3D SYSTEMS

Rapid Manufacturing
SLS® Design Guide

Applications and Technologies of Selective Laser Sintering

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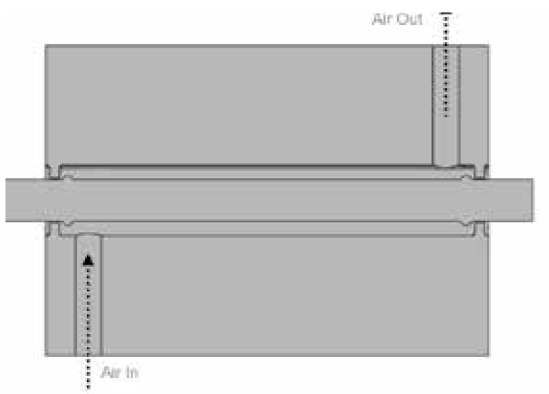
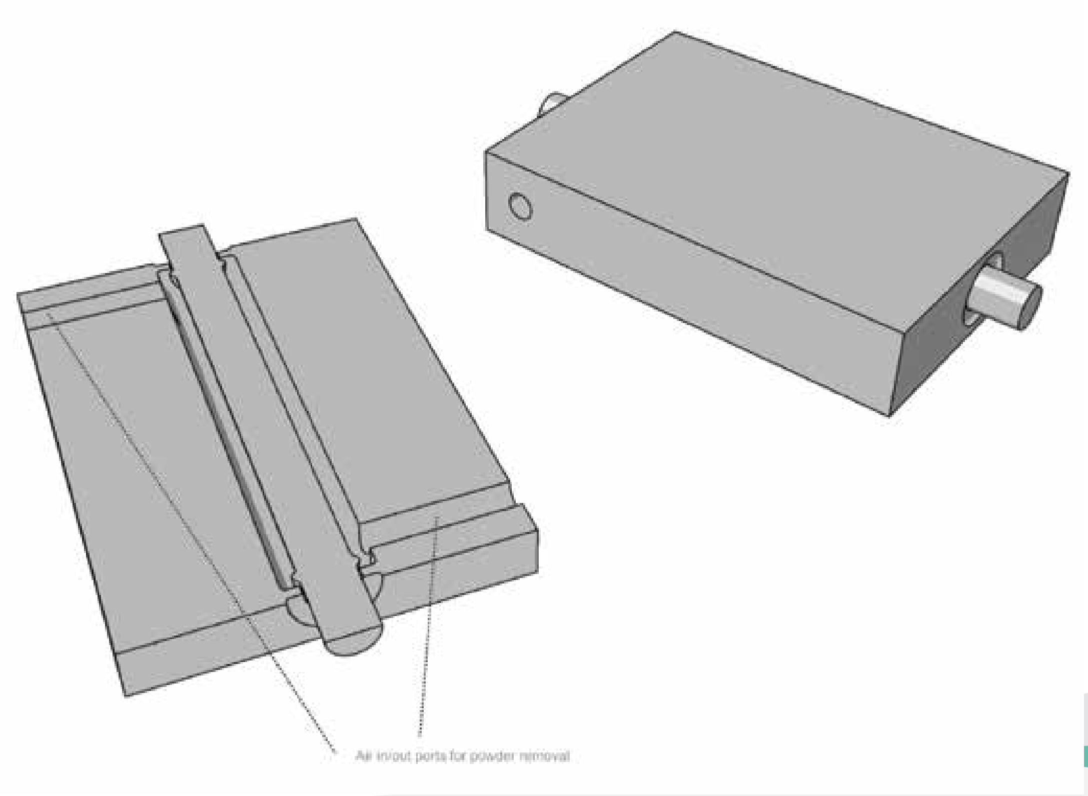
1 Axles

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.

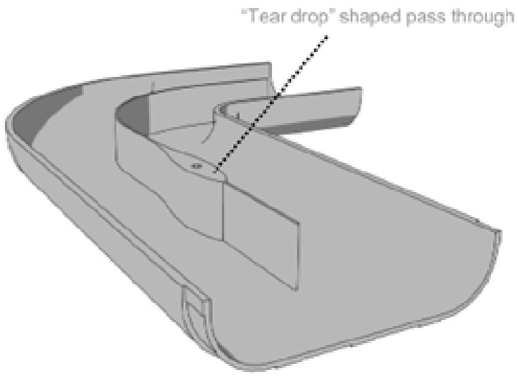


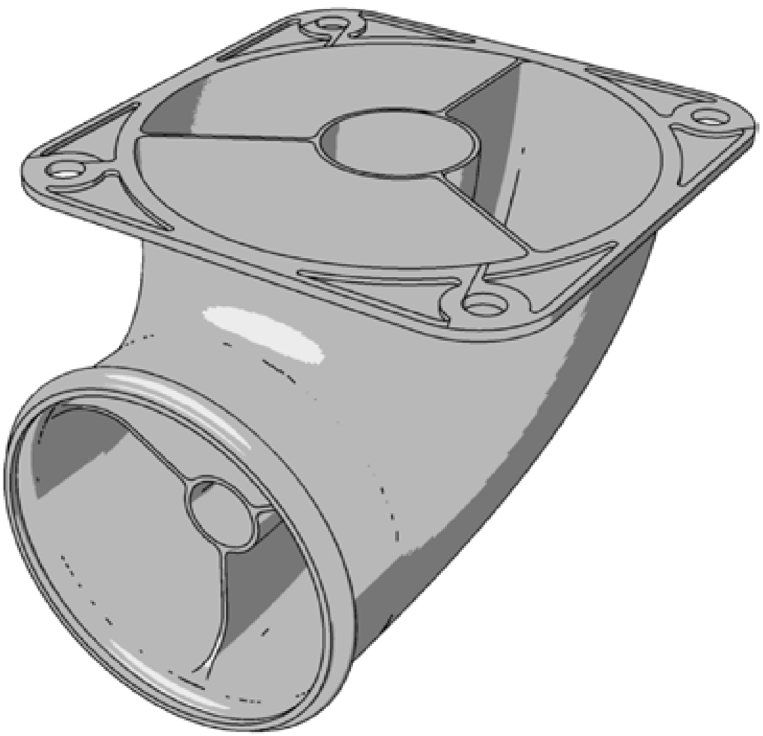
When removing powder, rotate and apply pressurized air in tandem to blast the powder out of the axle cavity. Nylon as a natural bearing material will provide a smooth low friction mechanism for low-load, low-velocity applications. For more demanding applications where friction can generate heat, and wear, consider #3 Inserted Bearings.



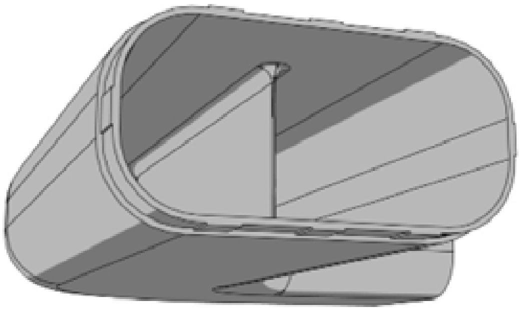
2 Baffles - Managing Air

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 both improve air flow efficiency as well as cut down on noise.





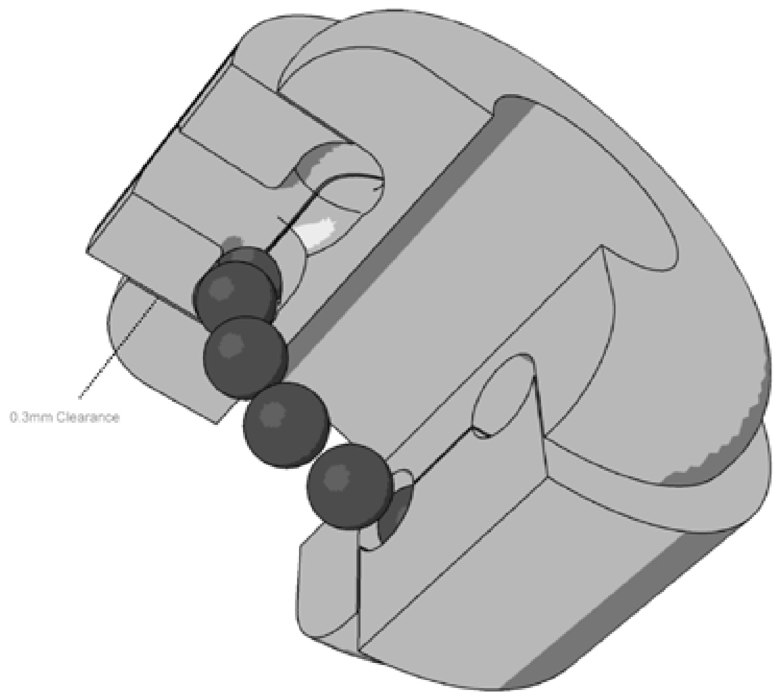
Always apply generous fillets to baffles to prevent side walls of ducts from splitting, especially if component will be exposed to pressure and/or cycling of temperature.

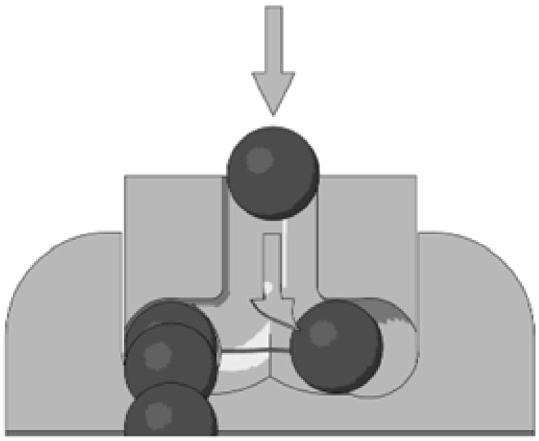


3 Inserted Bearings

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. It could be considered an integrated hybrid hinge mechanism.

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

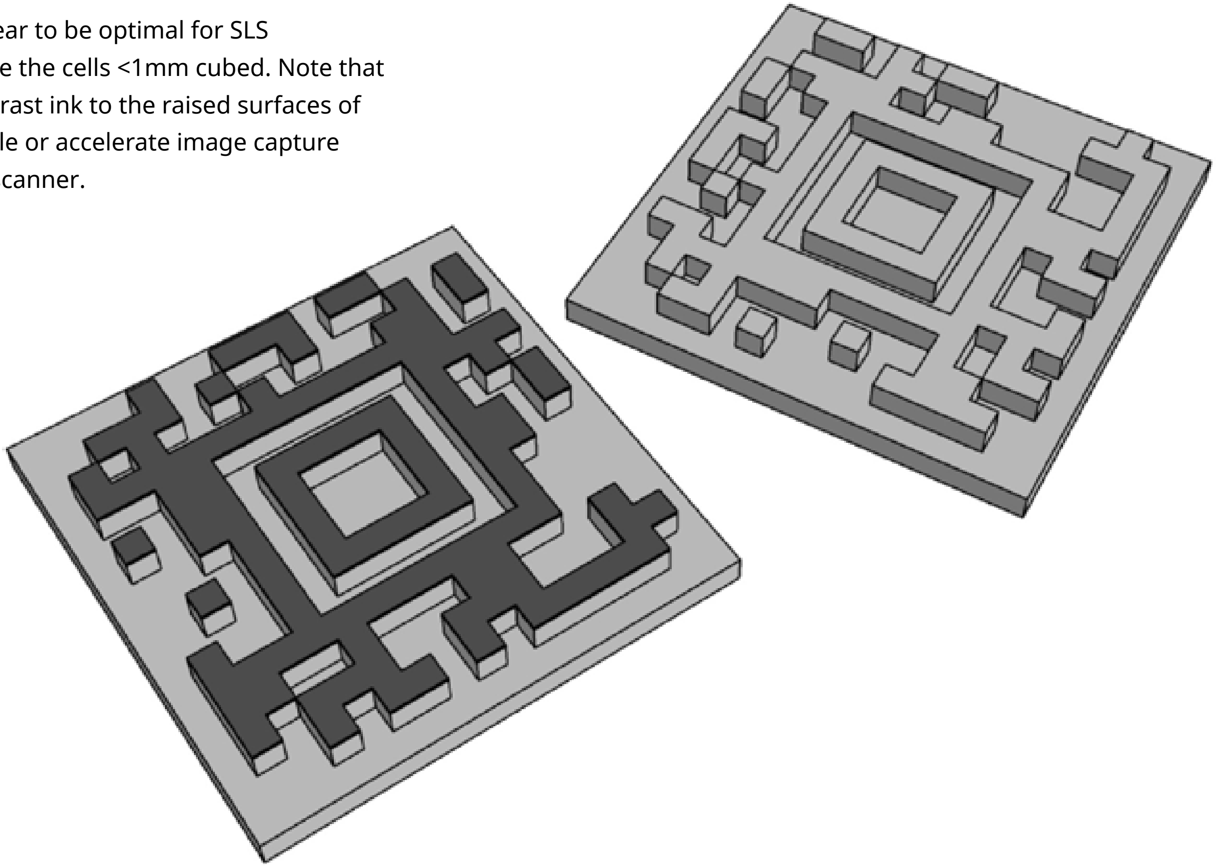




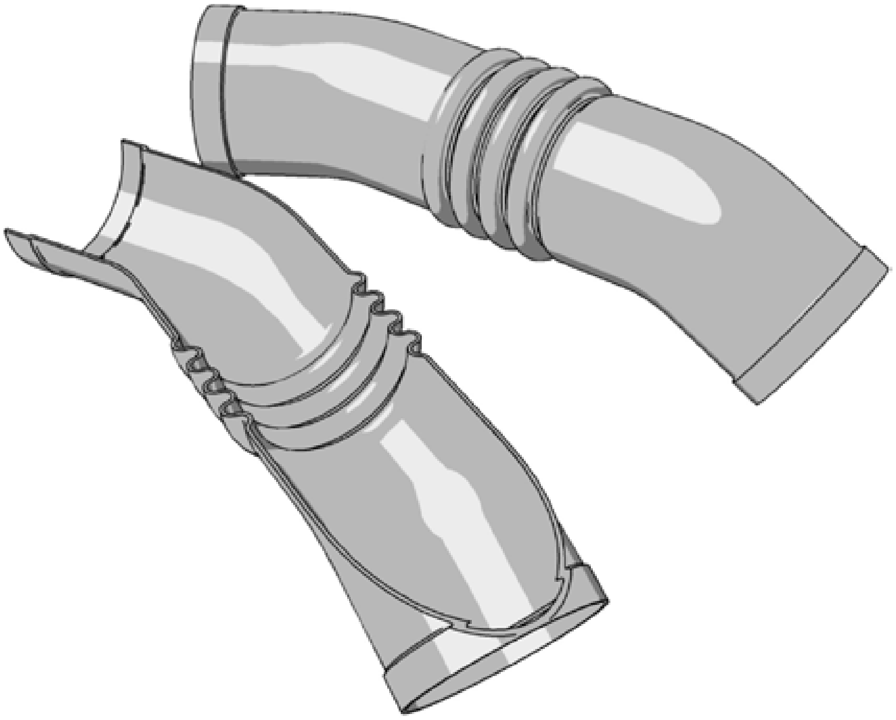
Once all the bearings have been dropped into the chase, a plug can be fixed to seal in the chase.

4 Barcodes

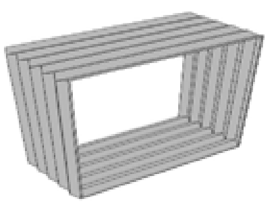
Aztec Barcodes appear to be optimal for SLS Manufacturing. Make the cells <1mm cubed. Note that you must apply contrast ink to the raised surfaces of the barcode to enable or accelerate image capture when exposed to a scanner.



5 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 to see 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, then you can still use SLS but you will get better performance and resistance to work hardening from the Polyethylene-based SLS materials such as Duraform® Flex.

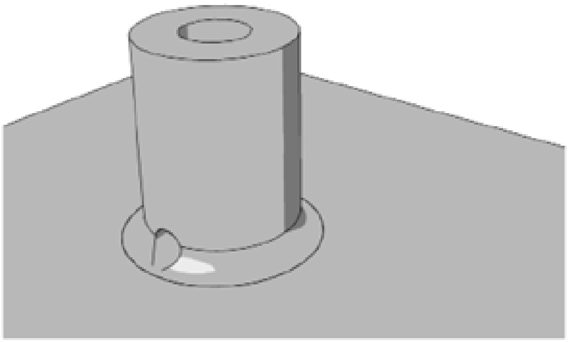


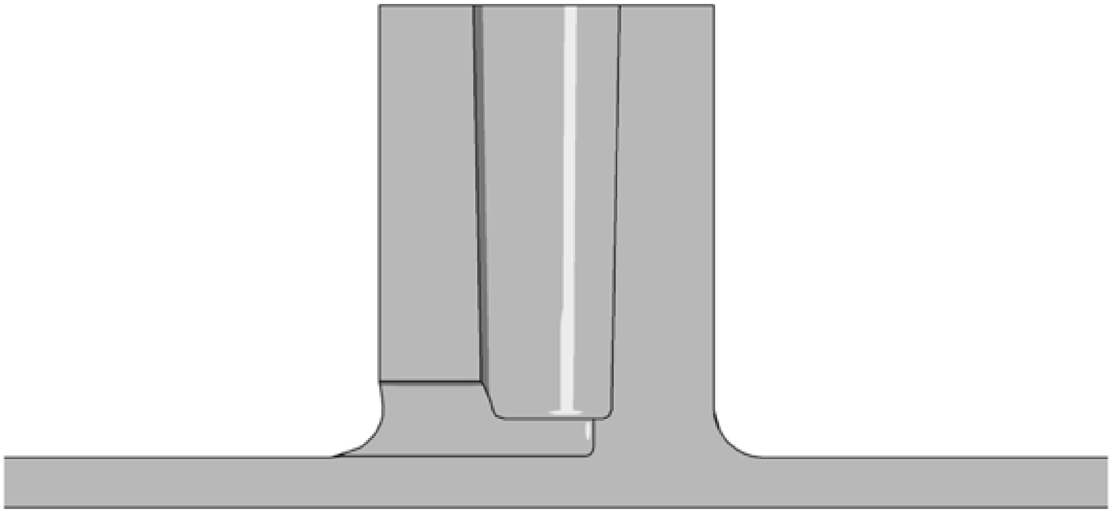
Circular bellows work best as they distribute the tensile stress points evenly around the cross-section. Any devolution from the circle will accumulate stress as you transition to the square bellow. In this case you may have to take a different approach by applying a similar structure as you will find in "Deardorff Bellows" (see above), basically a series of alternating cross-linked rectangles. However do note that this geometry is more sensitive to stress concentrations as it has low-radius corners, hence resultant sensitivity to fracture when exposed to cycling.

6 Blind Bosses

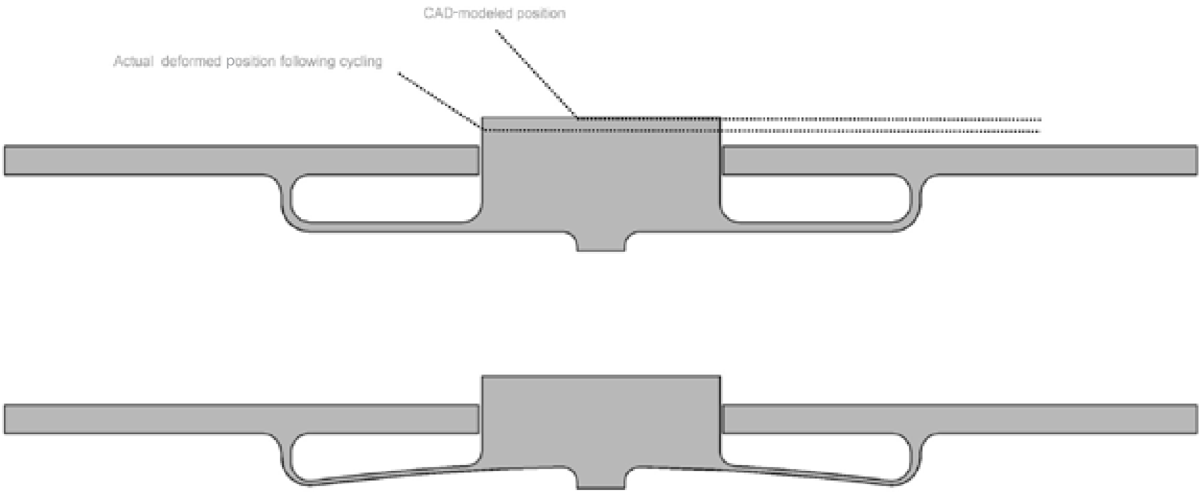
Blind holes can be challenging for efficient powder removal, so the solution here is to not make them blind. Simply apply a small hole >2mm in diameter at the base of the boss to enable bead blast material to exit.

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.





7 Buttons



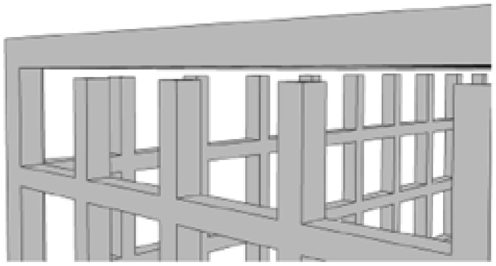
There are many different approaches to integrated button design. Allow at least 0.3mm clearance between the button and the slot or hole from which it emerges to prevent fusing. You should also CAD model the button to be higher than the final desired position, as the nylon “leaf springs” will tend to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

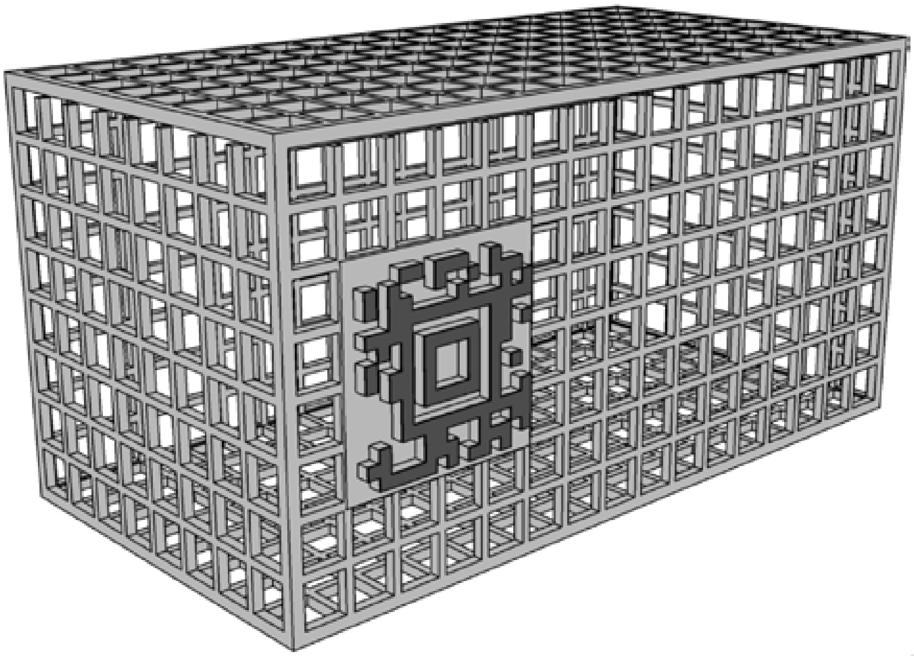
8 Cages

SLS Manufacturing 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 sterilization for surgical use, the batch can transition through the various processes within the cage. To remove the parts consider CAD modeling in hinge doors, apply snap-off regions or, as in this example, connect the lid with the four corner posts that can be cut off with wire snips.

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

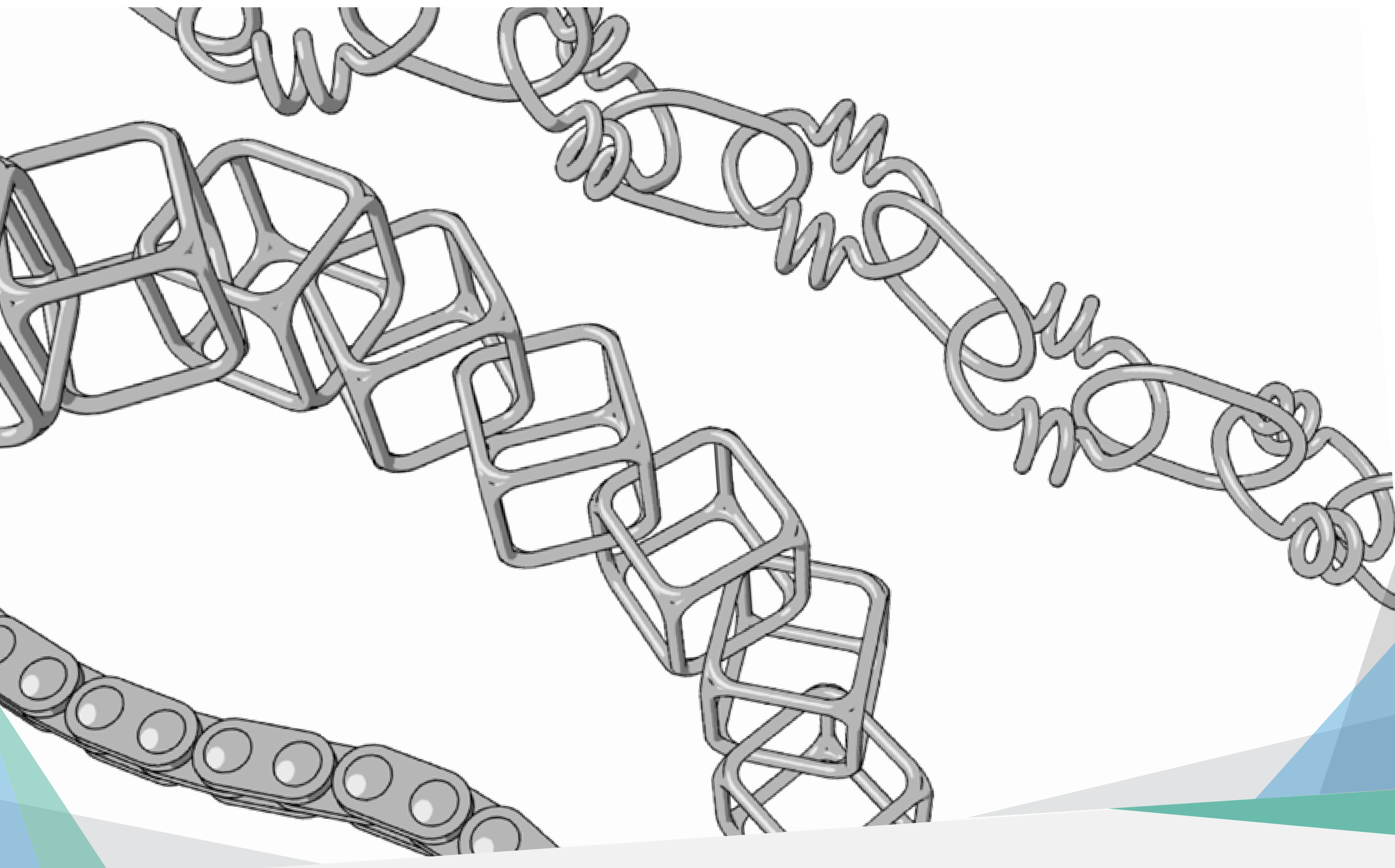




9 Chains

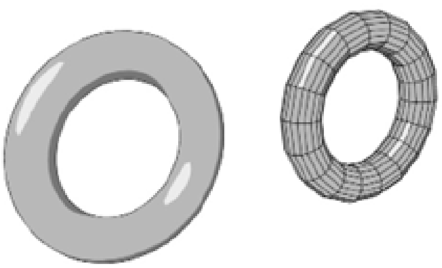
Designing Chains for SLS manufacturing can be a lot of fun, as with chainmail. It's also a very old geometry that has lots opportunity for novel and interesting forms.

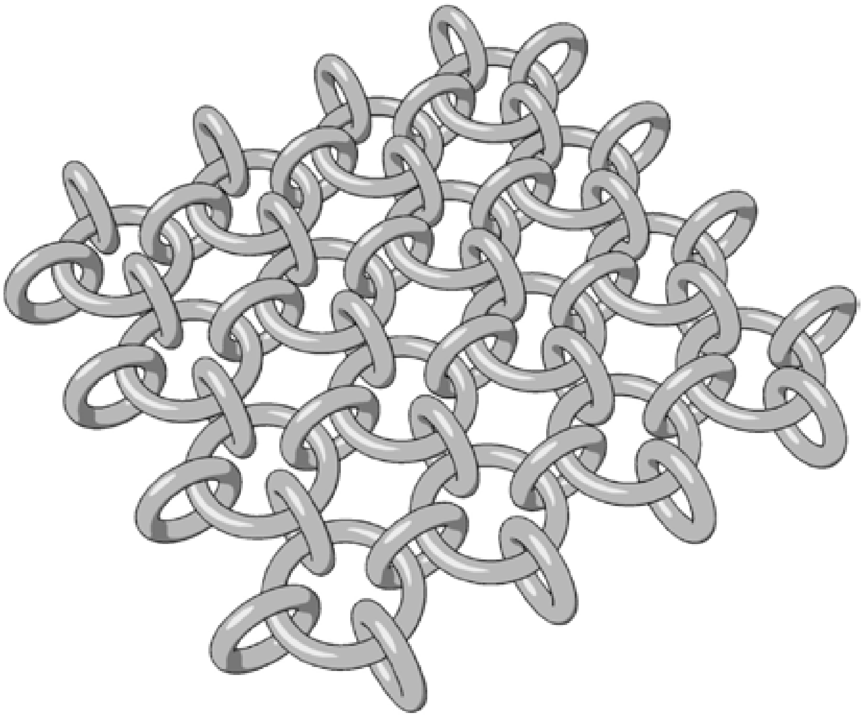
The earliest chains were hammered/forged rods bent into interconnecting loops. With SLS the only limitation to chain design is your imagination. And, yes, you can do bike chains… just keep the clearance 0.3mm between the shells.



10 Basic Chain Mail

For basic chainmail keep the link thickness >0.75mm and the keep clearance between the links over 0.5mm. For large pieces, consider designing the link to have a polygon cross section in both axis, this will reduce the tremendous file size as well as speeding up the design process.





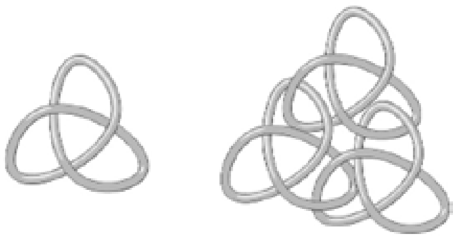
Invest time in getting a single link optimized before array duplication. Consider using a polygon instead of the circle to speed up link duplication and manipulation in CAD.

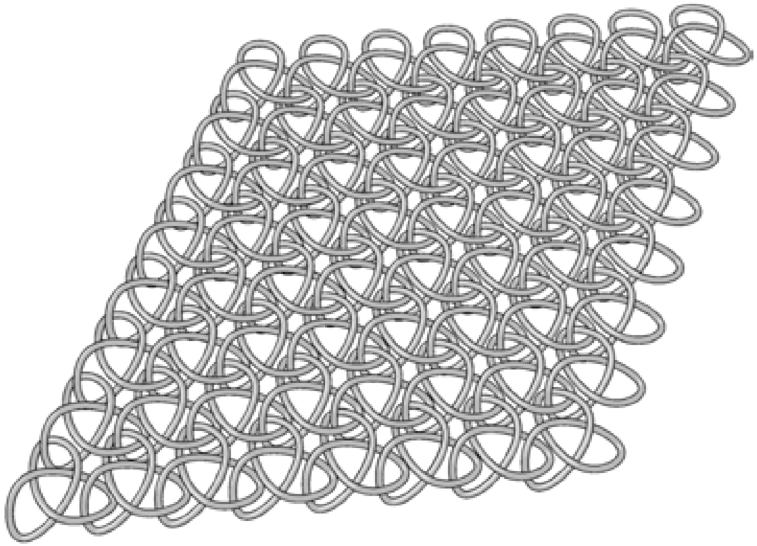
Note you can also fold your design like you would fold fabric to reduce the part cake volume taken up by your design. Particular care must be taken to avoid superimposing links.

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

11 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.





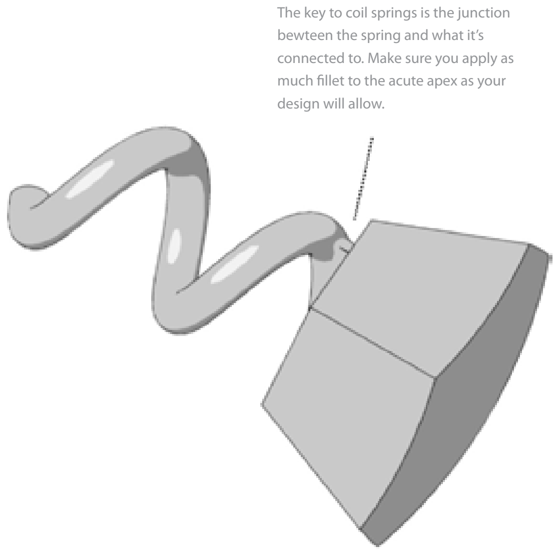
Consider chain mails that transition into plates and chain mails where the links get progressively thicker in regions enabling controlled zones of opacity and flexibility.

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

12 Coil Springs

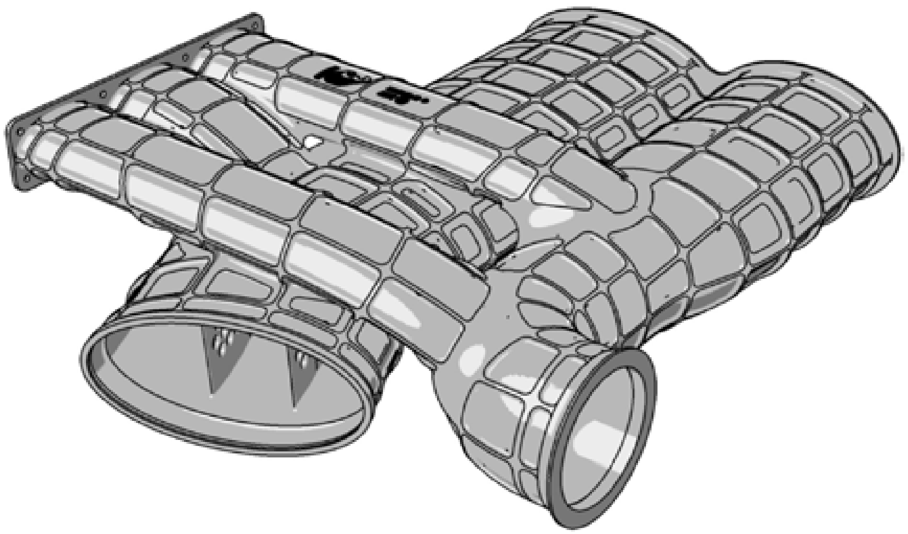
One of the most important features to consider with coil springs, is the generous application of the fillet at the junction where the spring connects to other features. Special attention should be given to the acute apex.

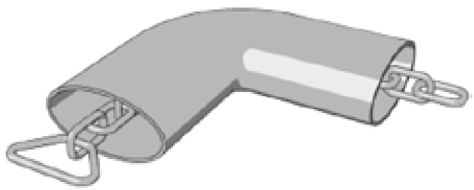
As with all materials, cracks can initiate very rapidly when exposed to cyclic loads. Also note that as with leaf springs, the final stable position of the spring will take several cycles of compression and elongation to become apparent.



13 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 optimized, very complex single piece structures. Take advantage of the fact that you can not only engineer in variable wall thicknesses but that you can increase the strength-to-weight ratio through the application of structurally optimized surface webbing. This is a very costly detail to apply with traditional manufacturing techniques. For SLS there is no cost from complexity.



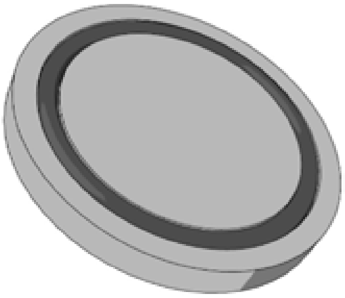


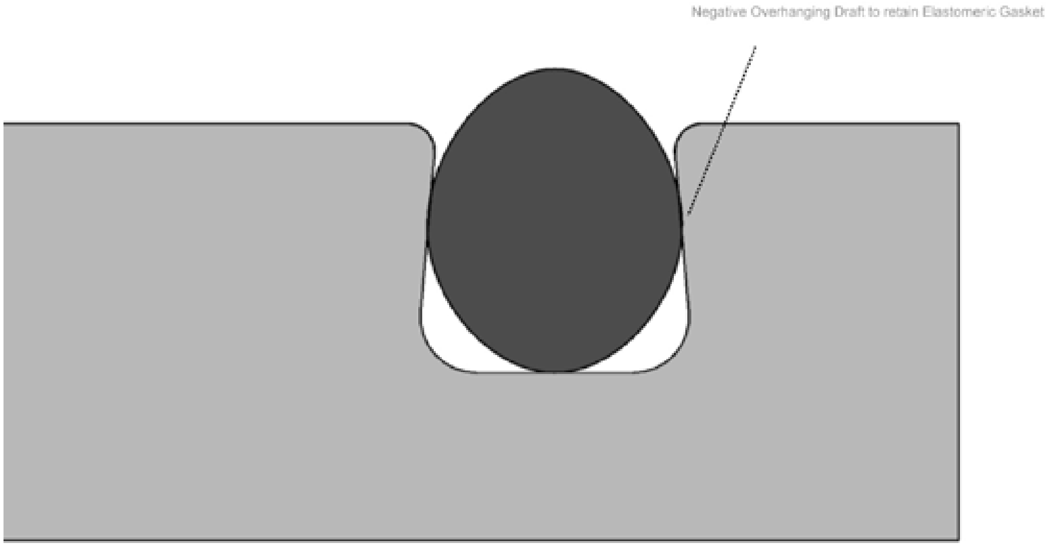
Consider CAD modeling in a chain through the duct. When finishing, a quick pull of this chain through the duct will clear an open channel for the bead blasting media to get a good cleaning velocity in the duct.

14 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 both allow for placement and retention of gasket.

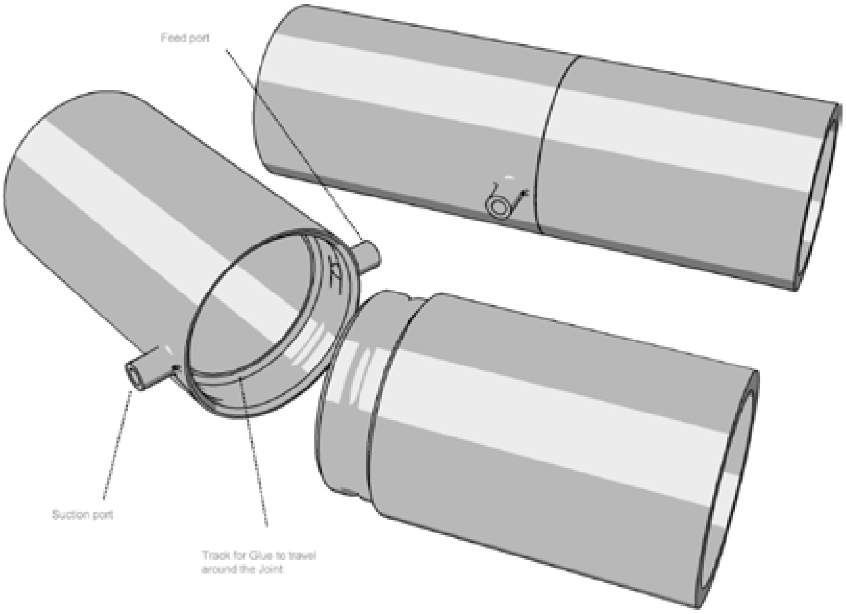
Note the same principle can be applied to the fixturing of other elastomeric components such as grip pads and button arrays.



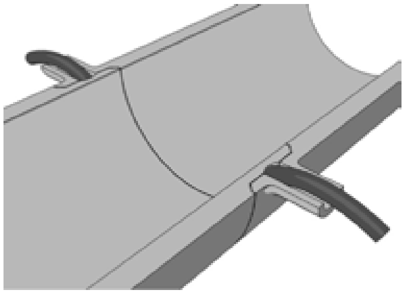


15 Glue Lines

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.



Also note that 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 100% fill track around the entire join region.

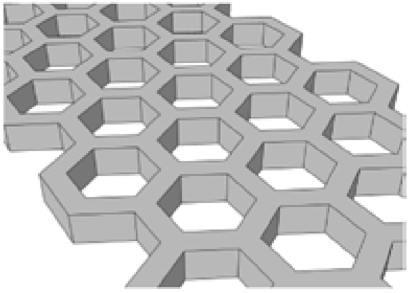


Above cross section shows glue (dark) getting sucked into radial cavity through access ports.

16 Grids

Hexagons are particularly optimized 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, then expect the file size to increase dramatically.

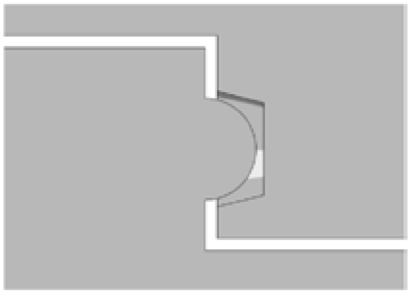


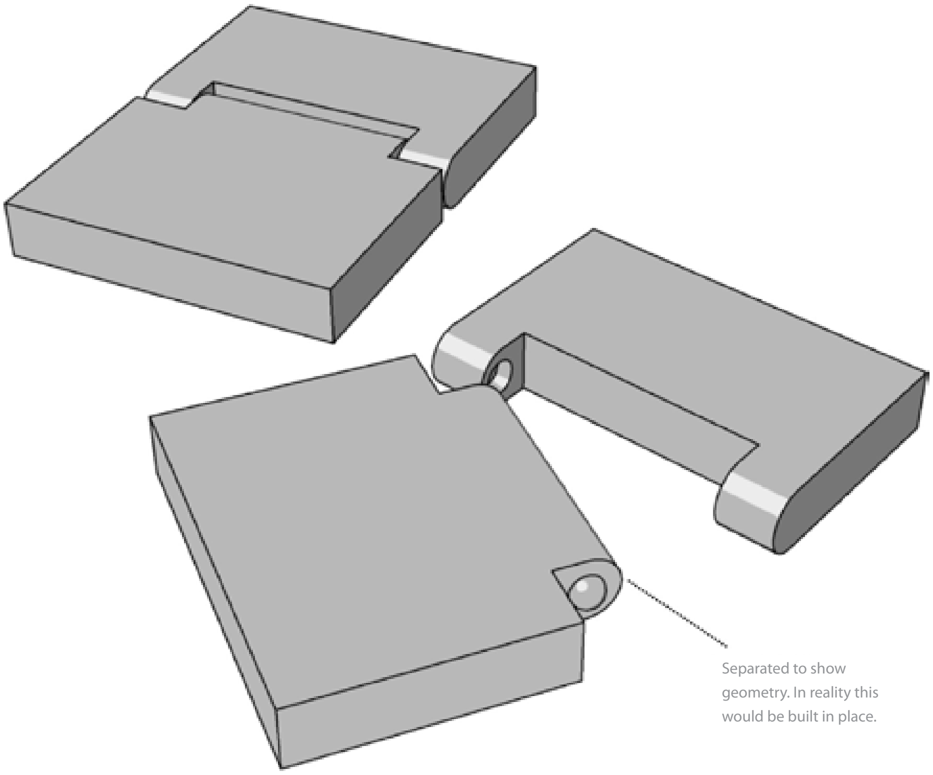
Also note that while you may cut down on the weight of the final part relative to a solid non-grid section, you will increase cleaning time and you will increase draw time on the systems, as the laser now outlines and fills in the feature rich cross-sections.

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 that solid parts due to extra draw time, but they look cool!

17 Integrated Hinges

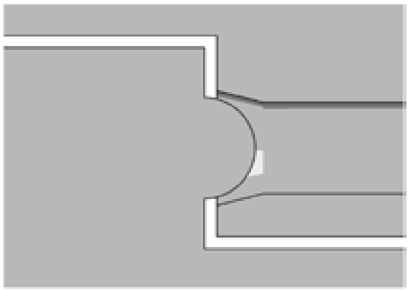
The sphere in a revolved trapezoidal cone works well for integrated hinges giving good stability, precision, low friction, and high yield. Allow a minimum clearance of 0.2mm between the positive sphere and the pocket.





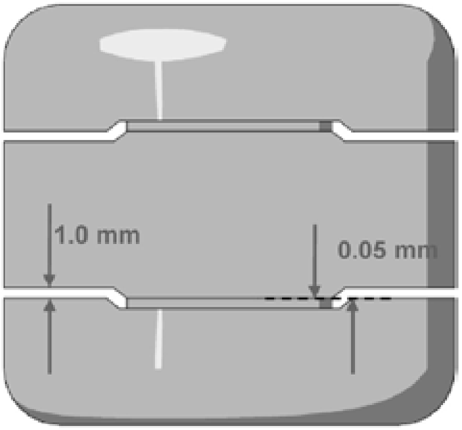
Separated to show geometry. In reality this would be built in place.

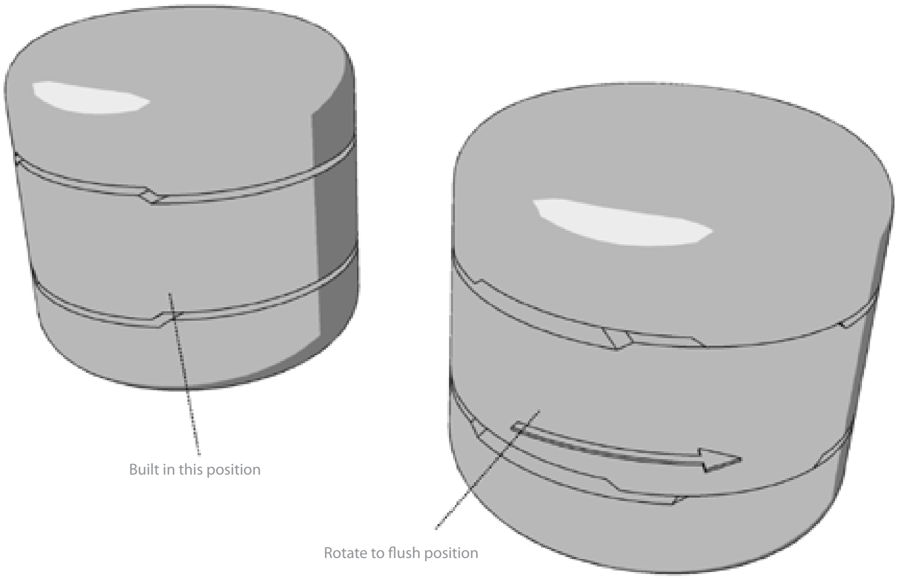
Allow 0.3mm+ clearance everywhere else. Note you also continue the pocket to punch-out the side. This will have no effect on hinge functionality, however it will enable much quicker and complete powder removal.



18 Flush Integrated Hinges

The balance between functional 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.

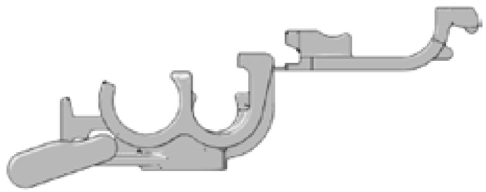


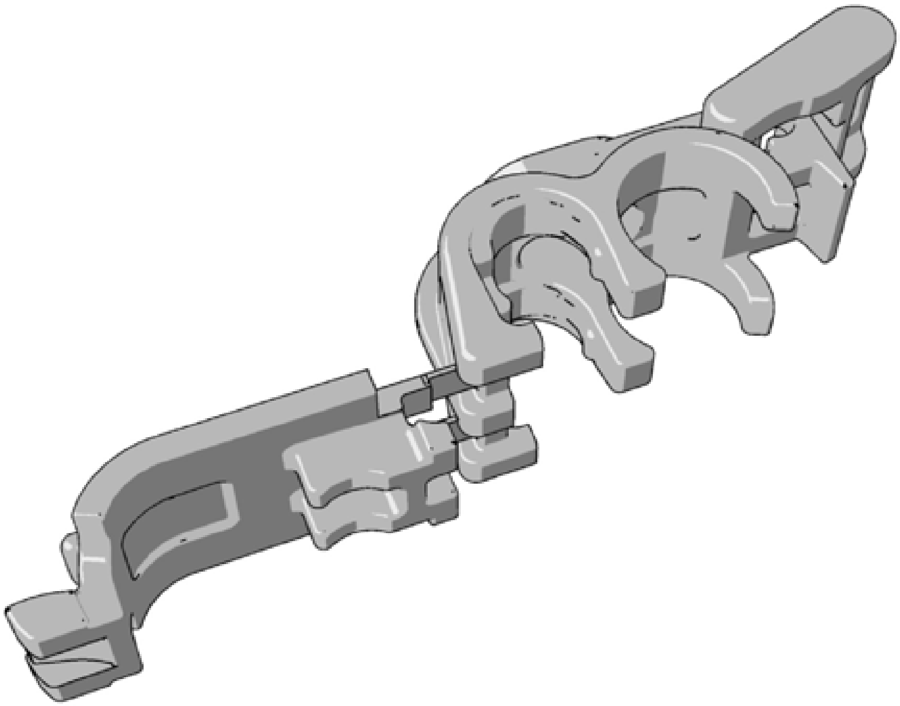


To solve this, one approach is to apply a form where the hinge rotates into a flush position. Generous tolerances in excess of 1mm can be applied in the disengaged state for building, while tolerances of approx 0.05mm will enable a flush intimate stable interaction in the engaged functional range of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

19 Living Hinges

The living hinge is more of a novelty for SLS and ofter 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?



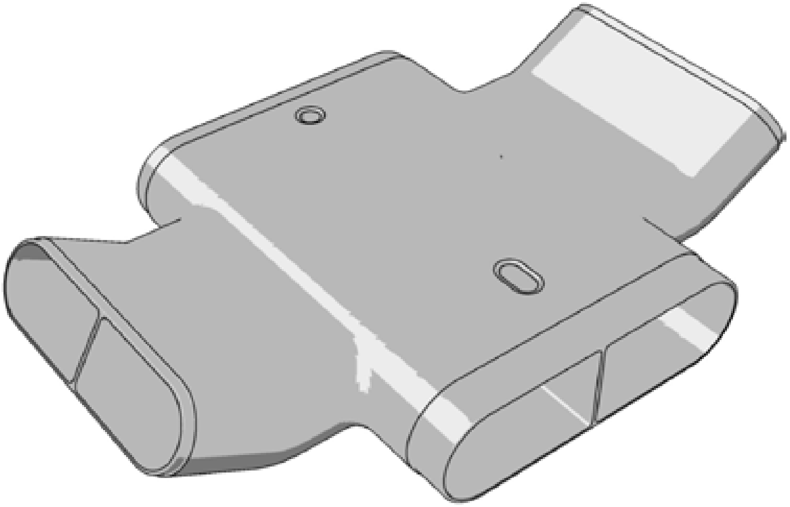


Conventional living hinges are designed and optimized for the thermoplastic injection molding materials and process.

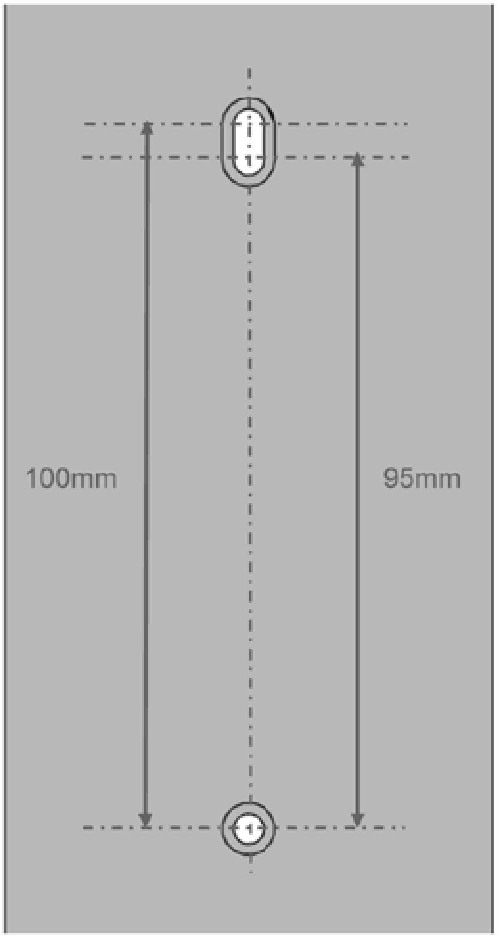
For SLS try to steer clear of a living hinge as SLS nylon does not have the same flex behavior as injection-molded thermoplastics. This is due to the resolution of the process—hinges have to be thicker than those designed for molding—and the tendency of nylon to work harder when exposed to cyclic deformation. 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. Also consider immersing in boiling water for 10 minutes to toughen (annealing) the nylon before flexing.

20 Design for Mounting



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.



3D SYSTEMS

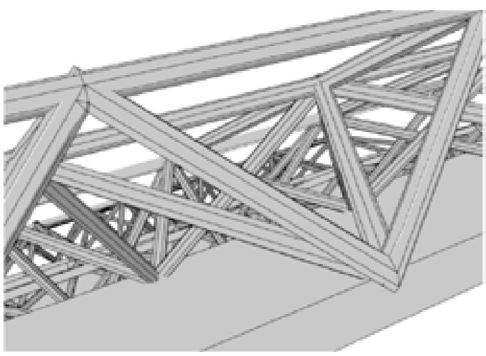
21 Lattice Structure

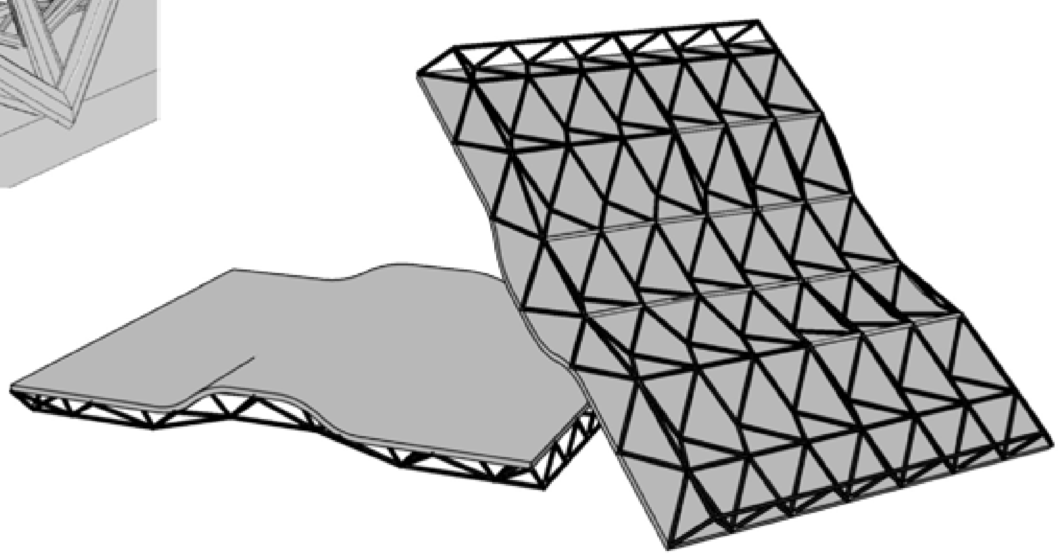
Lattice structures and other designed cellular materials enable designers to put material only where it is needed for a specific application. From a mechanical engineering viewpoint, a key advantage offered by cellular materials is high strength accompanied by a relatively low mass.

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 structure, so designers may want to create a macro or program to automate some steps. Or, use a specialized software package that automates the construction process.

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





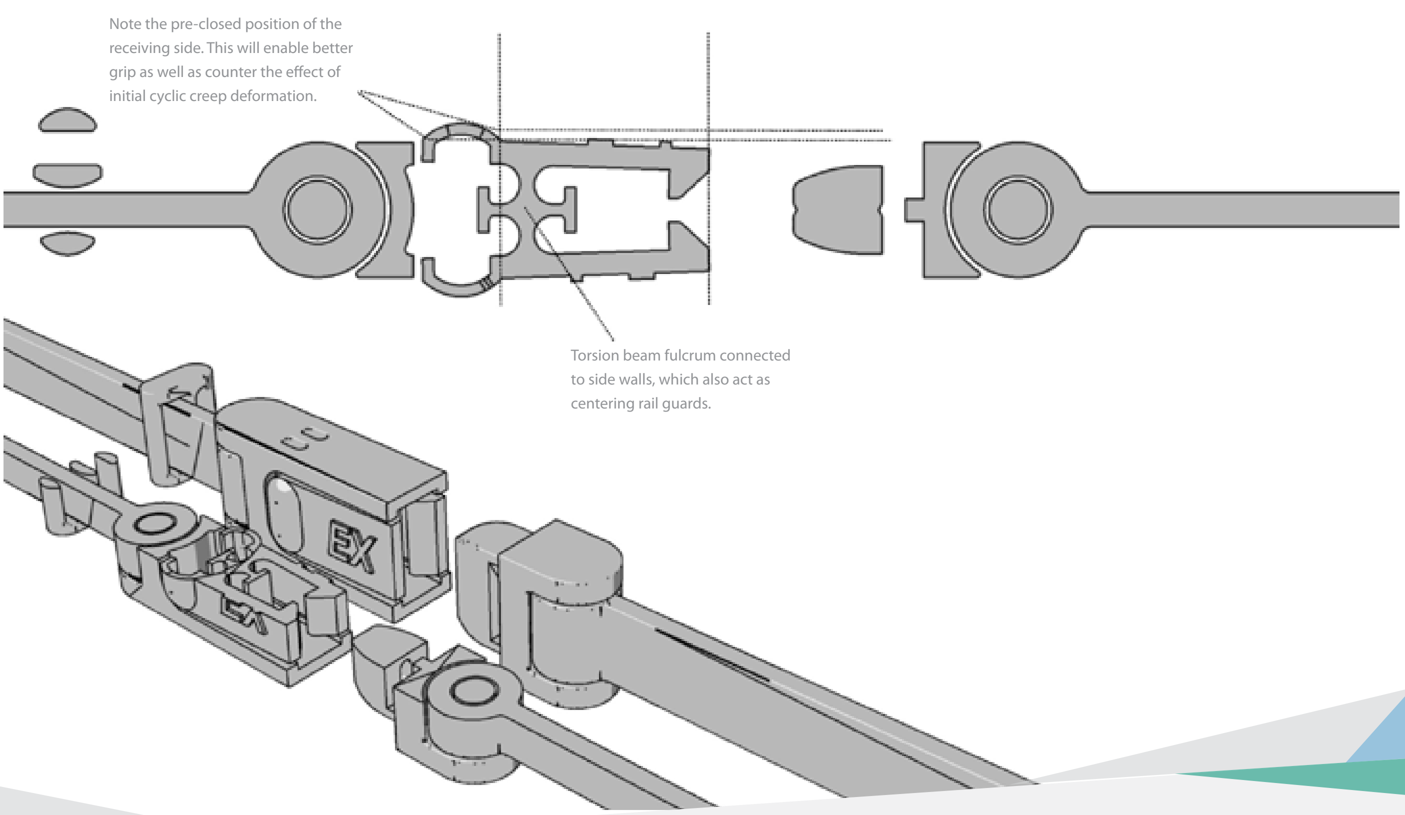
22 Snap Clips

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

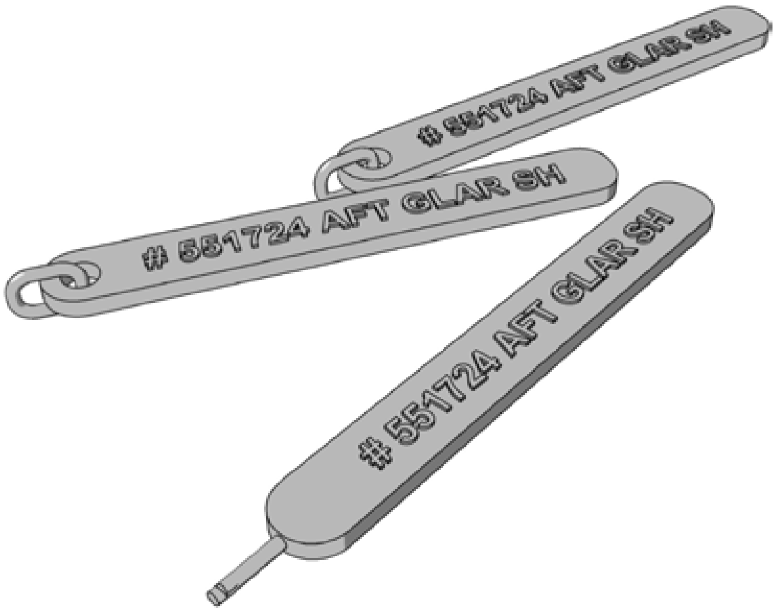
In this example from Colin Blain in the UK, a "squeeze release" button mechanism rotates the two grip arms around a torsion beam fulcrum. Note the generous application of fillets to prevent fracture as well as the deformed closed position of the grip teeth to counter the effects of initial cyclic creep.

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.

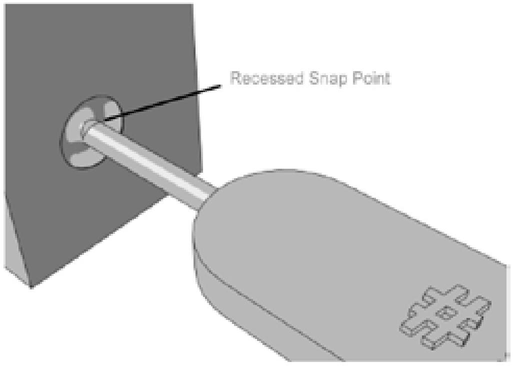
As with living hinges and leaf springs, consider boiling in water (annealing) for 10 minutes to improve the toughness and memory of the plastic.



23 Tags



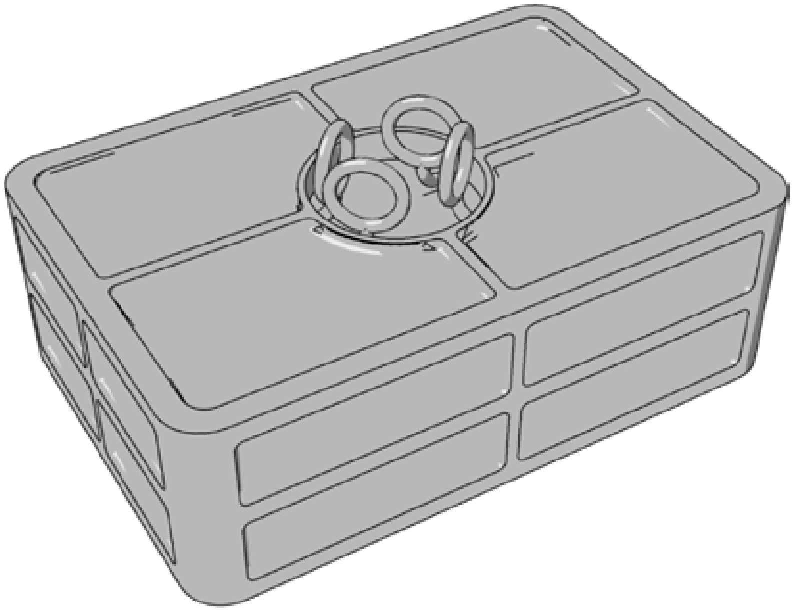
Tags connected by chains or sacrificial sticks are common ways to label SLS parts. Some STL conditioning software packages enable the automatic tagging of parts with STL file name. This is particularly useful in mass custom manufacturing applications. Try to keep all features above 1mm thickness.



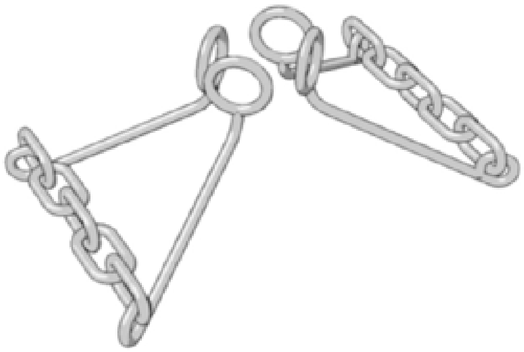
Note in the above stick, to "tag" connector the junction between the stick and the part is in a depressed filleted pocket, this reduces the impact on the mechanical integrity of the part. Also note the snap point in this case, a V notch modeled into the stick. The same can be applied to chains where 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.

24 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 quiet dense and require the application of extra labor for 100% removal.



As with #4 air ducts, when designing 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 ink 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 you will be able to blast pressurized air from below.

25 Engineered Tear

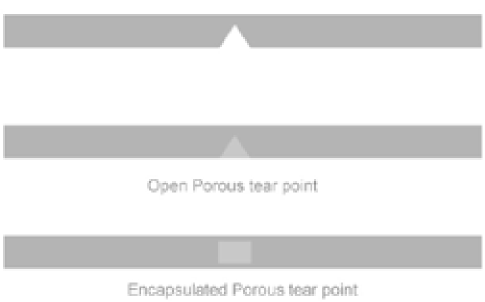
Controlled tear or fracture can be achieved using the traditional approach of physically designing a notch into the geometry.

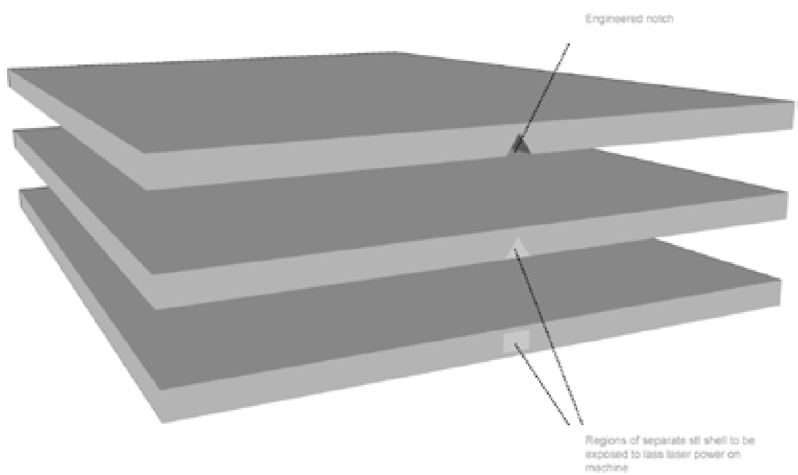
However with SLS manufacturing you also have the ability to selectively control the density of specific regions in the product.

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.

On the machine itself reduce the laser exposure to the shells where you want to 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.





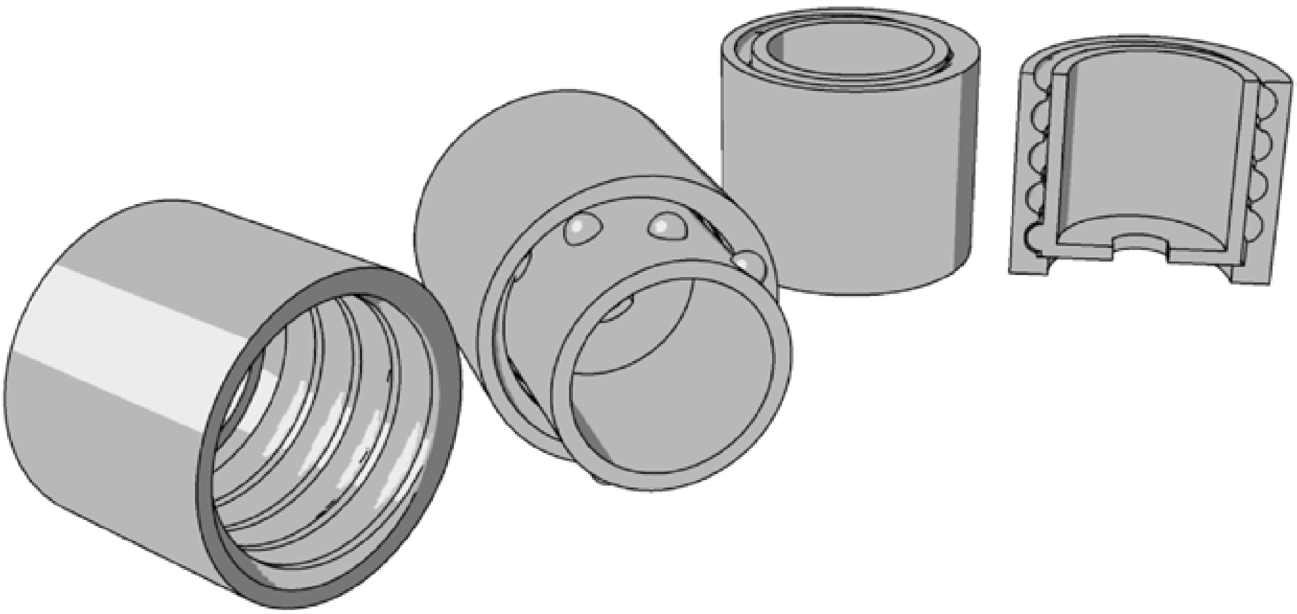
26 Threads

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, and it 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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