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Loops and Threads in FFF manufactured products

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Title: Loops and threads in FFF produced products

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Abstract: This publication relates to toolpath generation and a method for material deposition. We suggest the creation of loops in FFF produced products together with cross-connections through those loops, in order to increase the adhesion strength in between layers either of the same material or of different and potentially incompatible materials. By chaining of such loops and their cross-connections an interlocking microstructure arises which increases the Z-strength of the FFF manufactured (multi-material) product.

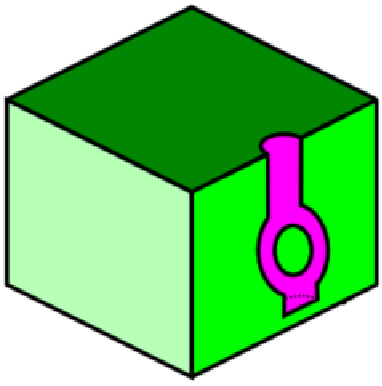
A well-known challenge in FFF is how to increase the Z-strength of products. Due to the layer-wise buildup of FFF produced products and the fact that the fusing of a layer with the previous layer is suboptimal, manufactured products which undergo a tensile force along the same direction in which it was printed (Z), will delaminate along the layer boundaries at a much lower force than when subjecting the products to a force in a horizontal direction with reference to the printing direction. This problem is exacerbated when the two consecutive layers are printed in different materials for which the inter-layer bonding is even less than with the same material.

To increase the Z-strength, we suggest inserting loops in FFF produced products together with cross-connections through those loops. By chaining of such loops and their cross-connections interlocking occurs which will increase the Z-strength.

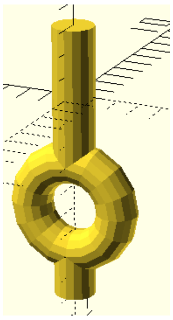
The loops may come in two variants: vertical and horizontal. We will first describe the vertical loops, then the horizontal loops, after which we will explain how to combine these together in order to form chains.

Vertical loops

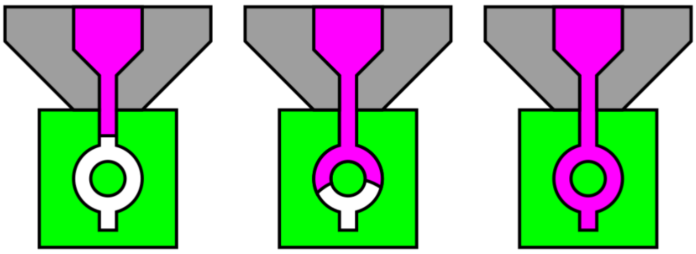
In the picture below green indicates a first print material and magenta indicates a second material:



A cavity is created in the first material which cavity is isomorphic to a torus and two cylinders and spans several layers, see below.



After the layers of the first material have been printed, the cavity will be filled by injection from above:

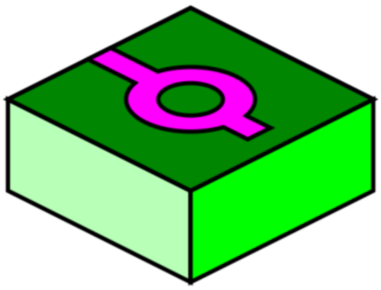


An example of the toolpaths of the first material are given as follows (left-to-right is bottom-to-top):

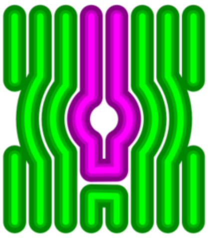
The toolpaths close to the cavity are kept constant, while some toolpaths farther away are cut into pieces.

Horizontal loops

Horizontal loops are fairly simple in itself, because they can be printed within a single layer; and the toolpaths for that layer could be replicated across multiple layers if needed.

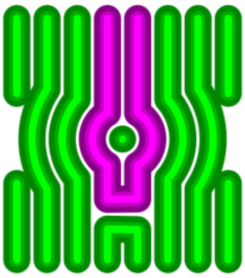


Toolpaths could be given as follows:

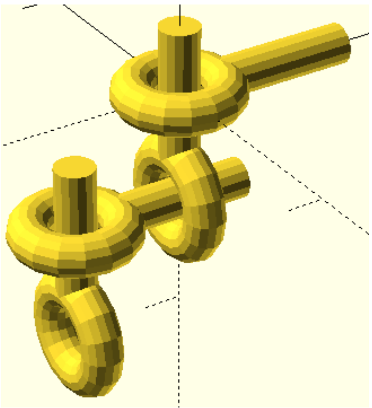


Note that the middle is left intentionally empty in this drawing.

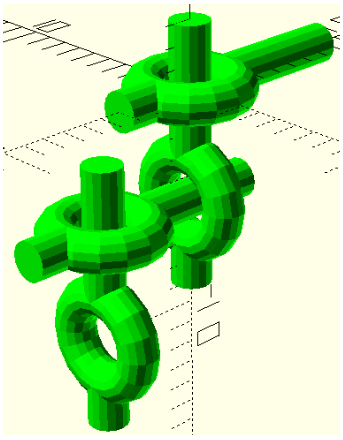
One could fill it up using a small extrusion like so:



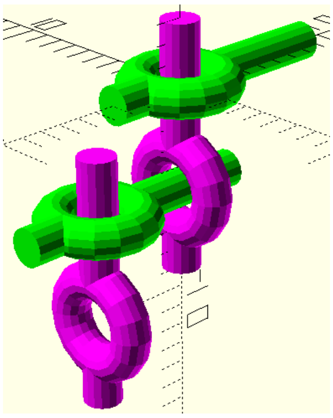
Chaining
However, an alternative would be to leave that space as an empty cavity as part of a vertical loop. This second loop could then be filled using a third material, which could be equal to the first and/or the second material, but it could also be a different type of material.
As such the loops can be joined together into chains.



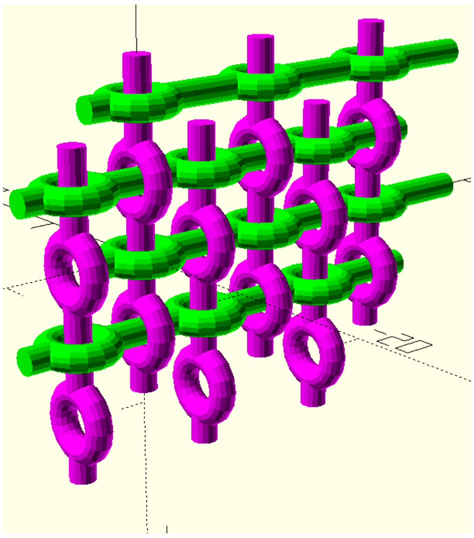
When using this method to improve the adhesion between different materials, one could print these chains in one material, surrounded by toolpaths done in the other material.



Alternatively, the material with which the loops are printed/injected could be alternated:

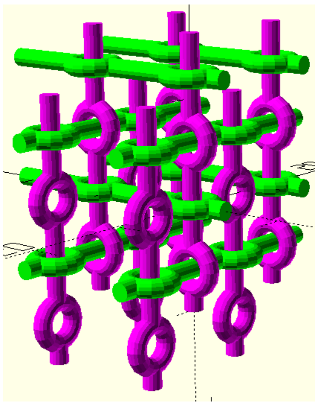


These chains could be laid down in a grid, such that an interlocking structure is formed where every X layers of the first material, the second material is injected downward around and through continuous toolpaths of the second material at a lower height.
(In the following the color of the loops does not necessarily refer to the material; instead green signifies horizontal loops and magenta vertical loops.)

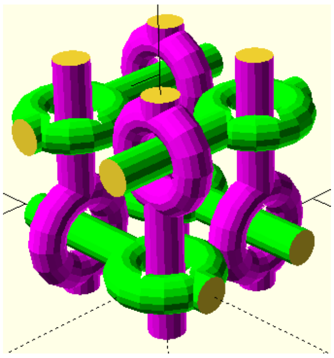


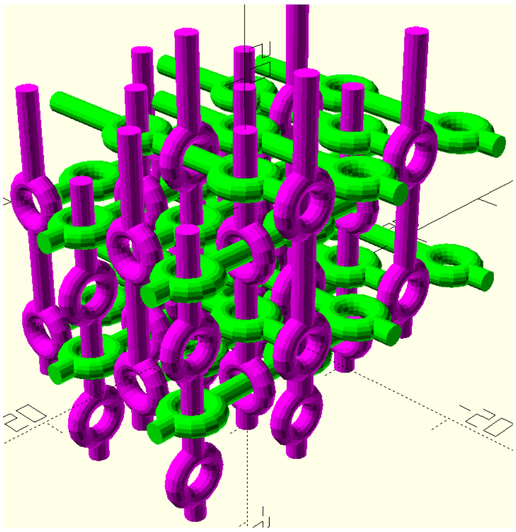
This forms a vertical sheet of interlocking cross-layer connections.

The direction of the cylinders of the horizontal loops could be alternated in order to connect multiple such sheets together – thus creating a 3D grid of interlocking loops and threads.



One way to alternate the directions of the loops results in a dense packing with a high number of interlocking loops per volume:





The benefit of the above solution is to increase the adhesion of layers in the Z direction – whether those layers are printed with the same or with a different material. When subjecting a products to tensile forces, the ultimate yield strength will be higher, compared to normal planar layers.