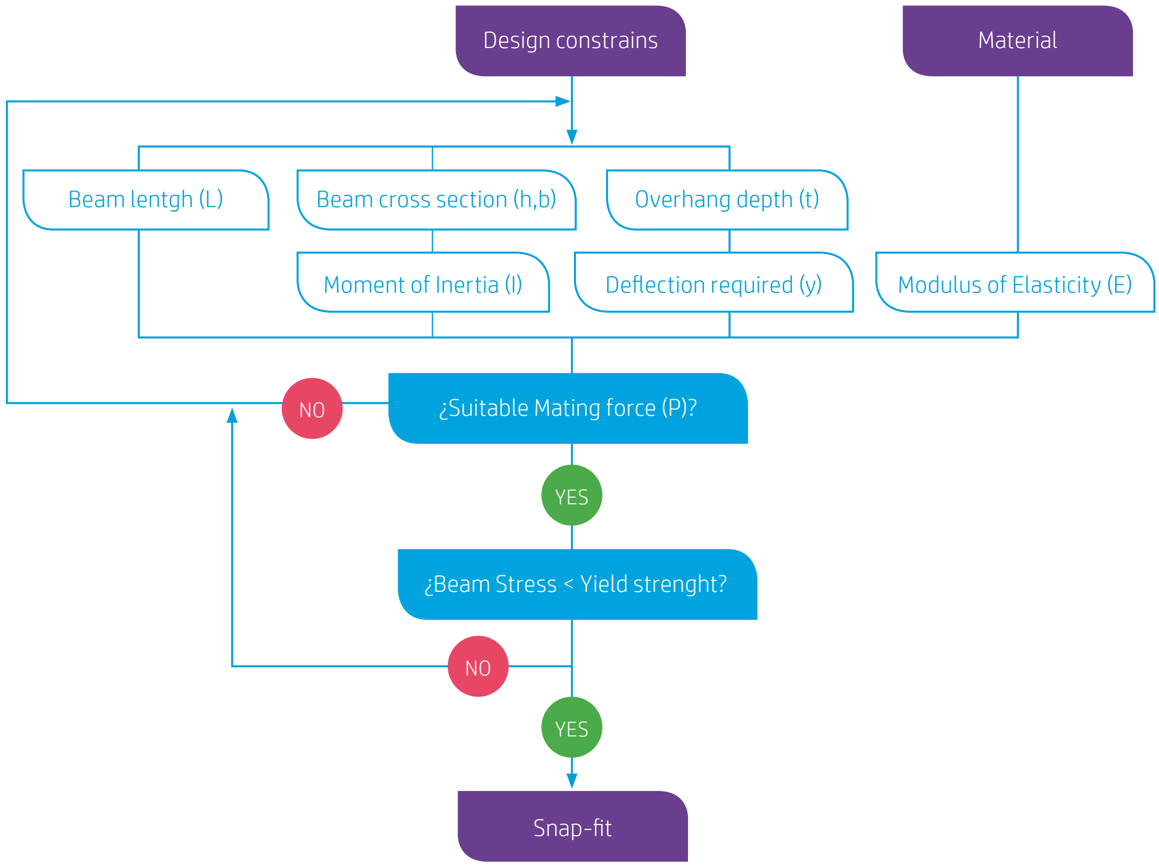


Figure 12. Design snap-fit flowchart

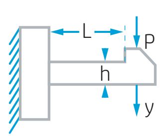
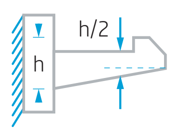
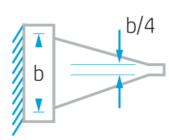
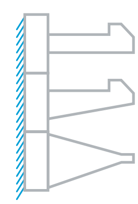
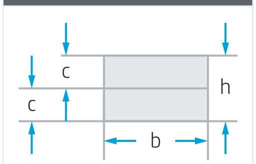
	(Permissible) deflection			Deflection force
Type of design				
Shape of the cross section  Rectangle	$y = 0.67 \cdot \frac{\varepsilon \cdot L^2}{h}$	$y = 1.09 \cdot \frac{\varepsilon \cdot L^2}{h}$	$y = 0.86 \cdot \frac{\varepsilon \cdot L^2}{h}$	$P = \frac{bh^2}{6} \cdot \frac{E\,\varepsilon}{L}$

*Figure 13. Snap-fit calculation equations**

**Note 1: Beam deflection (y) expressed in terms of allowable strain (ε), based on equations (1), (2)*
**Note 2: Mating or deflection force (P) expressed in terms of allowable strain (ε), based on equation (2)*

Design guidelines

There are several design recommendations when designing snap-fits with HP Multi Jet Fusion:

Minimum thickness (h)

The minimum recommended thickness at the base of the cantilever is 1 mm.

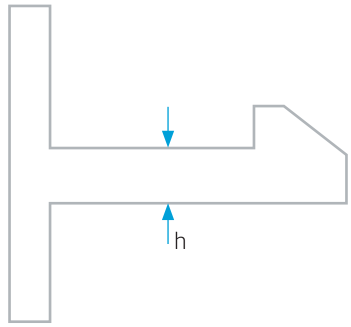


Figure 14. Minimum thickness at the base of the cantilever

Minimum overhang depth (t)

The minimum overhang depth (t) should be at least 1 mm.

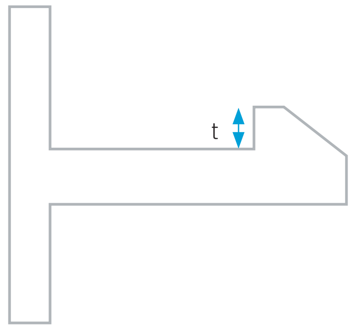


Figure 15. Minimum overhang depth (t)

Recommended common radius

It is recommended to add a common radius at the base of the cantilever to avoid sharp corners and reduce the stress concentration. This common radius should be at least half of the thickness (h) of the base of the cantilever.

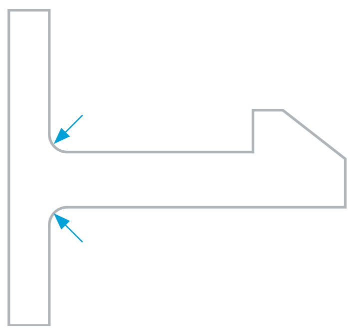


Figure 16. Common radius

Snap-fit overhang

It is recommended to avoid sharp edges at the end of the snap-fit overhang, adding a small chamfer to prevent breaking during the assembly operation.

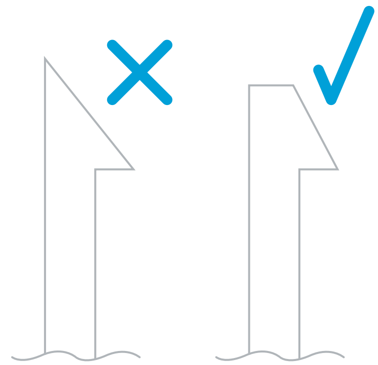


Figure 17. Snap-fit overhang

Assembly angle (α)

As mentioned previously, the snap-fit overhang usually has a gentle chamfer to facilitate the assembly operation. The inclination of this chamfer angle (α) directly affects the mating force (P). If the angle (α) is reduced, the mating force (P) will also reduce. The recommended assembly angle value should be between 35º and 40º.

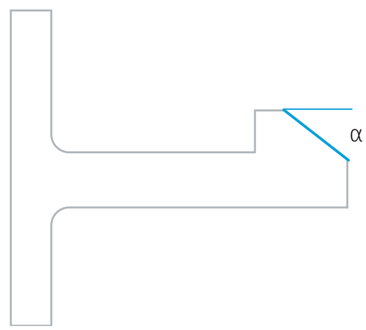


Figure 18. Assembly angle

Disassembly angle (β)

The way the overhang is designed determines whether the snap-fit can be disassembled and reassembled several times. The disassembly angle (β) affects the ease of joint disassembly. For example, a 90º angle (β) can never be disassembled. However, a snap-fit with a disassembly angle (β) equal to the assembly angle (α) will need the same mating force (P) for both operations.

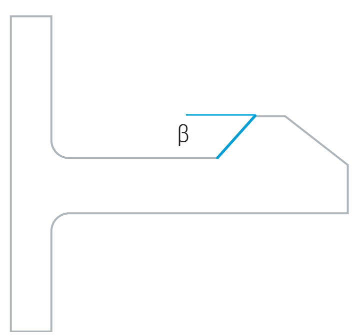


Figure 19. Disassembly angle

Tolerances between parts

When designing a snap-fit, there must be a gap between the protruding feature and the groove to ensure a proper performance, even including the worst tolerance case as shown in the following figure:

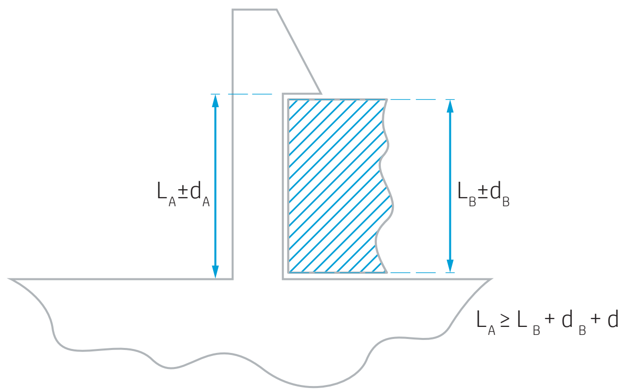


Figure 20. Tolerances between parts

Modifying the mating force (P)

Sometimes, after choosing the snap-fit material and geometry, the resulting mating force (P) is a non-desirable value. Based on the equation (3) and bearing in mind that when designing a snap-fit, the most common restrictive tolerances are the length (L) of the beam and the depth (t) of the overhang, the most common solution when modifying the mating force (P) is needed is to change the cantilever cross-section (h, b).

Reducing the mating force (P) will also reduce the beam stress (σ).

Tapered beam

One of the most recommended changes in the snap-fit cross-section is to design a tapered beam. While a snap-fit beam with a uniform cross-section has an uneven distribution of strain and concentrates the stress at its base, a tapered beam uses less material and results in a more even distribution of strain throughout the cantilever, thus reducing stress (σ) concentration and the assembly and disassembly force (P).

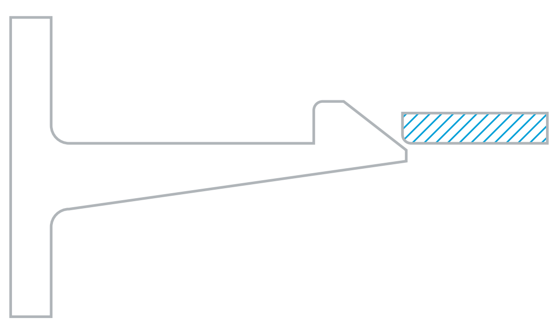


Figure 21. Tapered beam

Printing orientation

There are some recommended orientations when printing a snap-fit regarding its accuracy and proper performance.

For tight snap-fits

When printing tight snap-fits where the length of the beam (L) is critical, the XY plane orientation is recommended to achieve the best accuracy and, thus, a better performance.

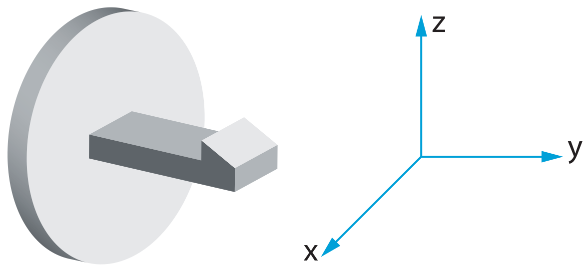


Figure 22. XY plane orientation

When the width of the snap-fit (b) is critical, the XZ or YZ plane orientation is recommended to achieve the best accuracy and to avoid excessive clearances on the XY plane, which can lead to noise and vibrations.

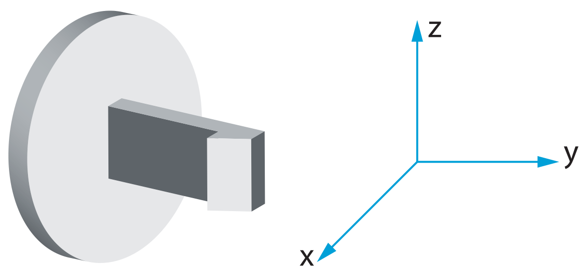


Figure 23. XZ or YZ plane orientation

To reduce printing issues

Printing the snap-fit inclined slightly in the X, Y, and Z axes can reduce the likelihood of typical printing issues.

Post-processing recommendations

HP MJF technology allows for different post-processing methods that can affect the finishing of the printed part. Although most of the post-processing methods should not affect a 3D printed snap-fit, there can be some automatic post-processes that affect it, such as the tumbler post-process.

The tumbler post-process involves hitting the 3D printed part with small abrasive pellets in order to reduce its roughness. In return, some dimensions and/or small features can be affected by the process.

In the case of the snap-fits, a tumbler process can reduce the mating force (P) of the assembly and even break it depending on the snap-fit geometry.

For this reason, if automatic post-processes are required, it is recommended to protect the part with a sinter box to prevent damage.

Calculation example

The following figure illustrates the calculation needed when designing a cantilever snap-fit.

In this particular case, a clipping system for an optical sensor must be designed as follows:

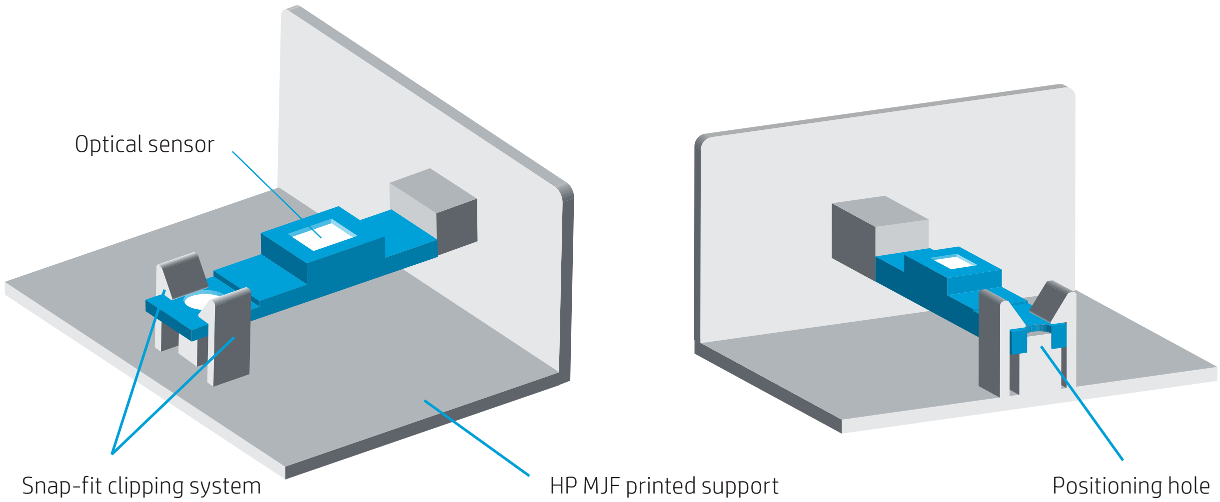


Figure 24. Optical sensor clipping system

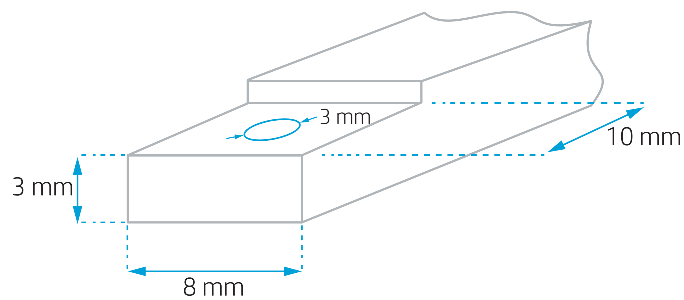


Figure 25. Optical sensor dimensions

The design requirements are listed below:

- The material used to print the part is HP 3D HR PA 12, with an elastic modulus of elasticity (E) of 1800 MPa.
- Due to optical requirements, the sensor must lay 5 mm above the base. Thus, the snap-fit total length must consider the worst-case tolerances and the optical requirements:

$$L = 3\text{ mm} + 0.1\text{ mm} + 5\text{ mm} + 0.2\text{ mm} + 0.2\text{ mm} = 8.5\text{ mm}$$

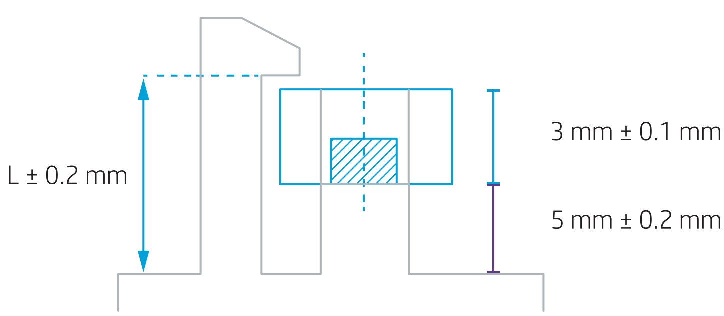


Figure 26. Snap-fit length calculation

- Due to constructive constraints, the snap-fit cannot overlap the positioning hole, which means that the overhang depth (t) must be between 1 mm—the minimum recommended value—and 2.5 mm—the maximum allowable distance to avoid contact between the snap-fit overhang and the sensor positioning hole:

$$\text{Overhang depth } (t) = y = 1 \text{ mm}$$

- The width must be smaller than 10 mm due to geometrical constraints:

$$b = 9.5 \text{ mm}$$

Once the snap-fit material and geometry (h, b, L, t) are clearly defined, the resulting mating force (P) must be calculated to check whether it is suitable. This calculation can be done using the equation (3):

$$P = \frac{3 \cdot E \cdot I \cdot y}{L^3} = \frac{3 \cdot E \cdot (b \cdot h^3) \cdot y}{12 \cdot L^3} = \frac{3 \cdot 1800MPa \cdot 9.5 \text{ mm} \cdot (1.5 \text{ mm})^3 \cdot 1 \text{ mm}}{12 \cdot (8.5 \text{ mm})^3} = 23.49N$$

The calculated mating force (P) value is inside the ergonomic range. Therefore, based on the equation (2) and (6), the next step is to check the strength of the snap-fit calculating the allowable strain (ε):

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

$$\varepsilon = \frac{P \cdot L \cdot h}{2 \cdot I \cdot E} = \frac{12 \cdot P \cdot L \cdot h}{2 \cdot (b \cdot h^3) \cdot E} = \frac{12 \cdot P \cdot L}{2 \cdot (b \cdot h^2) \cdot E} = \frac{12 \cdot 23.49N \cdot 8.5 \text{ mm}}{2 \cdot (9.5 \text{ mm} \cdot (1.5 \text{ mm})^2) \cdot 1800 \text{ MPa}} = 0.03 = 3\%$$

The calculated allowable strain (ε) shows that the snap-fit does not deform when it deflects due to the mating force (P) applied, without compromising its integrity and performance.

4AA7-4114ENW, February 2019

Threaded unions

Design for HP MJF: Union joints design

Introduction

The most widely used types of joints are screws and threaded parts because they can be disassembled several times and create strong and durable joints. The use of threads in plastic parts is common in the design of caps and customized fasteners or to join tubes.

General recommendations

HP Multi Jet Fusion technology allows users to print external and internal threads inside the part, eliminating the need for mechanical thread-forming operations.

It is recommended to print external and internal threads in sizes larger than 6 mm (M6 or ¼ inch per the Imperial system) to achieve favorable results in all printing orientations. If a small thread (less than 6 mm) is needed, it is recommended to use self-tapping screws, threaded inserts, or to machine the thread for the small tolerances required in these sizes.

Tolerances are dependent upon the material, print mode, and post-processing selected. For this reason, it is recommended to first validate the design with different offsets before printing multiple parts.

Design guidelines

Self-tapping screws

Although HP Multi Jet Fusion technology allows for the printing of small features such as external and internal threads inside the part, when a small thread (up to 6 mm) is needed, it is recommended to use self-tapping screws, which tap their own threads as they are driven into the part. Certain types of self-tapping screws require a pre-formed hole, the dimensions of which can be recommended by the screw supplier.

Figure 1: Self-tapping screw

Machined threads

Another alternative when a small thread (up to 6 mm) is needed is to machine the part after printing it in order to achieve the required accuracy. The tools recommended for machining HP Multi Jet Fusion parts are the same as other technical plastics. Although not recommended, tools for machining metals like steel or aluminum may also be used.

A standard machining process can achieve dimensional tolerances up to ±0.05 mm.

Internal threads

To machine an internal thread, it is necessary to start from a pre-formed hole and then machine the thread using the required tap. To design the pre-hole on the printed part, designers can refer to usual drill size recommendations for plastic and metal. For example, drill size recommendations for metric plastic threads are shown in the following table:

1. ISO Standard metric threads

ISO Metric thread size	Drill size (mm)
M3	2,5
M4	3,3
M5	4,2
M6	5
M8	6,8
M10	8,5
M12	10,2
M16	14
M20	17,5
M24	21
M30	26,5
M36	32
M42	37,5
M48	43
M50	47
M56	50,5

2. ISO Fine metric threads

ISO Metric thread size	Drill size (mm)
M3 x 0,35	2,65
M4 x 0,5	3,5
M5 x 0,5	4,5
M6 x 0,75	5,2
M8 x 1	7
M10 x 1,25	8,8
M12 x 1,25	10,8
M16 x 1,5	15,4
M20 x 1,5	18,5
M24 x 2	22
M30 x 2	28
M36 x 3	33

3. Whitworth threads

Thread size (inches)	Drill size (mm)	
	BSW	BSP
1/16	1,2	--
3/32	1,8	--
1/8	2,6	8,9
5/32	3,1	--
3/16	3,6	--
7/32	4,4	--
1/4	5,1	11,9
5/16	6,5	--
3/8	7,9	15,4
1/2	10,5	19
5/8	13,5	--
3/4	16,5	24,7
7/8	19,3	28,4
1	22	30,8
1 1/8	24,8	35,5
1 1/4	27,8	39,4
1 3/8	30,5	42
1 1/2	33,5	45,4

Table 1: Drill size recommendations for plastic threads

Usually when machining metal parts, a set of three taps must be used to complete the process. With HP plastic materials, this can be reduced and only the final tap is needed due to the low hardness of HP material compared with the steel material of the tap.

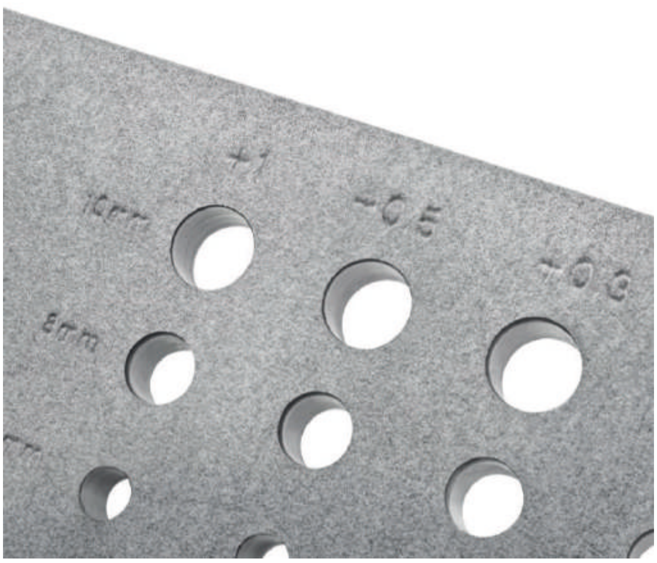


Figure 2: HP MJF pre-formed hole testing

External threads

To machine an external thread, it is necessary to start from a solid printed cylinder and then machine the thread using the required die. The diameter of the cylinder to be machined must be slightly smaller than the die's major diameter. Typical cylinder diameter recommendations for plastic and metal are applicable.

Figure 3: Metric die

Standard printed threads

To ensure a satisfactory assembly operation with HP Multi Jet Fusion technology, there are a few recommendations when designing threads larger than 6 mm under international standards (e.g., DIN 13-1, ISO 965-2, ANSI/ASME B1.1). These international standards usually specify tolerances relative to diameter and pitch of a thread.

When designing internal threads, the less restrictive tolerance values (maximum tolerance values) should be used, and when designing external threads, more restrictive tolerance values (minimum tolerance values) should be used. For example, when designing metric threads under the ISO 965-2 standard—threads with general-purpose tolerances (6H-6g) and normal engagement length—the recommended design values are shown in the following table:

		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.
M8	1.25	8	7.188	7.348	6.647	6.912	7.972	7.760	7.160	7.042	6.438	6.272
M10	1.5	10	9.026	9.206	8.376	8.676	9.968	9.732	8.994	8.862	8.128	7.938
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

Table 2: Recommended external and internal thread tolerances for HP MJF, based on ISO 965-2 tolerances

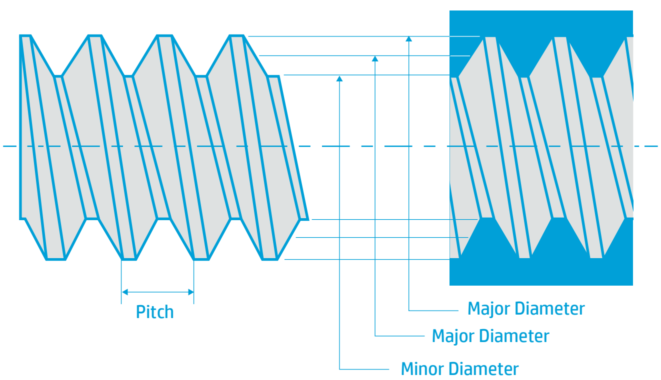


Figure 4: Features of external and internal threads

Customized threads

For customized threads, all external and internal threads should be designed with a gap of 0.2 mm to 0.4 mm between the external and the internal thread, as appropriate.

It is recommended to remove all sharp edges and apply a minimum radius of 0.1 mm when designing threads for HP Multi Jet Fusion parts.

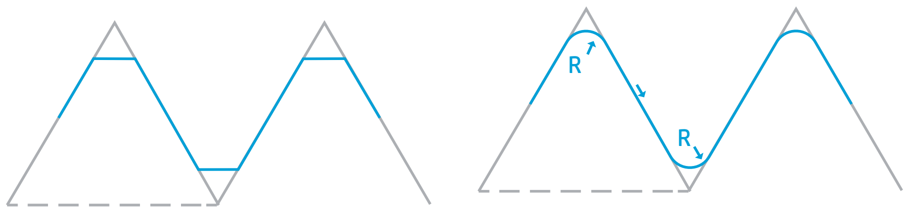


Figure 5: Round edges for custom-printed threads

Post-processing guidelines

Threads can be considered a very fine detail and should be cleaned using a manual or automatic sandblasting machine with glass bead particles that range from 70 to 110 microns in size and 3 to 4 bars in terms of pressure. For cases in which a vibratory finishing (tumbling) is required to improve surface roughness in other areas, it is recommended to first clean the threads using a sandblasting machine. Usually the media used in vibratory finishing are too big to clean the space between the threads.

> It is more difficult to clean internal threads; for this reason, it is better to reduce the length of this type of thread and make through holes when possible. For internal and external threads, it is possible to use taps and dies if they are not completely cleaned or if there is excessive friction.

Painting the threads is not recommended in any case; parts can be painted only if they are already assembled.

For this reason, dying is the best option for coloring threaded parts without altering the dimensional accuracy.

4AA7-4110EEW, February 2019

Hinge design
Innovative designs

General introduction

Hinges are another type of interlocking part that can be printed as a single assembly. Here, too, there must be sufficient space around the interconnecting pieces to prevent them from fusing together. There are several different kinds of hinges, and because of the space required around the different pieces, different types of hinge designs will be more wobbly than others.

Scaling

These two hinges are very similar; they both have two pieces that connect to an object on the left, and a middle piece that connects to an object on the right. They both have a rod that goes through the centers of the hinge pieces and gaps each end.

However, for the one on the left, the middle piece rotates around the rod, as do the pieces connecting to the left. For the hinge on the right, the rod and middle piece are one solid piece, so it is only the top and bottom parts of the hinge that rotate around the rod.

This second hinge wobbles less because there does not need to be any space between the middle piece and the rod. They are one piece.

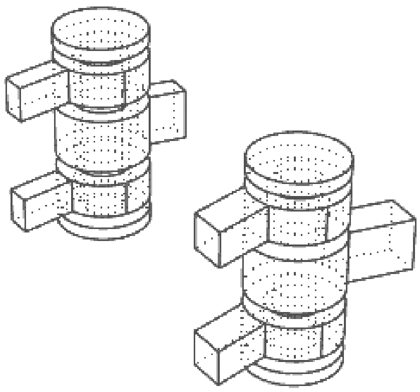


Figure 1: Examples of hinge design strategies

Examples

Figure 2: This intricate egg features a tiny hinge connecting its two halves.

Figure 3: Another type of hinge uses cones that fit into matching divets. These modules by can snap apart and back together.

Living hinges

Basics

It is possible to print a finitely flexible part with HP 3D HR PA 12 by adjusting its wall thickness and geometric structure. A thin and folded section performs like a living hinge, and it allows 3D printed parts to be collapsible and expandable to a certain degree.

To design and print flexible parts successfully, it is important to have an appropriate wall thickness; to maintain the curves and angles of folded hinges when converting the model to mesh; and to specify the print orientation.

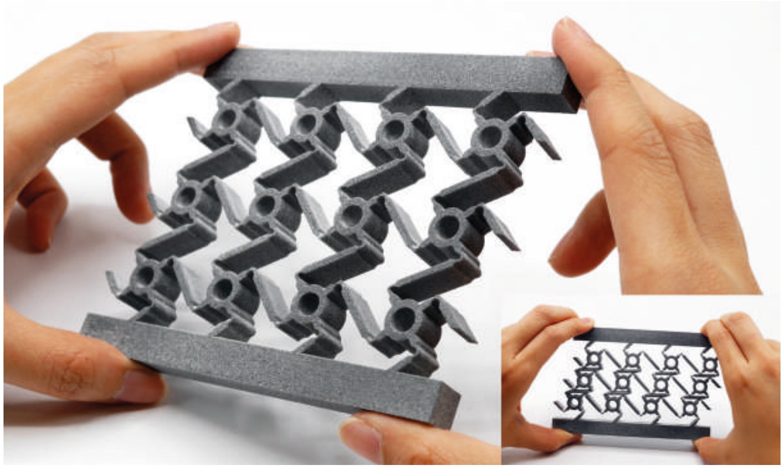


Figure 4: An array of living hinges, collapsible by hand

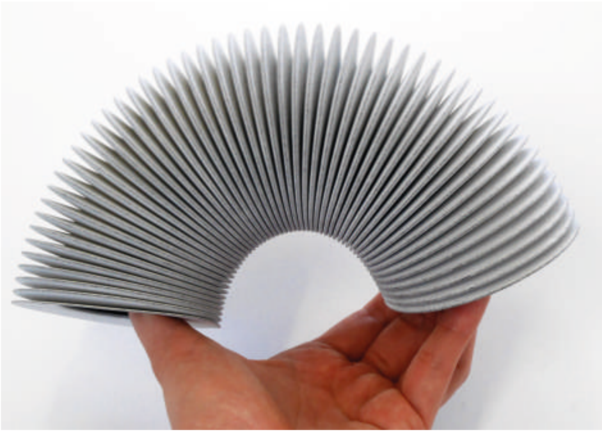


Figure 5: Tube with cosine-curve shaped walls

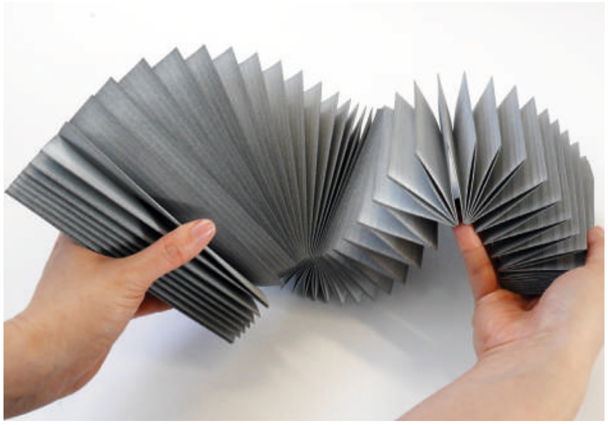


Figure 6: Accordion structure composed of a number of connected plates

Wall thickness

Even a difference in wall thickness of 0.1 mm has a great impact on the degree of the part's flexibility, and if walls are too thin, the part will not survive cleaning and sandblasting. It is recommended to experiment with varied and controlled wall thicknesses to find the suitable resilience and robustness for a part's purpose.

Geometry of structures

A part's structural geometry controls its mechanical behavior when outside force is applied. Different folding designs can be applied to create specific effects, such as springy tension and smooth motion. The shape and tightness of the folding has a direct impact on a part's movement. Make the apex of the fold hinge slightly rounded to avoid the risk of being snapped when the printed part is stretched or pressed.

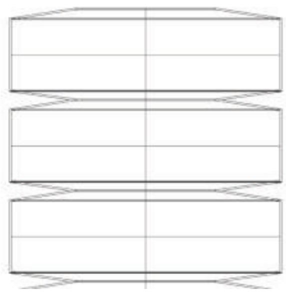


Figure 7: V-shaped connectors create springy tension in the folds.

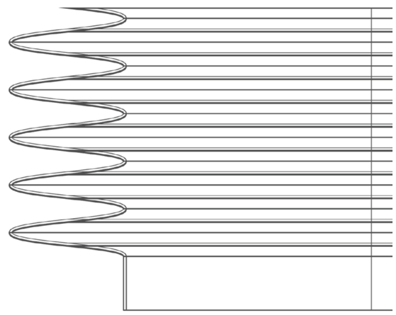


Figure 8: Cosine curve shapes create smooth motion.

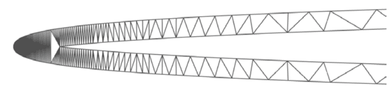


Figure 9: The highly dense mesh applied to the accordion structure maintains the folds' roundness.

Print orientation

To maximize the durability of the thin structure, it is recommended to print the part in an orientation such that its thin planes are approximately parallel with the X/Y plane. Specific print modes, such as mechanical mode and fast cooling, can be used to maximize elongation at the break point of the part if necessary.

There are some exceptions where thin parts benefit from being printed at an angle, such as the tambourine shown under "Designing for Sound."

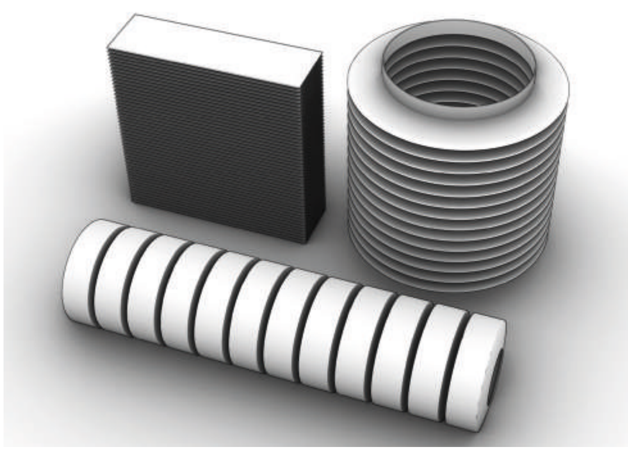


Figure 10: Recommended print orientation for sample designs

4AA7-5180ENW, April 2019

Adhesive bondings
Design for HP MJF: Union joints design

Introduction

When using HP Multi Jet Fusion technology, it is sometimes necessary to split a part into different pieces and then re-join them. There are two main reasons why bonding parts together may be necessary:

Splitting big parts

Some big parts do not fit inside the build chamber of HP Jet Fusion 3D printers. Therefore, the parts can be split into several pieces and then re-assembled after printing. This can occur in the automotive industry or in applications such as jigs and fixtures, where big parts could require bonding to ensure a strong joint and achieve a proper solution.

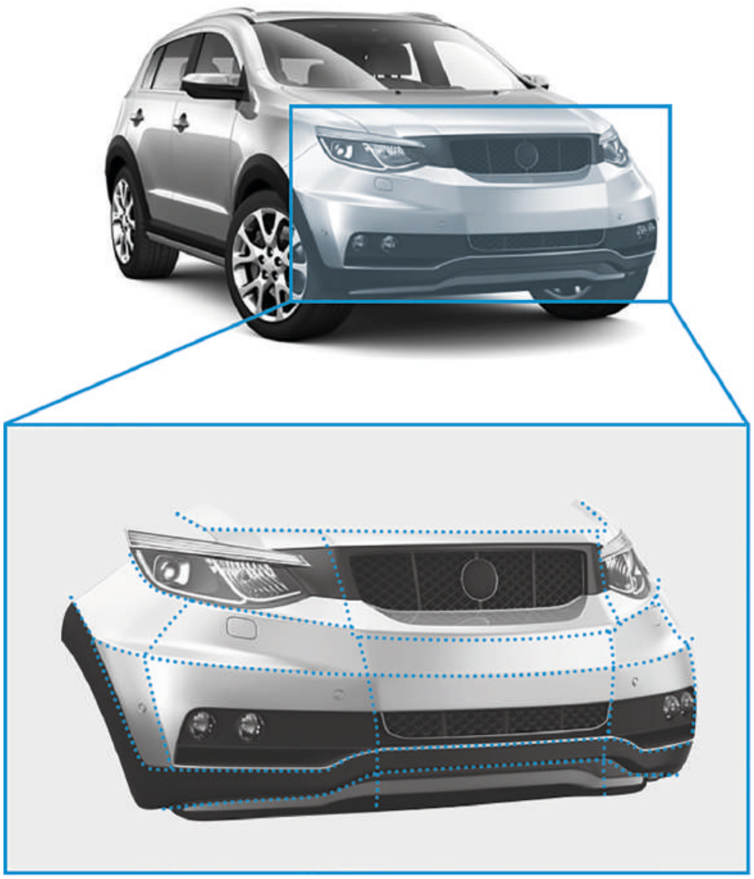


Figure 1: Bumper split proposal

Increasing packing density

The maximum printing efficiency in terms of cost and productivity is achieved by increasing the packing density. Depending on the geometry, there may be packing limitations for the achievable maximum value. In these cases, splitting the parts is a possible option.

For example, a part's packing density could be optimized by adding hinges that allow it to fold. These could be blocked after printing by using an adhesive or other mechanical locker.

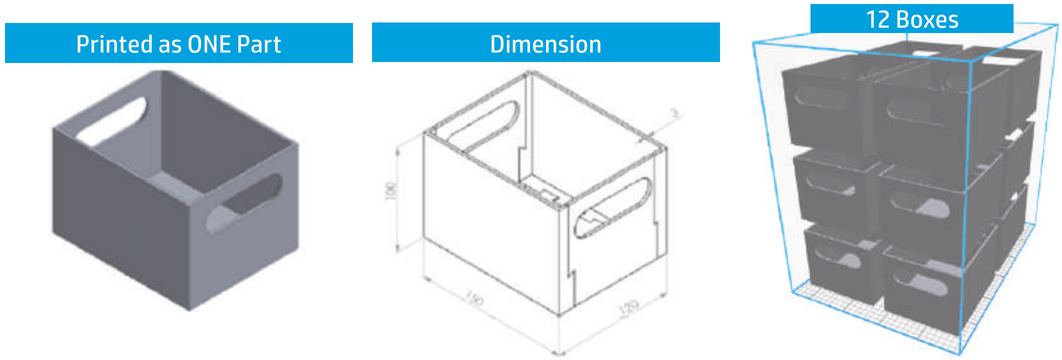


Figure 2: Example of packing density optimization: Box original design and number of parts that fit in the print bed. Data courtesy of Henkel AG & Co. KgaA

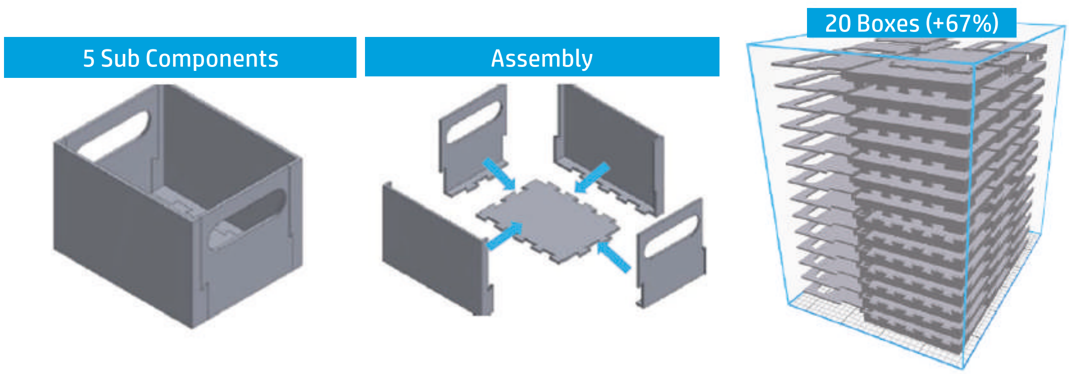


Figure 3: Example of split part to optimize packing density: With the split, the packing density increased by 67%. Data courtesy of Henkel AG & Co. KgaA

Design guidelines

Bonding robustness depends highly on the design of the union and the way the part has been split or cut into different pieces. A proper bonding design is critical for success.

Union design

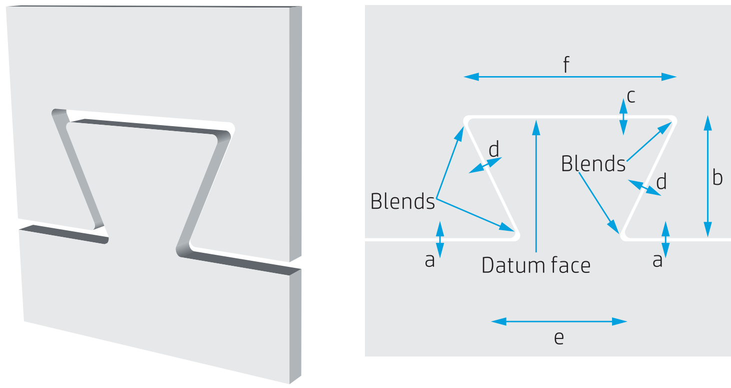
The union design of the bonding is key to ensure proper performance of the bonding in the final part. The time invested in designing a proper union may depend on the final use of the pieces that will be bonded. For example, a visual prototype that will not withstand any loads would require a simple design union, while an automotive part that will be included in the final product should be designed to optimize its performance.

Design options depend on the thickness of the bonded parts and on the possibility of modifying the final geometry.

Thickness < 1.7 mm with no geometry modification allowed

One of the objectives in the design of the union is to increase the bond area as much as possible. Including features that will help reference one piece to the other during bonding will help achieve the proper position between the parts and will optimize the final result. The most recommended design option for this case is a dove or jigsaw feature, as shown below:

Dove/Jigsaw



Recommended dimensions:

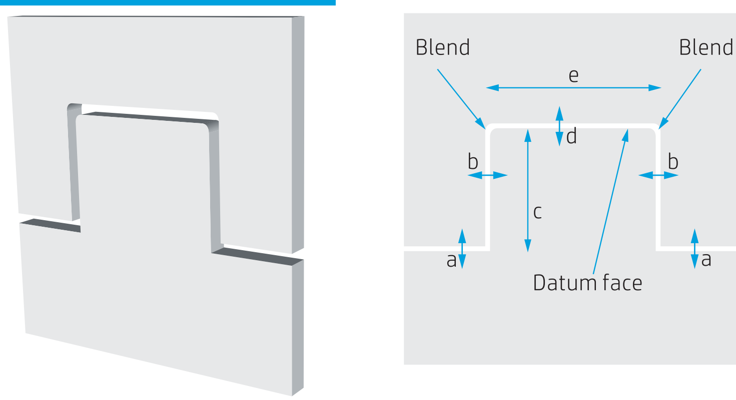
a:	0.2 mm
b:	10 mm
c:	0-0.1 mm
d:	0.2 mm
e:	10 mm
f:	20 mm

Figure 4: Dove/jigsaw design recommendations

This type of union will help increase the bonding area and, at the same time, it positions and holds both pieces that will be assembled.

There are also other design options that are simpler and will also provide satisfactory results, which could be an option for faster designs:

Square tongue

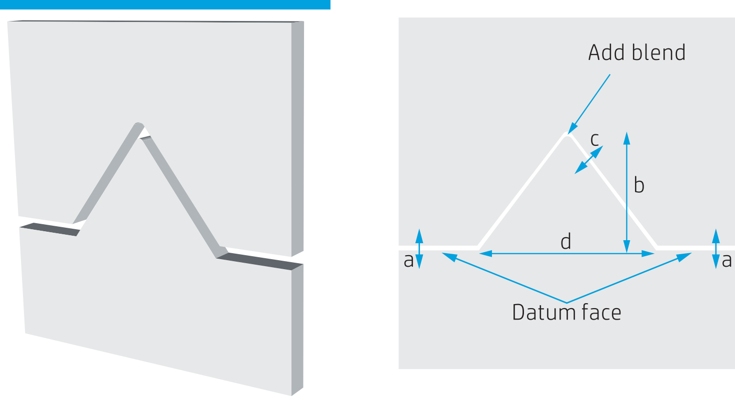


Recommended dimensions:

a:	0.4 mm
b:	0.2 mm
c:	10 mm
d:	0-0.1 mm
e:	10 mm

Figure 5: Square tongue design recommendations

Tooth



Recommended dimensions:

a:	0-0.1 mm
b:	10 mm
c:	0.2 mm
d:	20 mm

Figure 6: Tooth design recommendations

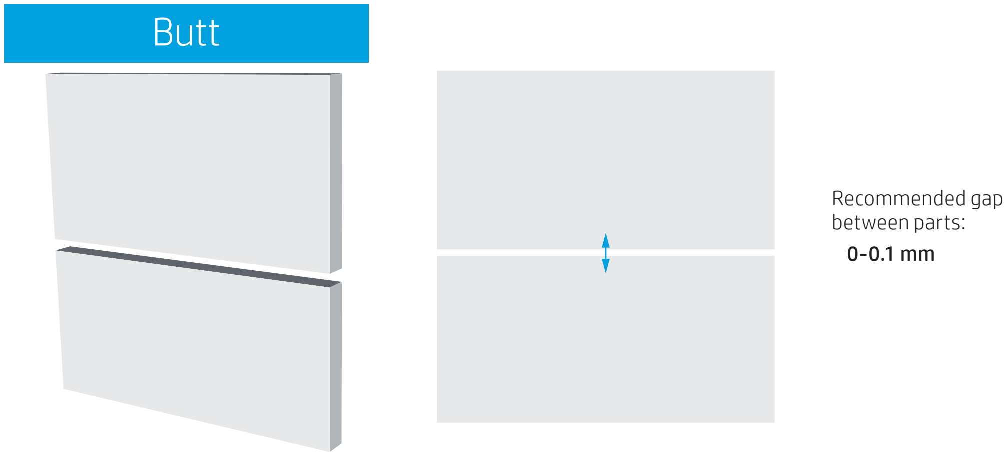


Figure 7: Butt design recommendations

When adding a union design that is not viable due to geometrical constraints (such as a dove, square tongues, or a tooth), a butt union design could be an alternative, bearing in mind that having a straight line in the bonding area is the weakest union design option due to its less-available bonding area.

> All design options can be easily applied to a part using 3D software, such as Materialise Magics, or they can be directly designed using CAD software.

Thickness < 1.7 mm with geometry modification allowed

If a modification in the geometry is allowed, the bonding area can be increased and mechanically reinforced by adding an overlap between the bonded areas.

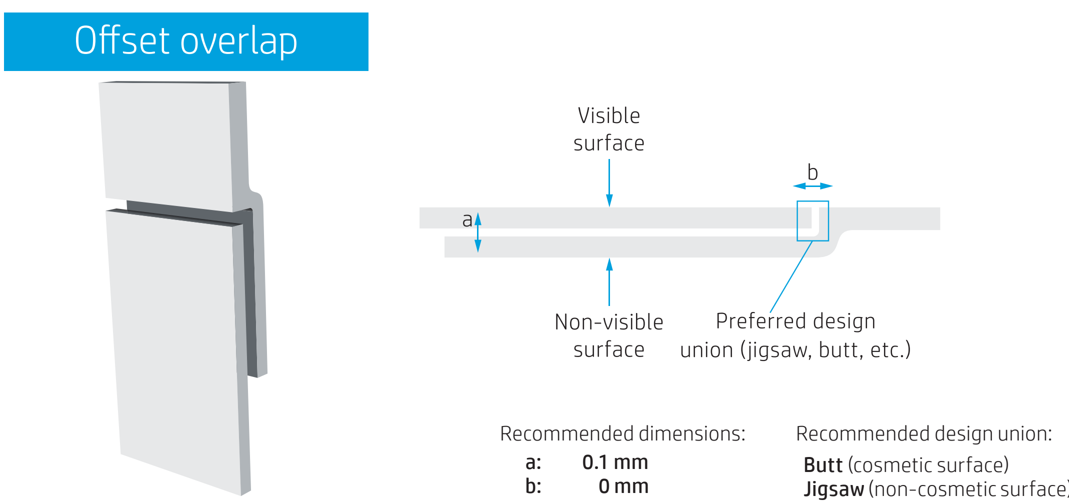


Figure 8: Offset overlap design recommendations

Thickness > 1.7 mm

When there is adequate thickness to add an overlap between the parts, it is no longer necessary to modify the final geometry to reinforce it. The improvement and optimization of the bonding union can be executed directly in the original design, thus increasing and reinforcing the bonding area.

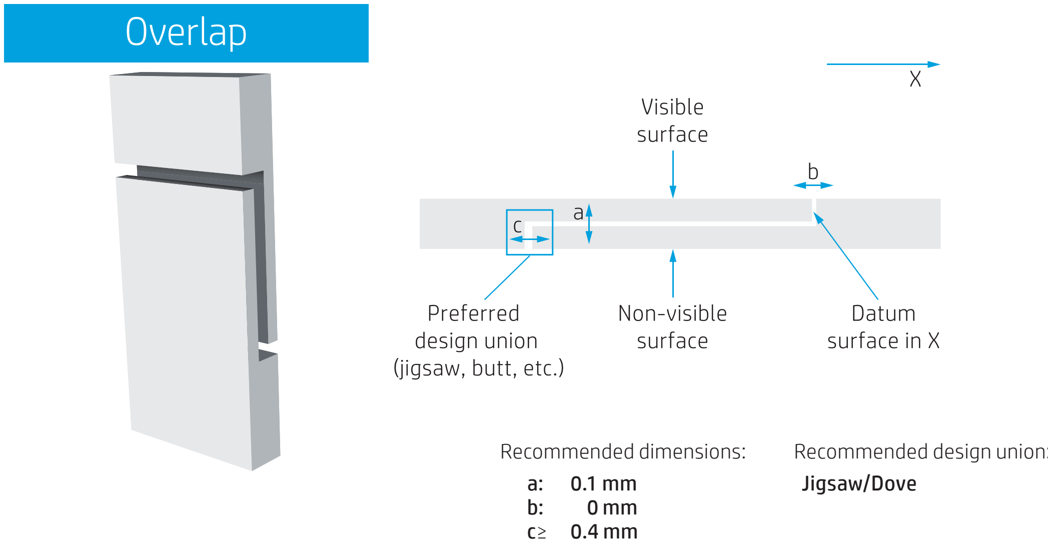


Figure 9: Overlap design recommendations

Adding more than one union feature

When the bonding line is long, it may be helpful to add multiple features that will hold both pieces together when the adhesive is applied. Regardless of whether the position between both parts is critical to the design, the features design must be executed by first adding a reference feature that will position both parts in the XY plane, and then by adding the remaining features with a higher clearance in order to absorb any dimensional variation.

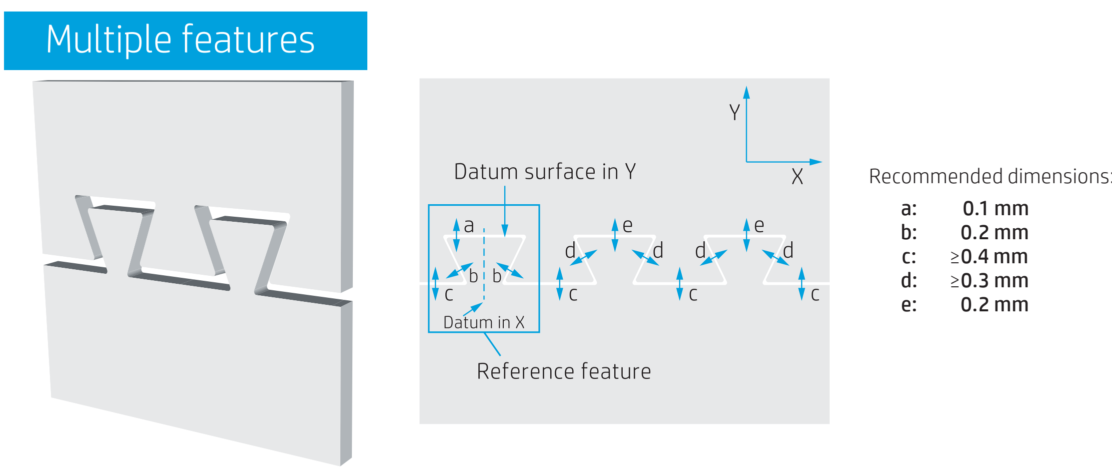


Figure 10: Multiple union features: Design recommendations

<u>Combination of overlap joint with multiple jigsaw features</u>

When taking into account all of the design recommendations mentioned above, the preferred union design is the combination of the overlap joint with reference features such as the jigsaw. Those reference features can be added to the non-visible surface and will help reference the two pieces between them to optimize the bonding performance.

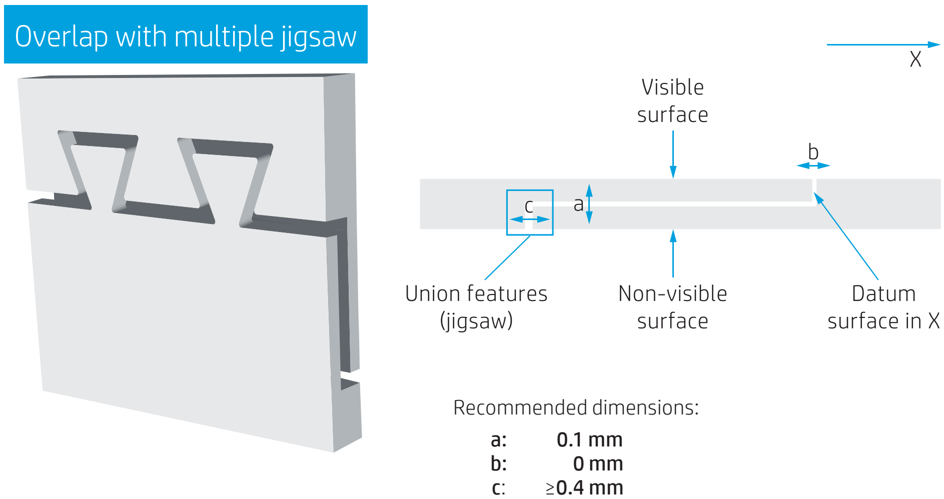


Figure 11: Overlap with multiple jigsaw features: Design recommendations

Additional options to increase bonding adhesion

When the adhesive material has the ability to fill gaps, the mechanical adhesion between the adhesive and the bonding parts can be improved by adding textures to their surfaces. This roughness improvement allows for mechanical interlocking by adding "teeth" to the surface and increases the total effective bonding area.

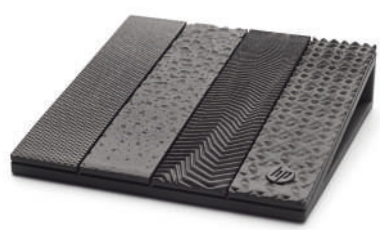


Figure 12: Example of texture to increase adhesion

An additional option to increase the bonding area is to include grooves to the bonding parts' surfaces.

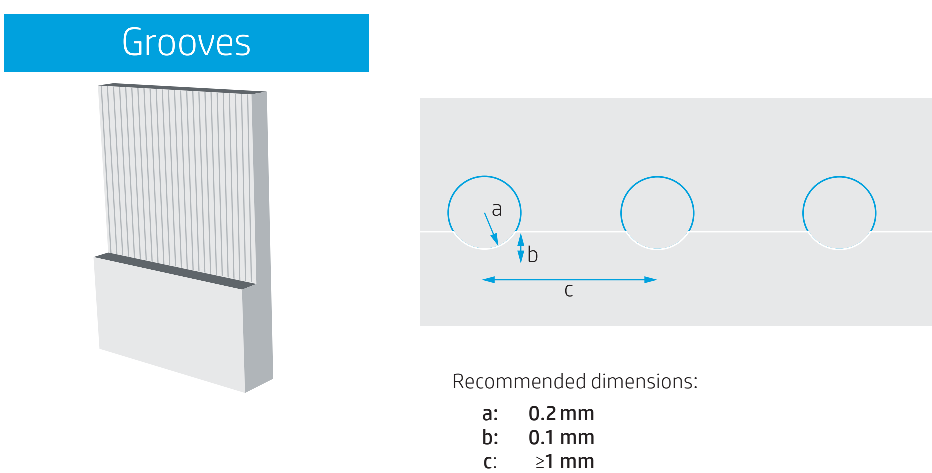


Figure 13: Grooves to increase bonding area: Design recommendations

Cutting recommendations

When a part needs to be cut, bear in mind which parts are the loads that will be applied to the final bonded assembly, as the bond robustness can be highly optimized depending on the design decisions.

The stress that appears in the bonding area depends on the applied loads. The most common are as follows:

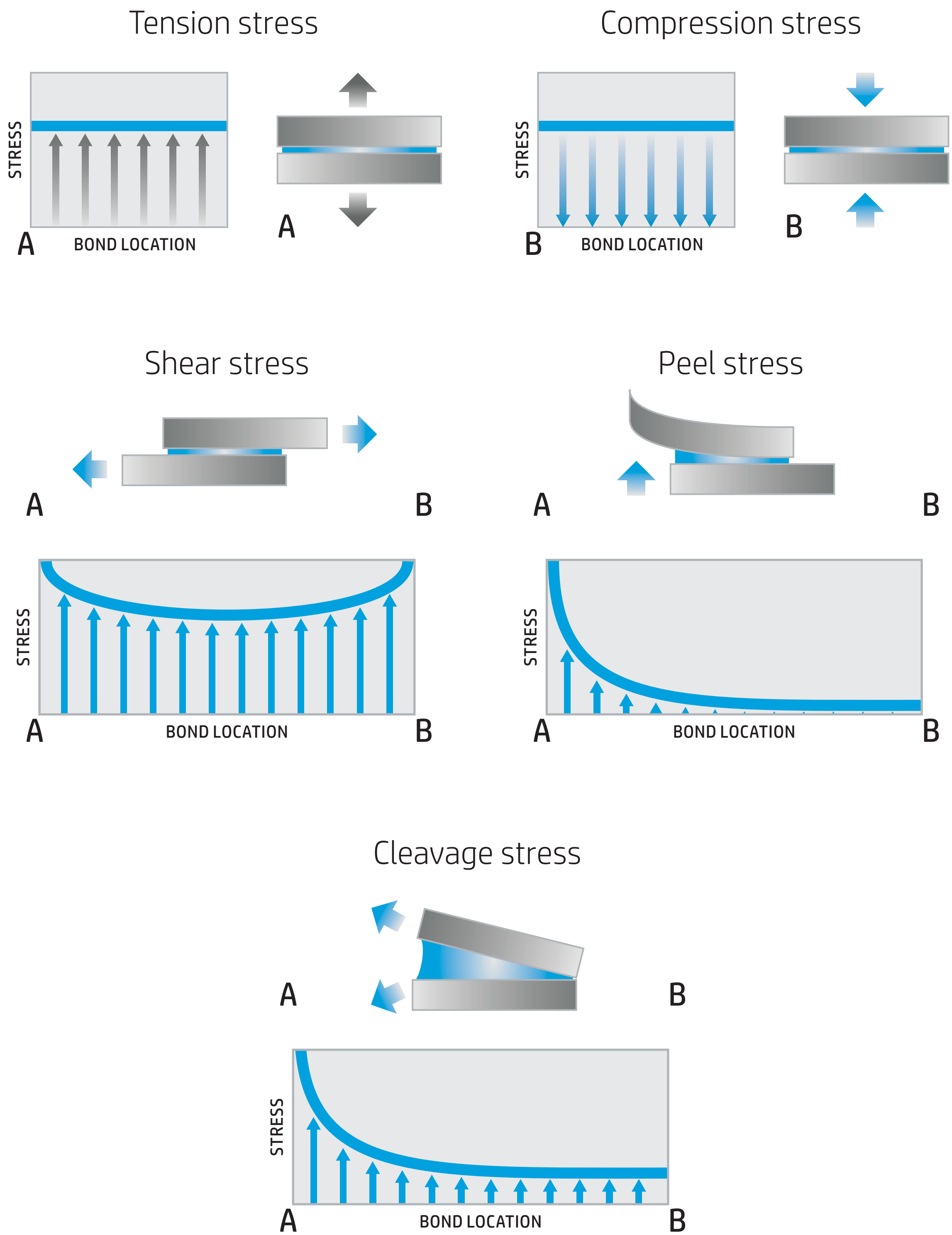


Figure 14: Stress distribution generated by different loads. Data courtesy of Henkel AG & Co. KgaA

When the cut is created, the design should be finished in order to prevent the development of peel, cleavage, or tension stress. The adhesive bondings work better under shear or compression stress, and the design should maximize the generation of those types of stresses to achieve a robust joint. The introduction of the overlap in the joint helps develop a bonding that works better under shear stress, which maximizes the performance of the union.

It is recommended to have a wider overlap area rather than a longer one. Having a wider overlap helps distribute more stress along the width and reduces the maximum values that appear on the sides.

4AA7-4112ENW, February 2019