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Reducing stress in 3D objects made using Fused Filament Fabrication

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Title: Reducing stress in 3D objects made using Fused Filament Fabrication

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Abstract: We propose a new 3D printing method to lessen the effects of tension in FFF printed objects. By only simply changing the toolpaths of the outer wall traces we can print materials that otherwise would need a heated chamber and strict temperature control to avoid deformations.

Currently, the most used 3D printing technology is Fused Filament Fabrication (FFF), sometimes referred to as FDM. In this technology, 3D objects are built using thermoplastic polymers, like acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA). The thermoplastic polymer is warmed up to glass transition temperature, becoming fluid. Then, it is extruded through a nozzle, following a deposition path to build 3D objects. But as the thermoplastic cools, a lot of tension may build up in the final printed object. This may result in unwanted warping during printing often resulting in a failed print. But it may also result in deformation of the object later as the polymer still tries to relax long after the print is done.

The built-in tensions can be relaxed by annealing in a post processing step, but this usually leads to deformation as well. Some material suppliers put additives in their filament to minimize the effects of the tension.

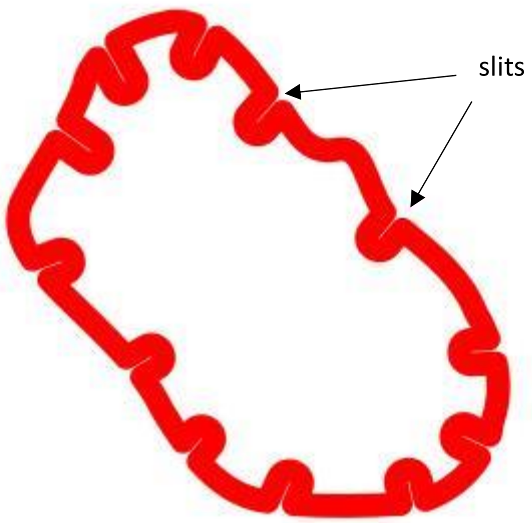
Several attempts were made to solve the tension issues in the pre-processing of the 3D objects, i.e. in the slicing process. Tian-Ming Wang et al [1] have developed a mathematical model for warp deformation in the FDM process. According to their model, one of the factors which heavily influences on warping deformation is stacking section length. Guerrero de Mier et al [2] discussed a slicing algorithm that was able to split a 3D model in hexagonal or squared bricks. The aim was to limit the stacking section length, and thus reduce warp deformation. Splitting pieces in bricks limits the maximum stacking section length to brick size. Therefore, maximum warp deformation will also be limited. Weiming Wang et al [3] have developed an algorithm for generating non-planar layers for a 5+ axis 3D printing machine. It optimizes the shape and order of the layers such that the final deformation is minimized.

In our research we have found that a considerable percentage (10% to 40%) of the deformation is along the print traces for most materials. Longer and more straight traces have more warp and the longer the printed trace the more tension it can build up.

In order to lower the tension in the objects, we suggest to interrupt long traces by introducing “slits” into the side walls of the object. These slits can be designed using a slicing software program such as ULTIMAKER CURA®.

Figure 1 is a top view of an example of one layer of a 3D model generated by our slicing program which was programmed to produce the new features. In the drawing of figure 1, only the wall traces are visible. In this example five wall traces are shown wherein a number of slits are arranged along the circumference. The width and depth of a slit may be varied depending on the dimensions and shape of the circumference. It is noted that preferably the depths of the slits are not too large so that the slits do not split a layer of an object in two parts.

Figure 1.



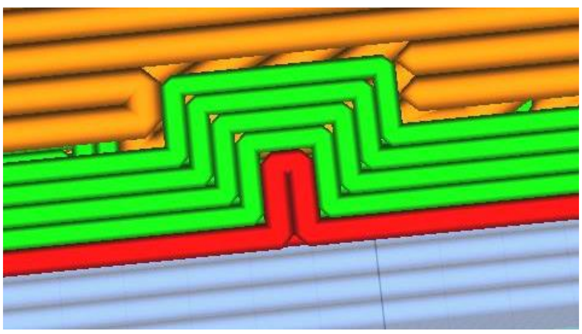
The slits may be arranged at the same locations for each subsequent layer. This will result is slits extending in the Z-direction as high as the number of layers containing the slits. Alternatively, the location of the slits may vary each N layers with N being a 1,2,3, ...

In the example of figure 1, the slits are straight, but it should be clear that the slits could be curved as well. Also, the slits could have an angle different from 90° with the circumferential line.

As mentioned, the location of the slits may differ every layer. The exact location of the slits may be randomized a bit in order to scatter the impact of the slits on the surface quality. Aligning the slits might improve their stress reducing function, though.

Figure 2 shows a top view of a detail of an object having a slit in the wall traces. The red line in figure 2 is the outer wall trace, and the four green lines are the so-called inner wall traces. The light brown lines at the top are the infill lines.

Figure 2



Due to the slits in the walls, the wall traces are made longer and the inward trajectories around the slits make the traces more flexible so that tension in the walls can be absorbed/avoided. Once the tension in the wall traces can be reduced, the risk of warping and/or deformation of the printed object can be reduced.

By reducing warp, we can get more predictable dimensional accuracy and less print failures. The suggested solution can be used for all sorts of polymers, such as PLA, ABS, PC, Nylon.

A surrounding aesthetic wall can be added to smoothen the outside of a 3D object, wherein the esthetic outer wall does not have the slits.

List of References

[1] T. Wang et al, "A model research for prototype warp deformation in the FDM process", The International Journal of Advanced Manufacturing Technology, vol. 33, pp. 1087-1096, 2007

[2] A. Guerrero de Mier et al, “Bricking: A New Slicing Method to Reduce Warping”, Procedia Engineering, 2015/12/31, vol. 132, pages 126-131.

[3] Wang, Weiming, et al. "Space-time topology optimization for additive manufacturing." Structural and Multidisciplinary Optimization 61.1 (2020): 1-18.