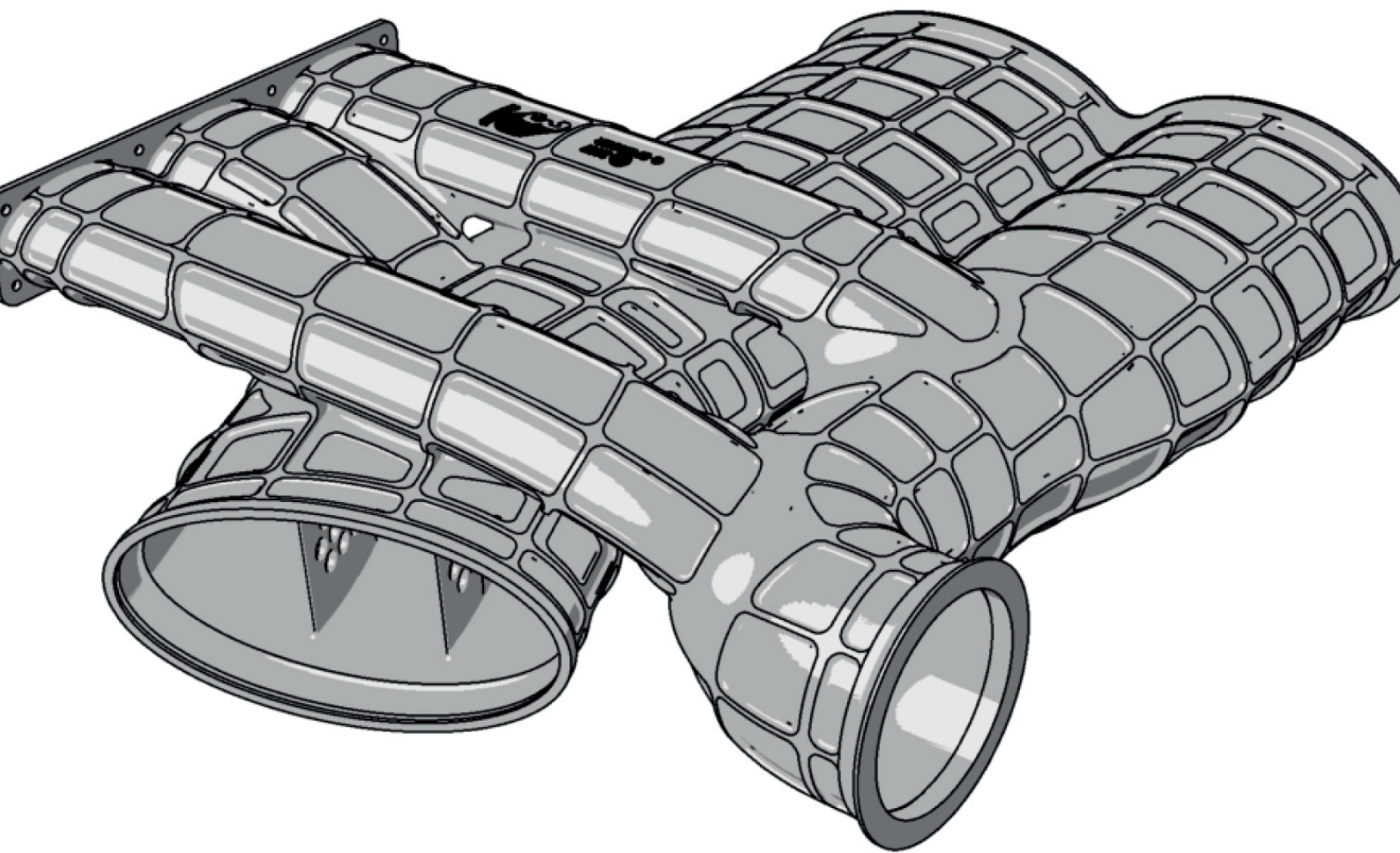


prototypeprojects

3D MADE. SIMPLE.®



Applications and design tips for Selective Laser Sintering

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Introduction

Digital direct thermoplastic manufacturing offers exceptional quality while opening the door to novel design parameters not possible with injection moulding. Thermoplastic additive manufacturing also bypasses the long lead time and up-front investment in injection moulding tooling. If you measure your finished parts on the three dimensions of quality, time-to-market, and cost per cubic inch, in many situations, industrial Selective Laser Sintering (SLS) offers a better total value proposition.

Prototype Projects offers a wide variety of thermoplastics for 3D printing, engineered for a range of applications. Materials specialists, designers, and manufacturing engineers can collaborate on getting the exact features they need for both aesthetics and function. These new design and manufacturing options open the door to improved products, new designs, new business models, and new markets. SLS technology is at the heart of a growing trend in mass custom manufacturing as well as functional prototyping.

SLS printers use a high-powered laser to fuse small particles of powdered nylon to form three-dimensional parts. The model is built one layer at a time, using 3D CAD data. This process is ideal if you are looking to produce tough, functional parts, with the possibility to achieve excellent surface finish and fine detailing. SLS parts can be designed with part consolidation in mind, eliminating assembly processes common to traditional manufacturing. Engineers can now design geometries for production that no other technology can produce, saving time and money.

This guide covers specific details on how to ensure successful builds of better parts when designing for SLS, such as axles, cages, complex ducting, living hinges, lattice structures, snap clips and more.

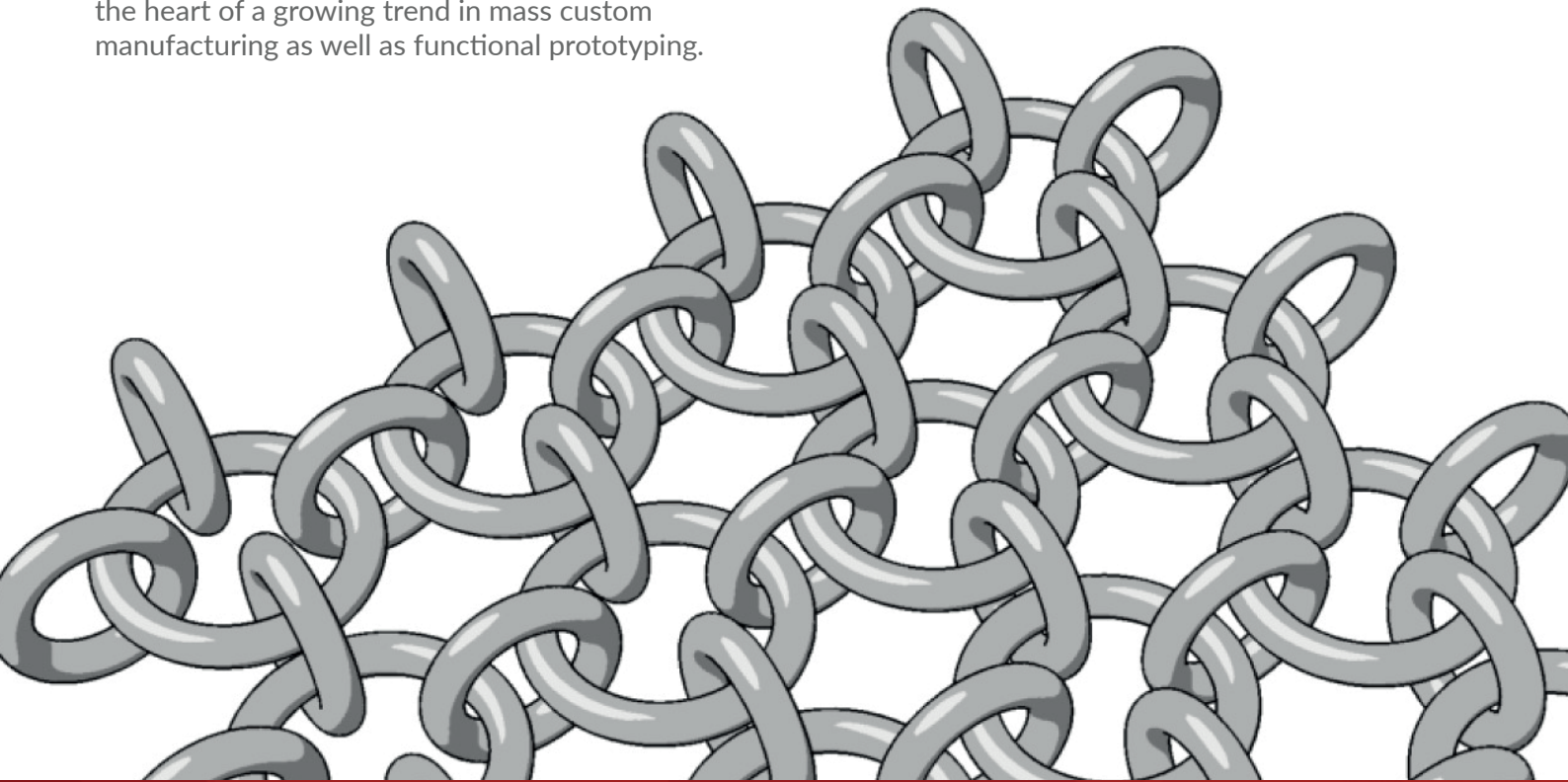
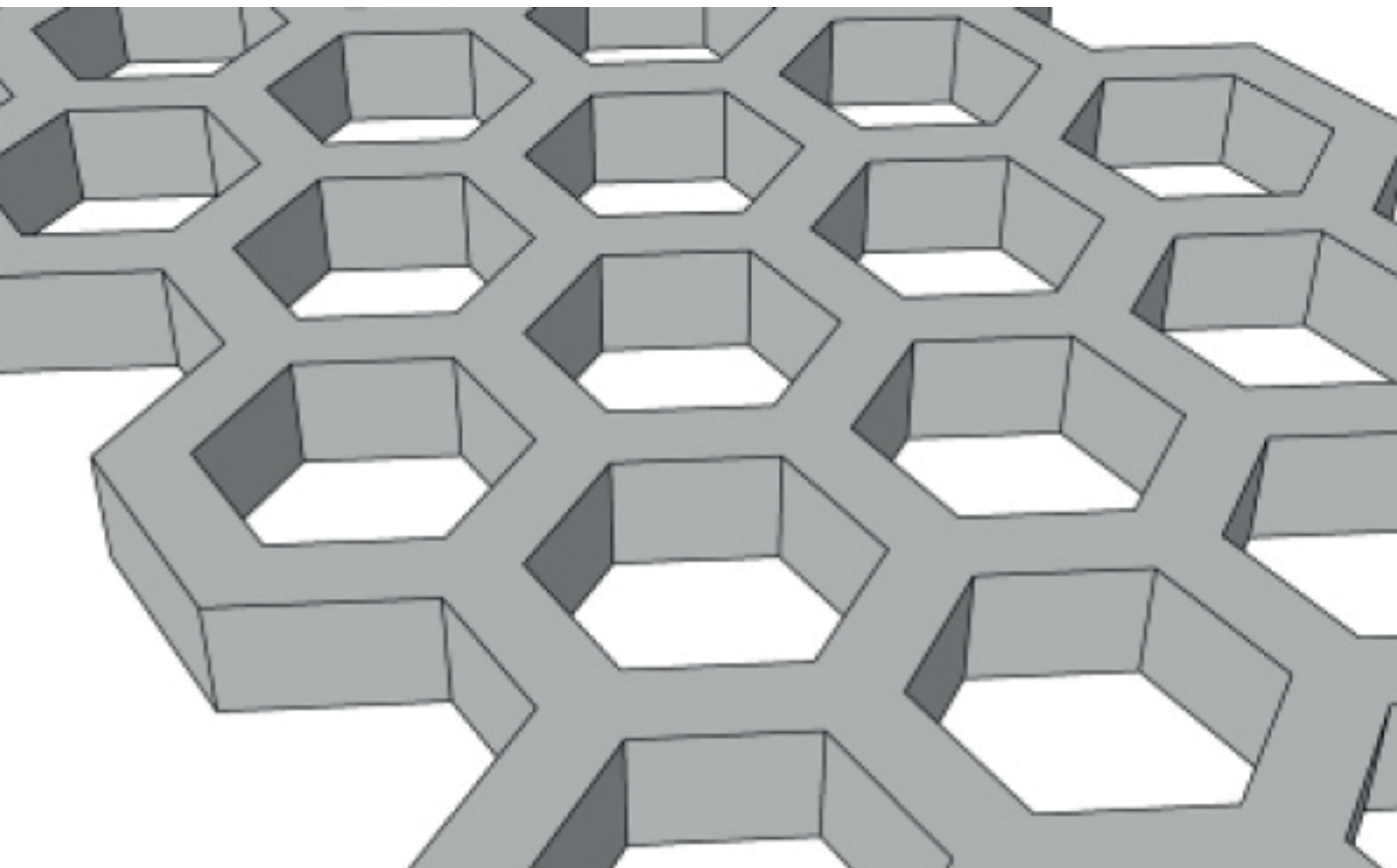


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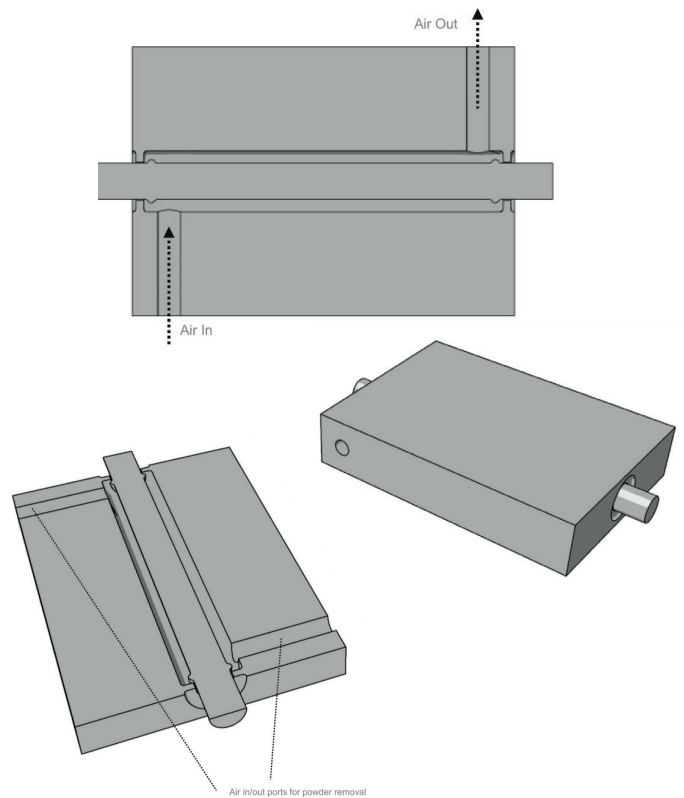
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Axles

Friction, fit and powder removal are the three factors in play with axle design for SLS manufacturing. Manage friction by applying 1-2mm rails on the static, “not stressed” side of the assembly. Keep the clearance between the rails axle tube at 0.3mm. In regions away from the rails, a clearance of 2mm+ will enable complete and easy powder removal by blowing compressed air through the powder removal access ports modeled into the static side.

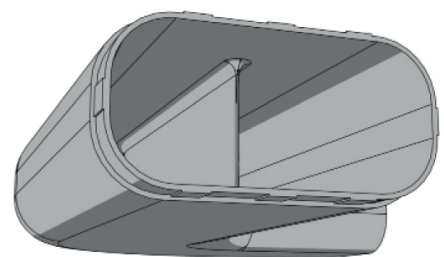
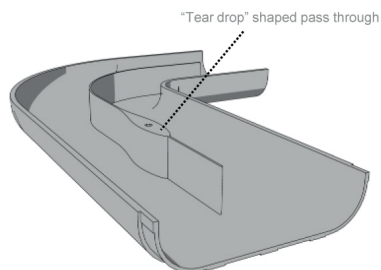
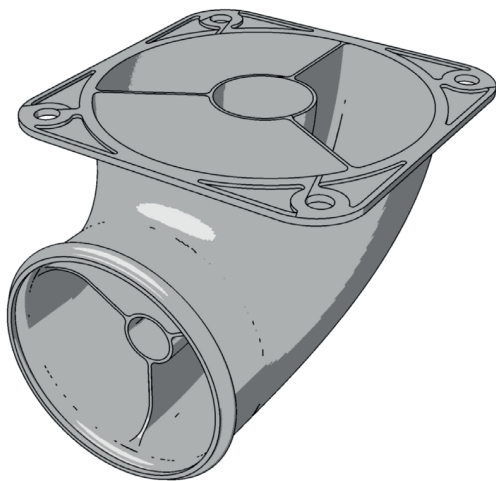
To remove powder, the part is rotated and pressurised air is applied to blast the powder out of the axle cavity. As a natural bearing material, nylon will provide a smooth, low friction mechanism for low-load, low-velocity applications. For more demanding applications where friction can generate heat, and wear, consider inserted bearings, described on page 5.



Baffles - Managing Air

If you need to pass a mounting point through a baffle, elongate and form an aerodynamic teardrop shape to reduce sites for turbulence formation. This will improve air flow efficiency and cut down on noise.

Always apply generous fillets to baffles to prevent side walls of ducts from splitting, especially if components will be exposed to pressure and/or cycling of temperature.

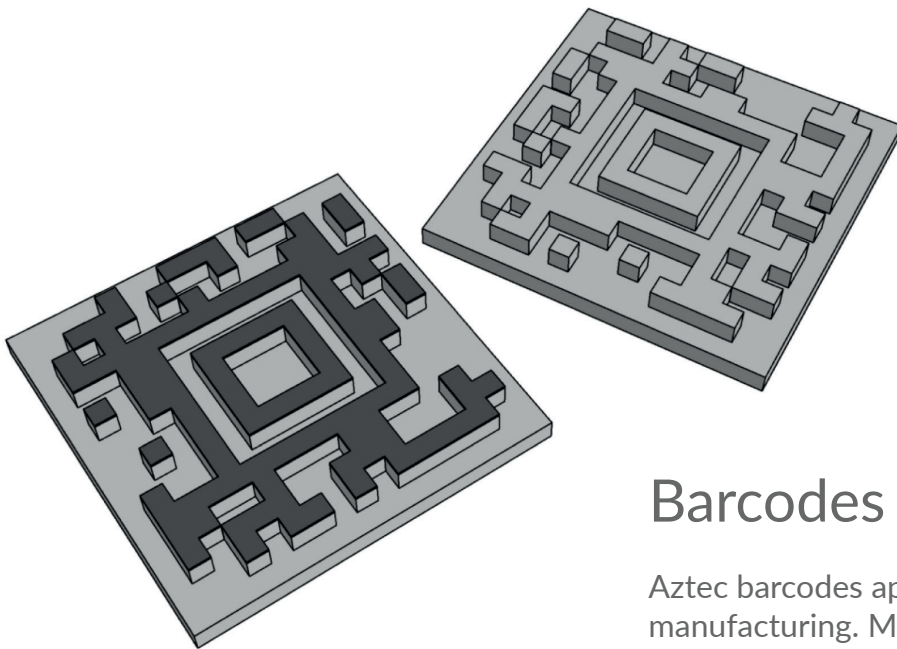
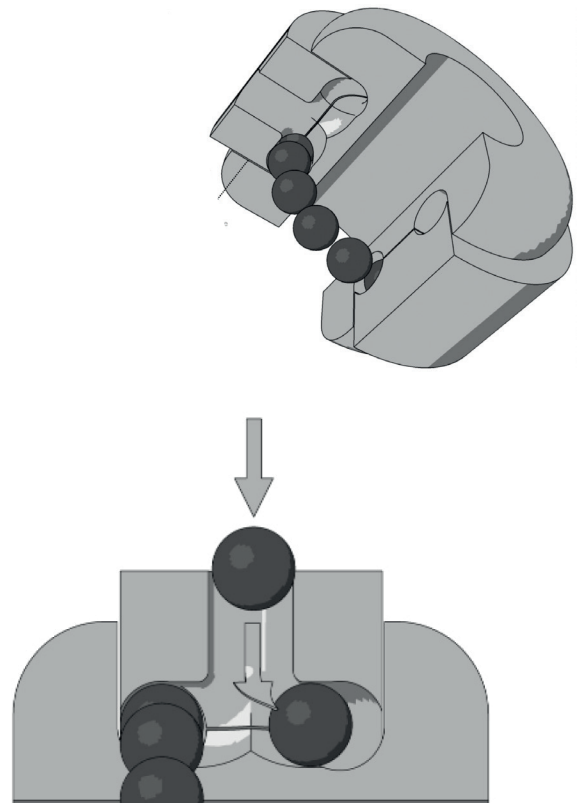


Inserted Bearings

In this example we see the introduction of ceramic ball bearings into a chase, CAD modeled as a torus cavity between the A and B side. This could be considered an integrated hybrid hinge mechanism.

Nylon is a naturally good bearing, low-friction material. In applications where you expect long-term repetitive load-bearing cycles, however, you can generate a very durable and smooth mechanism by replacing CAD-modeled, in-place ball bearings with ceramic ball bearings introduced through the access point.

Once all the bearings have been dropped into the chase, a plug can be fixed to seal in the chase.

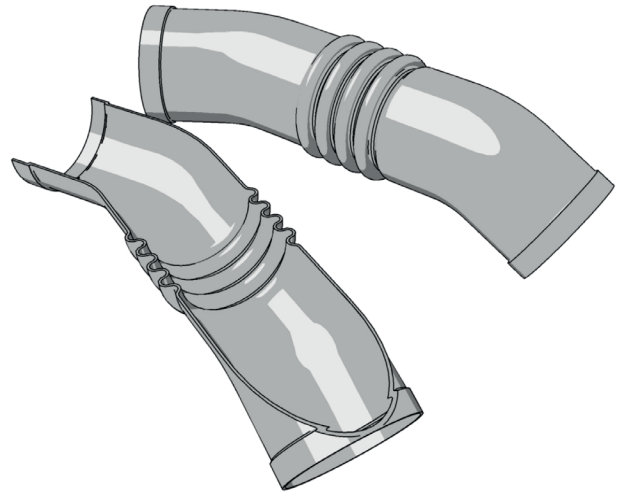


Barcodes

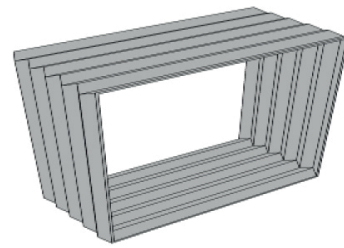
Aztec barcodes appear to be optimal for SLS manufacturing. Make the cells <1mm cubed. Note: you must apply contrast ink to the raised surfaces of the barcode to enable or accelerate image capture when exposed to a scanner.

Bellows

SLS manufacturing can be used to make functional “bellow” sections for applications where some flexibility is required in assembly or coupling. However, note that nylon performs poorly in applications where you would expect repetitive cycling, such as wire and hose shrouding in mechanisms. Instead, only consider applications where parts will be exposed to very low frequency flex cycling. If you require regular exposure to significant flexing, you can still use SLS but you will get better performance and resistance to work hardening from Polyethylene-based SLS materials.



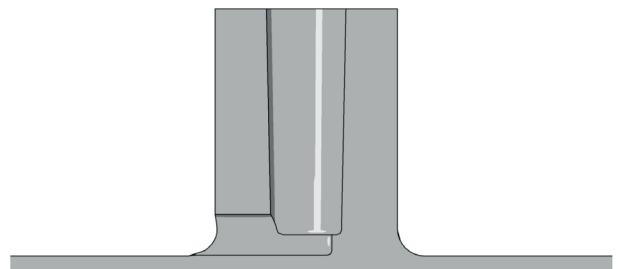
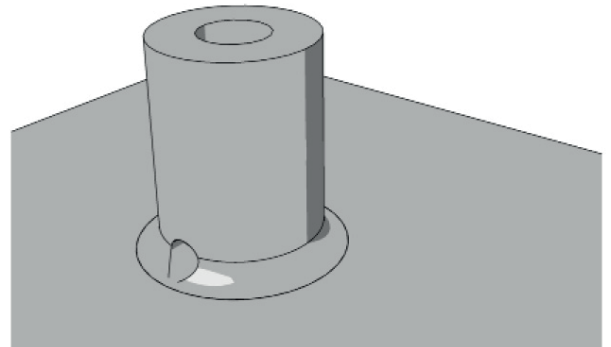
Circular bellows work best when they distribute the tensile stress points evenly around the cross-section. Any deviation from the circle will accumulate stress as you transition to the square bellow. In this case, you may have to take a different approach by applying a similar structure to the “Deardorff Bellows”, which is basically a series of alternating cross-linked rectangles. Note: this geometry is more sensitive to stress concentrations as it has low-radius corners, hence resultant sensitivity to fracture when exposed to cycling.



Blind Bosses

Blind holes can be challenging for efficient powder removal. The solution here is to not make them blind. Simply apply a small hole >2mm in diameter at the base of the boss to enable bead blast material to exit.

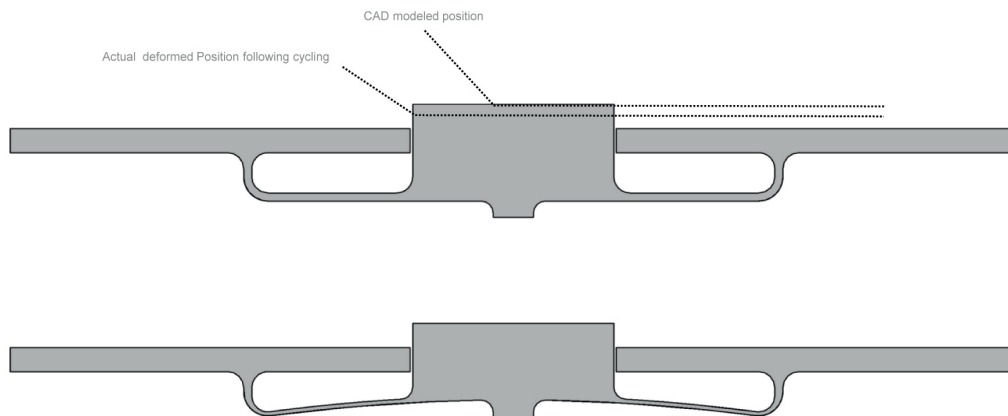
There is no need for draft, however for self-tapping plastic screws, it's best to apply the principles of conventional design to the surfaces that engage the teeth.



Buttons

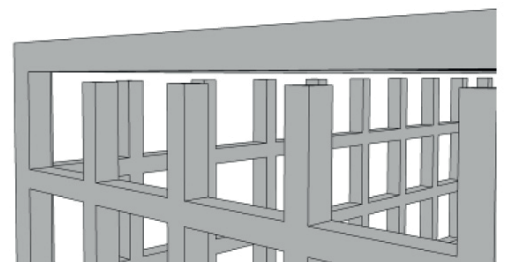
There are many different approaches to integrated button design. Allow at least 0.3mm clearance between the button and the slot or hole from which it emerges to prevent fusing. You should also CAD model the button to be higher than the final desired position, as the nylon “leaf springs” will tend to deform into a slightly depressed position. For example, if you want the button to be flush with the surface and model it as such, you will find that it will recess into the surface after a couple of cycles.

As with leaf springs, the magnitude of this deformation will depend on the density as well as the length and thickness of the springs. The top lower button example below is a form of leaf spring known as a “dual stable state” switch. In this case the button will resist and then ease into the deformed position, sometimes with a click.

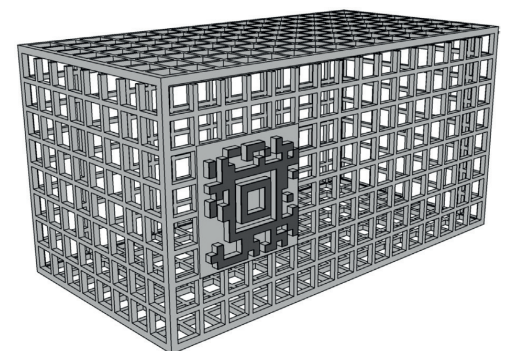


Cages

SLS is excellent for manufacturing lots of small, complex plastic parts, such as electrical connectors and clips. Consider CAD placing a box around small parts to prevent them getting lost during break out and post-processing. 1.0mm square bars work well with 5mm+ openings to allow bead blast media to clean parts as a batch within the cage.



In applications requiring additional post-processing, such as sterilisation for surgical use, the batch can transition through the various processes within the cage. To remove the parts, consider CAD modeling hinge doors, applying snap-off regions or, as in this example, connecting the lid with four corner posts that can be cut off with wire snips.

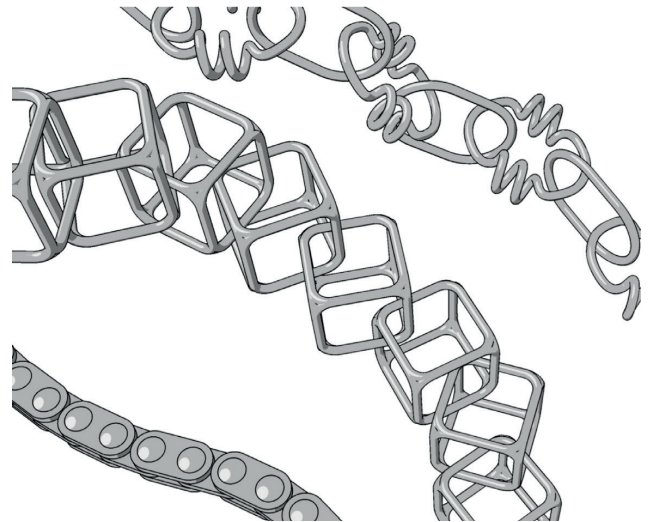


Another option is the application of connector sticks, resulting in a similar batch grouping function that you get with injection moulding sprues on some kit toys.

Chains

Designing chains for SLS manufacturing can be a lot of fun, as with chain mail. It's also a very old geometry that offers lots of opportunities for novel and interesting forms.

The earliest chains were hammered/forged rods bent into interconnecting loops. With SLS the only limitation to chain design is your imagination. You can even do bike chains: just keep a 0.3mm clearance between the shells.



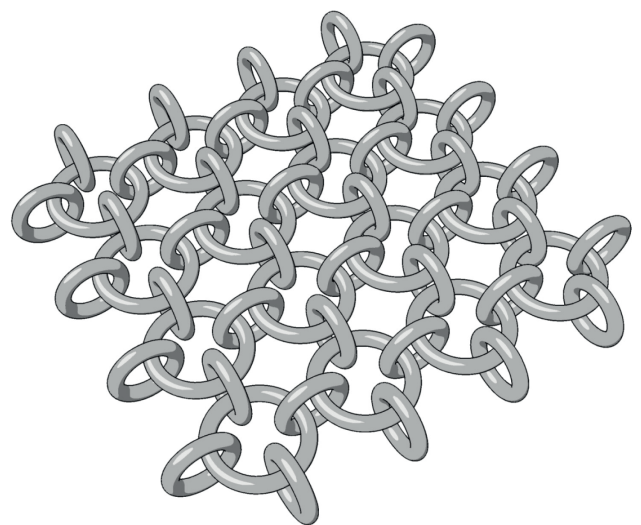
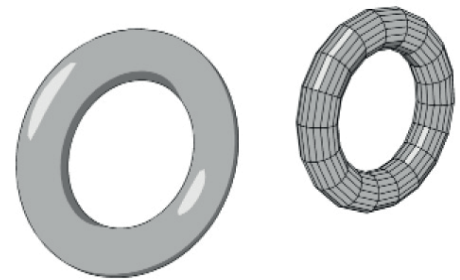
Basic Chain Mail

For basic chain mail, keep the link thickness $>0.75\text{mm}$ and keep clearance between the links over 0.5mm . For large pieces, consider designing the link to have a polygon cross section in both axes. This will reduce the file size as well as speed up the design process.

Invest time in getting a single link optimised before array duplication. Consider using a polygon instead of a circle to speed up link duplication and manipulation in CAD.

You can also fold your design like you would fold fabric to reduce the part cake volume taken up by your design. Particular care must be taken to avoid superimposing links.

For bounding box efficiency consider folding and/or telescoping large sheet arrays to reduce the amount of space taken up by your design.

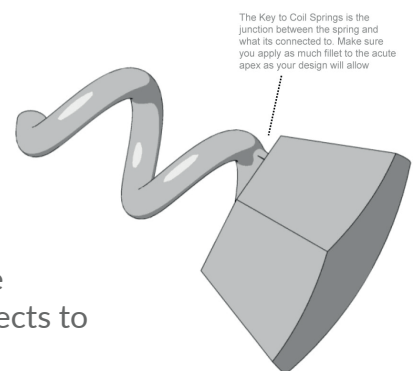
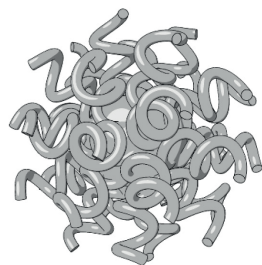
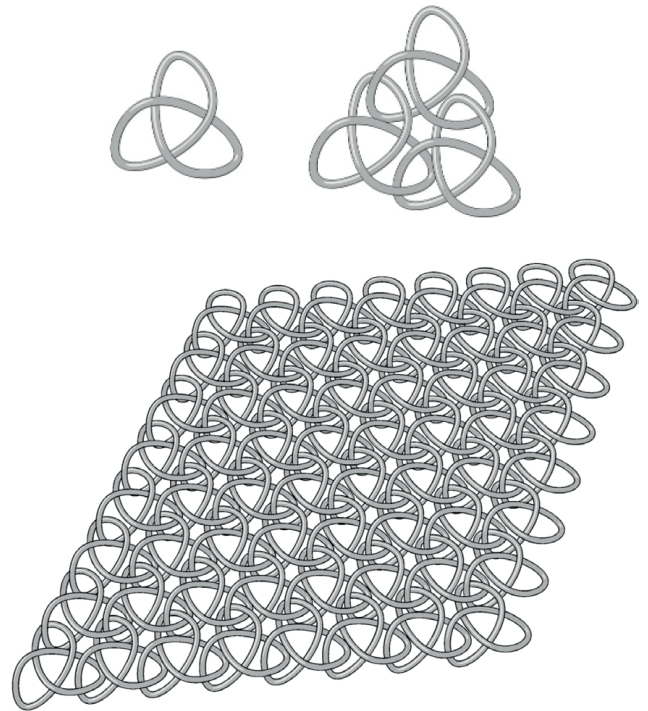


Complex Chain Mail - Möbius Elastic

Your creativity is your only limitation when designing complex engineered textiles or chain mails. In this example, a three-sided Möbius link not only generates an interesting structure but actually generates an elastic network of links in which each can be stretched when pulled in all directions.

Consider chain mails that transition into plates and chain mails where the links get progressively thicker in regions enabling controlled zones of opacity and flexibility.

The application of spikes to every link, combined with hooks for quick release and fastening, enables some interesting textiles for novel applications in fashion.



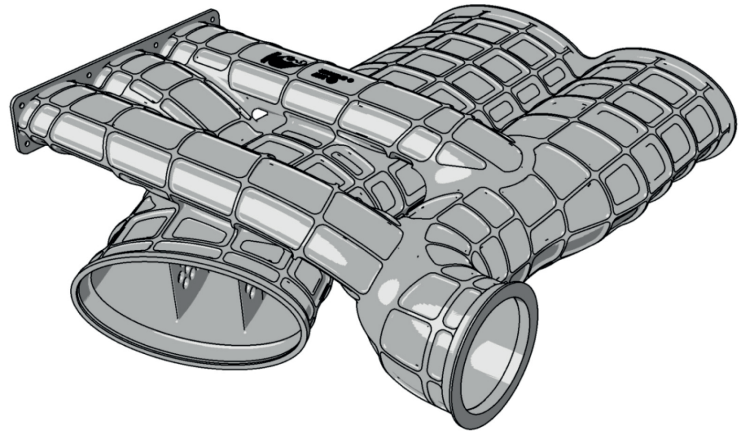
Coil Springs

One of the most important features to consider with coil springs, is the generous application of the fillet at the junction where the spring connects to other features. Special attention should be given to the acute apex.

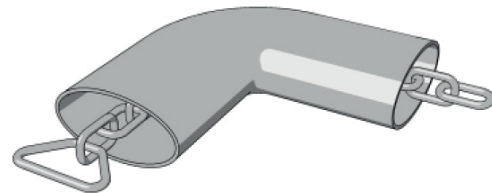
As with all materials, cracks can initiate very rapidly when exposed to cyclic loads. As with leaf springs, the final stable position of the spring will take several cycles of compression and elongation to become apparent.

Complex Ducting - Webbing

By using SLS to manufacture non-structural, low-volume ducting, such as ECS ducting for aerospace and performance racing, you can design highly optimised, very complex single piece structures. Take advantage of the fact that you can not only design in variable wall thicknesses, but that you can increase the strength-to-weight ratio through the application of structurally optimised surface webbing. This is a costly detail to apply with traditional manufacturing techniques. For SLS, there is no added cost due to complexity.



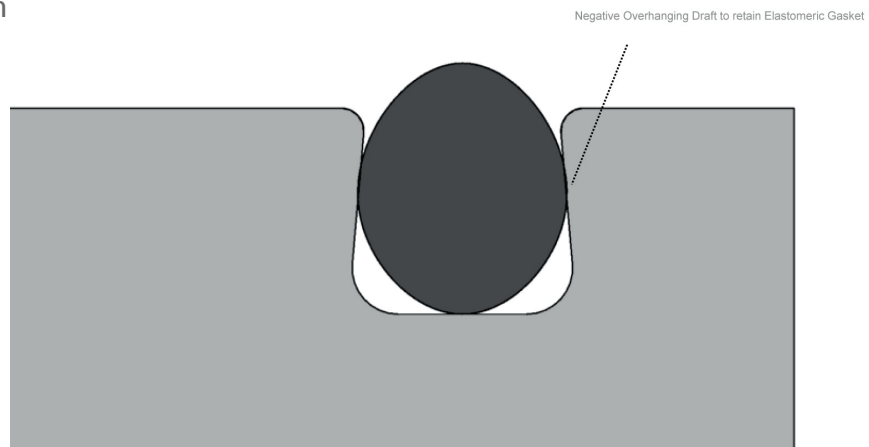
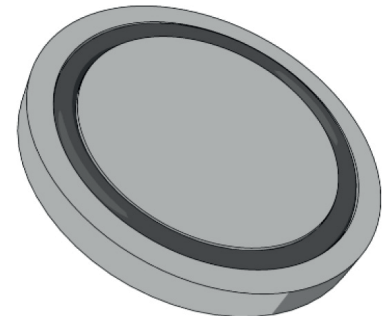
Consider CAD modelling a chain through the duct. When finishing, a quick pull of this chain through the duct will clear an open channel for the bead blasting media to get a good cleaning velocity in the duct.



Gasket Channels

The ability to manufacture “negative draft” enables an interesting approach to fixturing of soft elastomeric products like rubber gaskets. You may have to experiment a bit based on the specific durometer of your gasket. Usually a channel with a minimum width 10% less than that of the uncompressed gasket diameter will allow for placement and retention of the gasket.

Note: the same principle can be applied to the fixturing of other elastomeric components such as grip pads and button arrays.

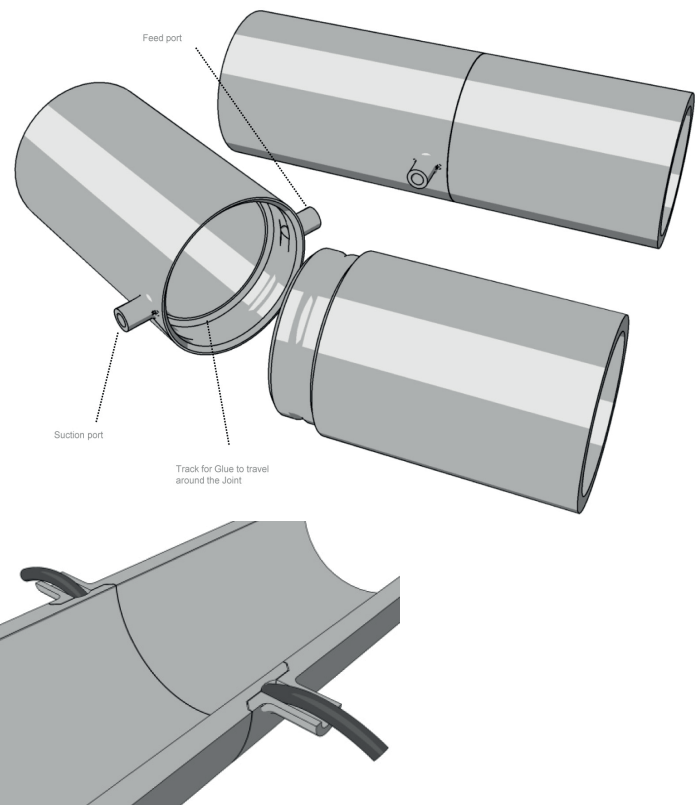


Glue Lines

To achieve void-free, sealed coupling, vacuum draw (not push) two-part thermo set epoxy into the radial channel through the CAD modeled in/out ports at the join intersection. This is a great approach for complex join profiles where you have to guarantee a seal.

Once set, it will be impossible to separate without fracturing the physical parts. Always suck the glue into the channel via vacuum. Do not inject the epoxy, as it will likely take the path of least resistance and potentially not fill track 100% around the entire join region.

The cross-section to the right shows glue (dark) getting sucked into radial cavity through access ports.



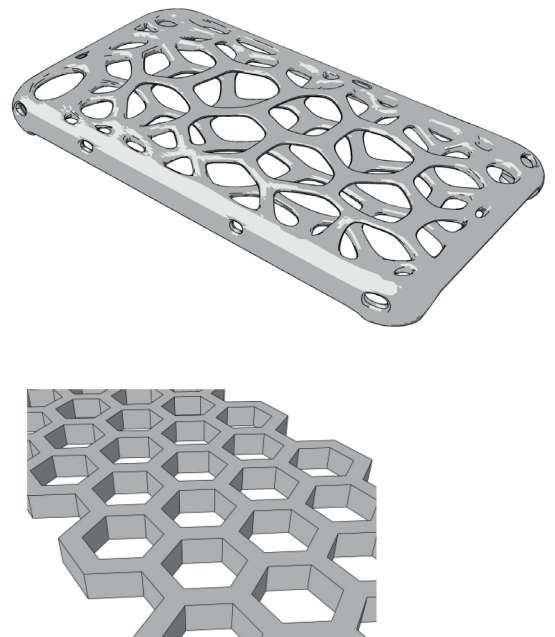
Grids

Hexagons are particularly optimised for SLS, not just because of how they fundamentally manage stresses and nest efficiency, but also because very few triangles (12) are required to accurately express them.

If you use circular forms for grid holes, expect the file size to increase dramatically.

While you may cut down on the weight of the final part relative to a solid non-grid section, you will increase cleaning time and increase draw time on the systems, as the laser now outlines and fills in the feature rich cross-sections.

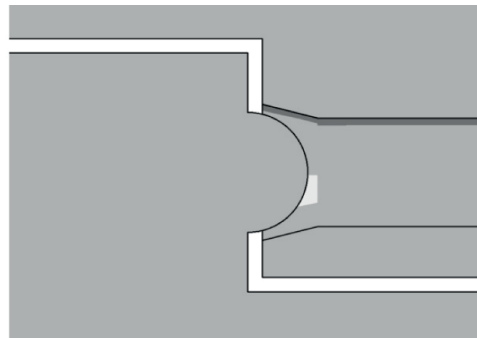
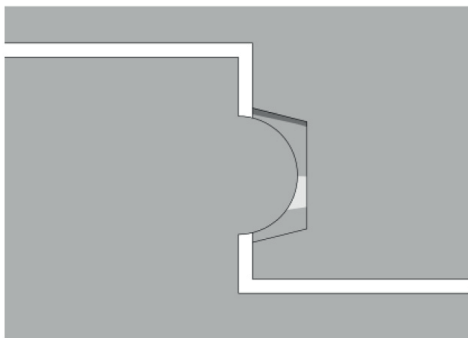
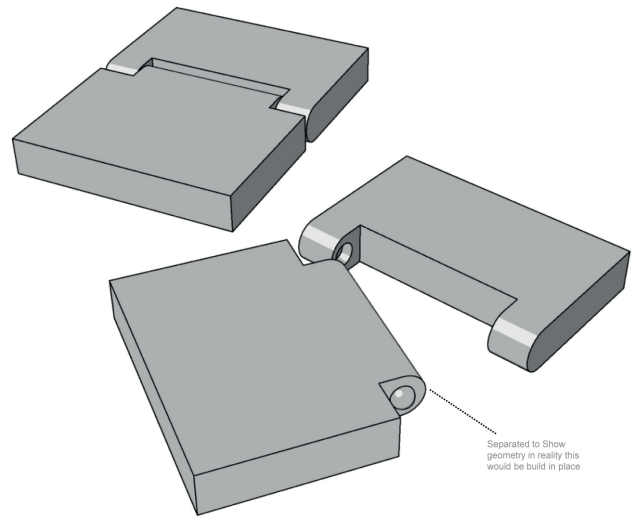
As with hollowing parts, the amount of powder not exposed does not strongly correlate with extra material for recycling. This is due to close-to-part thermal exposure. In fact, grid parts cost more to make than solid parts due to extra draw time.



Integrated Hinges

The sphere sitting in a revolved cone works well for integrated hinges giving good stability, precision, low friction, and high yield. Allow a minimum clearance of 0.2mm between the positive sphere and the pocket.

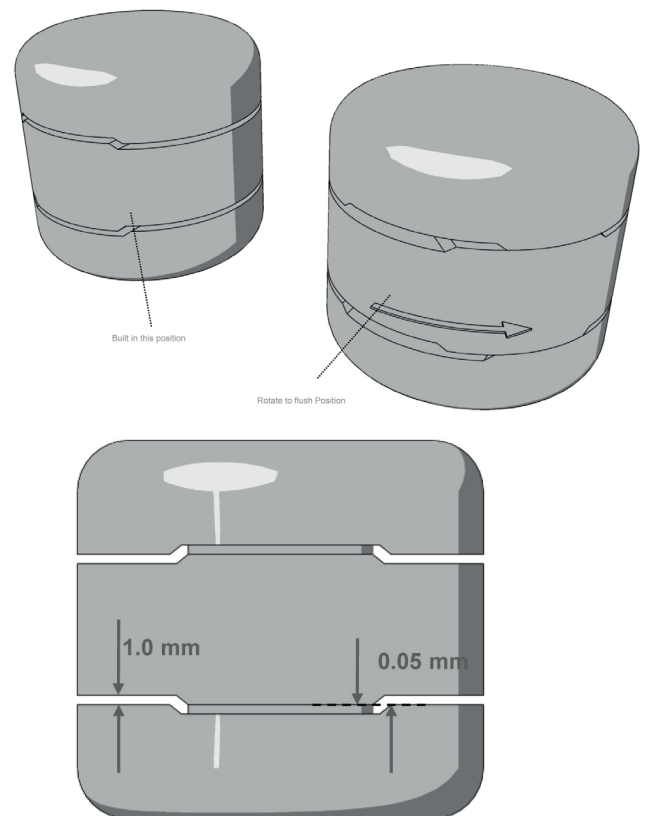
Allow 0.3mm+ clearance everywhere else. You will also need to continue the pocket to punch-out the side. This will have no effect on hinge functionality, however it will enable quicker and more complete powder removal.



Flush Integrated Hinges

The balance between function and quality of mechanism is in play when it comes to the effects of tolerance. Too little clearance and the mechanism will weld together, too much and it will be loose and unreliable.

To solve this, one approach is to apply a form where the hinge rotates into a flush position. Generous tolerances in excess of 1mm can be applied in the disengaged state for building, while tolerances of approx 0.05mm will enable a flush intimate stable interaction in the engaged functional range of the rotation.



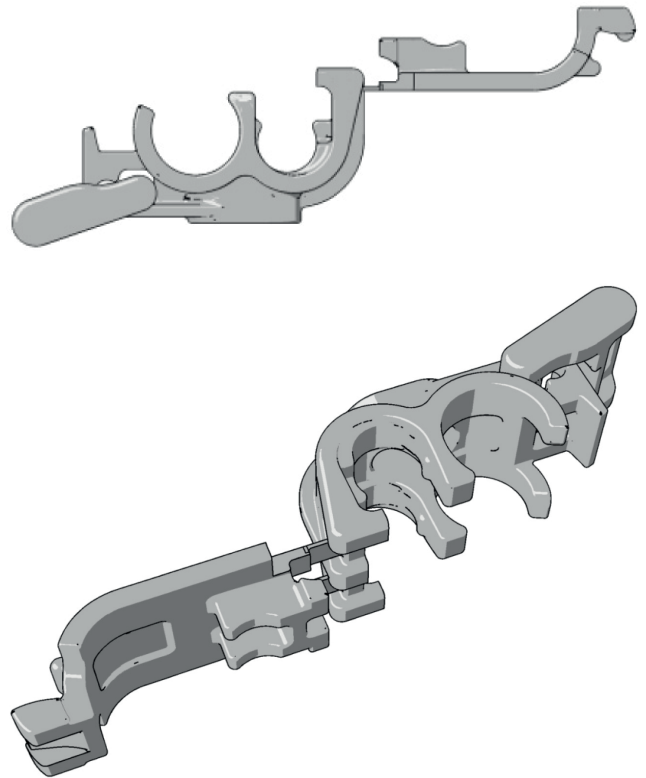
Living Hinges

The living hinge is more of a novelty for SLS and often not an ideal solution when it comes to articulation. The question to ask here is: Why build a living hinge when you can design and build an integrated hinge?

Conventional living hinges are designed and optimised for thermoplastic injection moulding materials and processes.

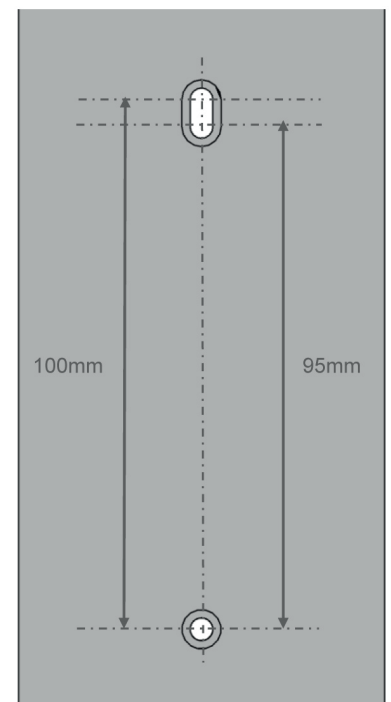
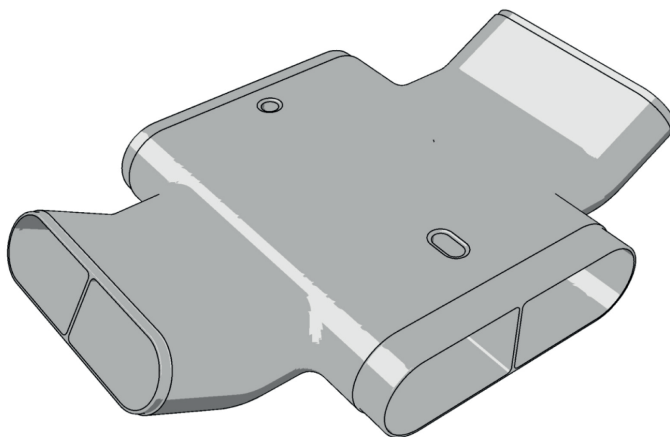
For SLS, try to steer clear of a living hinge as SLS nylon does not have the same flex behaviour as injection-moulded thermoplastics. This is due to the resolution of the process—3D printed hinges have to be thicker than those designed for moulding—and the tendency of nylon to work harder when exposed to cyclic deformation. This can be useful in applications where there is a one-time fold-to-use application and it makes sense to keep components connected together.

For build orientation, try to avoid stair steps coinciding with the tensile surface of the hinge. Immersing in boiling water for 10 minutes before flexing can toughen (anneal) the nylon.



Design for Mounting

A single elongated connection mount point allows for the thermoplastic variation you see on long sections. Elongate the adaptive hole at a minimum rate of 5mm per 100mm.



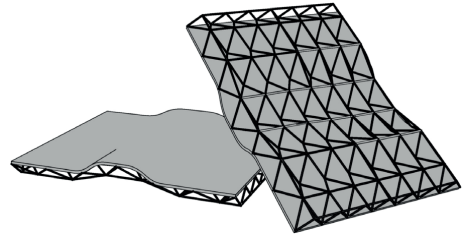
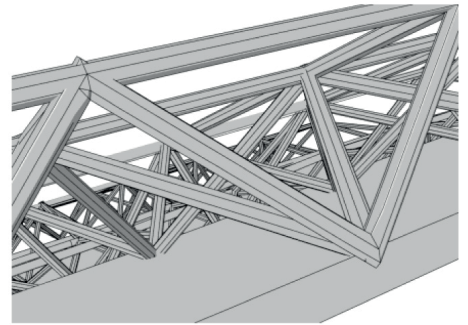
Lattice Structures

Lattice structures and other designed cellular materials enable designers to put material only where it is needed for a specific application. From a mechanical engineering viewpoint, a key advantage offered by cellular materials is high strength accompanied by a relatively low mass.

These materials can provide good energy absorption characteristics and good thermal and acoustic insulation properties as well. Cellular materials include foams, honeycombs, lattices, and similar constructions.

It can be tedious to manually construct lattice structures, so designers may want to create a macro or program to automate some steps. Or, use a specialised software package that automates the construction process.

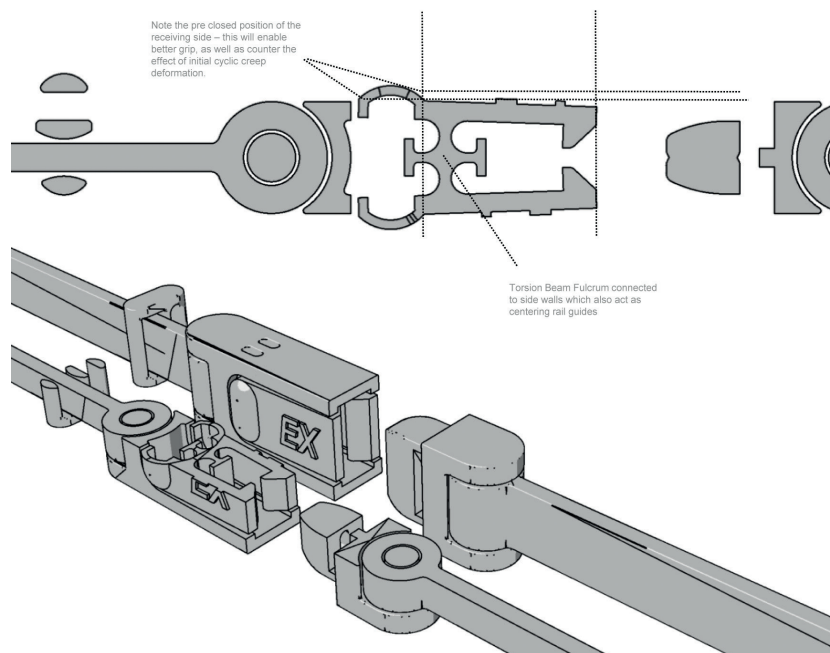
SLS machines can fabricate lattice struts down to almost 0.5 mm in diameter.



Snap Clips

There are many successful manifestations of the plastic clip design for SLS. Compared to injection moulding, the reduced limitations on design complexity with SLS enables far more sophisticated and complex systems for clipping, snapping, holding and releasing.

In this example, a “squeeze release” button mechanism rotates the two grip arms around a torsion beam fulcrum. Note the generous application of fillets to prevent fracture as well as the deformed closed position of the grip teeth to counter the effects of initial cyclic creep.



It's critical with design for SLS that, as with all beams that undergo cyclic deformation, you take into account the initial creep that the plastic will undergo before it settles into its final stable position.

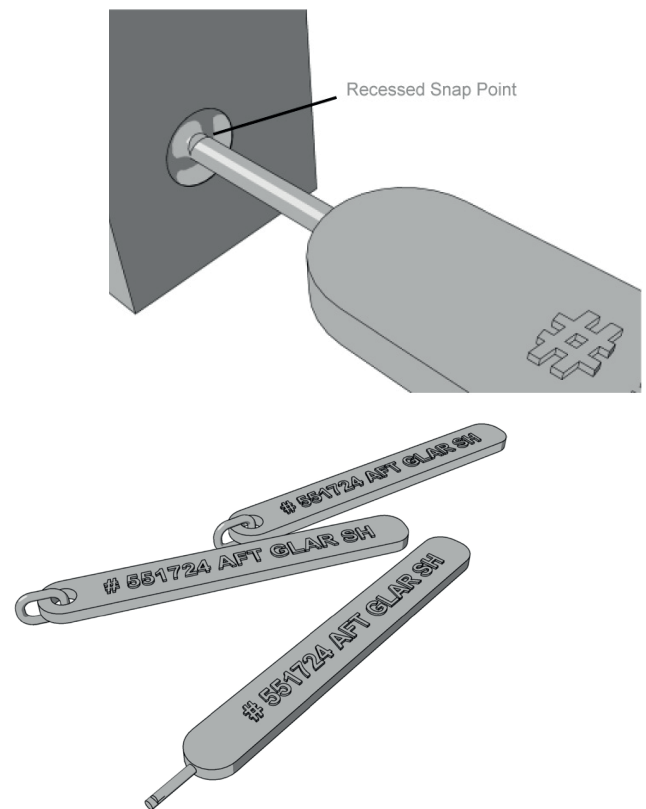
As with living hinges and leaf springs, boiling in water for 10 minutes can improve the toughness and memory of the plastic.

Tags

Tags connected by chains or sacrificial sticks are common ways to label SLS parts. 3D Sprint® software enables the automatic tagging of parts with STL file names. This is particularly useful in mass custom manufacturing applications. Try to keep all features above 1mm thickness.

Note: in the above stick, to “tag” connector the junction between the stick and the part is in a depressed filleted pocket. This reduces the impact on the mechanical integrity of the part. Also note the snap point in this case, a V notch modeled into the stick. The same can be applied to chains where you want to enable easy controlled removal of the tag.

By placing the V notch within the depressed pocket, no fit interfering artifact is left behind following its removal.

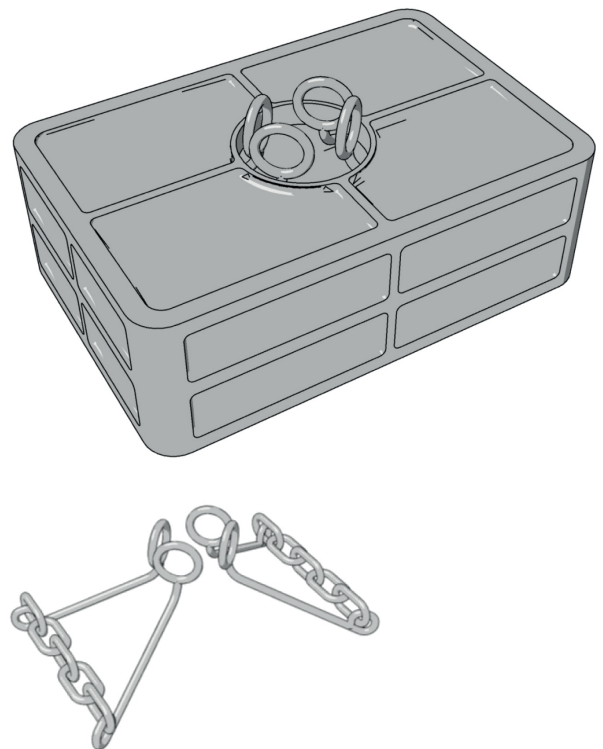


Tanks

A correctly sintered SLS nylon tank (density >0.98g/cc with a wall thickness >1mm) is capable of holding both a fluid and a gas under pressure. For aggressive solvents and fuels, consider infiltration with Imprex. Often the part cake within the tank, confined by geometry and exposed to extra heat, can become quite dense and require extra work for 100% removal.

As with air ducts, consider the placement of nested tools and powder removal aids. In this case a combination of rods and chains are used to cut and pull the material cake from the internal corners.

A chain/rod link diameter >2mm is usually sufficient. You can also model a stick within a hollow cone that attaches to an air line. With the removal of this pull stick pressurised air from below can be blasted.



Engineered Tear

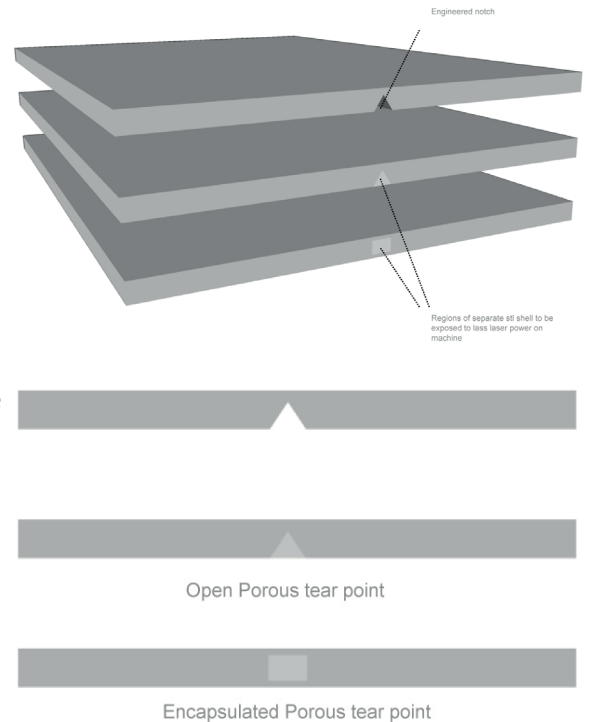
Controlled tear or fracture can be achieved using the traditional approach of physically designing a notch into the geometry.

However, with SLS manufacturing you also have the ability to selectively control the density of specific regions in the product.

You do this by CAD modeling the regions where you want to have low density as a separate STL file shell. When the part as an assembly is placed on the machine, be careful not to separate the shells through nesting.

The laser exposure can be reduced on the machine where you want density to be low. This will result in the selective fabrication of regions that are of low density, and hence much higher sensitivity to fracture.

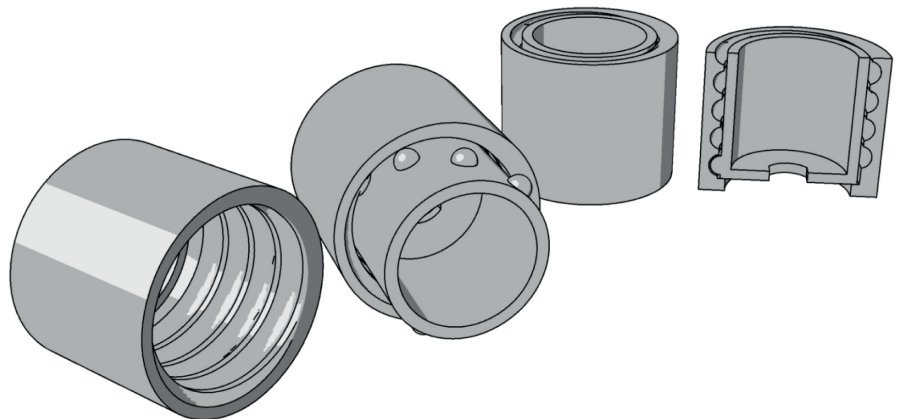
Note that material exposed to less densification has less shrinkage. The area where the lower density has been placed can be shy and more opaque than the surrounding denser regions.



Threads

As the surface texture of SLS can be relatively rough, friction can sometimes interfere with the screw thread mechanism.

In this example, the positive thread is replaced with “hemispheres” that align with the grooves in the negative side of the assembly.



By taking this approach, friction is dramatically reduced while “fit yield” is improved. Fit yield is where both parts are exposed to the same process variation. SLS is very sensitive to process variation. For example, when the beam offsets are incorrect, the positive side can be bigger and the negative side can be smaller, which would amplify interference.

This is a classic example of not being blinded by the conventional design approach to threads and getting guidance from the desired functional objective of the mechanism.

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