

Common failures in amateur 3D printing: Becoming familiar with and improving fused filament fabrication processes

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Abstract

3D printing polymers using the method of fused filament fabrication (FFF) is currently the most cost-effective method for the public to utilize additive manufacturing. To print working parts effectively there are many factors that amateur printers, students, and/or hobbyists do not consider. These factors are outlined here in three categories of common novice printing failures which include design flaws in the part, material/manufacture for the chosen application, and factors that can be fine-tuned and controlled during the manufacturing process. Many of the failures can be remedied or mitigated with printer tuning and overall experience manufacturing with the FFF method to become familiar with the process.

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1. Introduction

Fused filament fabrication (FFF) is currently one of the most cost-effective ways to get involved in 3D printing [1]. A low-grade printer costing under \$200 with some of the most common printing materials costing under \$30 (a kilogram of polylactic acid, PLA) to get started. Although it is one of the easiest methods of additive manufacturing (AM) for the public to have access to, there are many factors that need to be considered to produce working prototypes or parts.

Amateur students, hobbyists, or those otherwise interested in 3D printing may not consider these factors which can lead to poor print quality, failed prints, and broken printers. This paper will explore factors that lead to failure from three categories, their likely cause, and possible remedies for issues in printed parts.

The first of these categories include shortcomings in part design. When designing original parts or printing parts from an open source digital design website it is important to keep design intent in mind. In amateur 3D printing and part design this is usually limited to deficiencies in the structural integrity of the part.

The second category involves issues in the chosen method of manufacture meaning that the materials chosen, or the method chosen (FFF) could not produce a part that met the requirements of the prototype or printed part in the desired application.

The third category of failed 3D prints is centered around printing parameters. Printing parameters cover a wide range of controllable aspects during a print. For the purposes of this paper, they will be limited to part infill, print temperature, and build plate temperature.

This paper will outline these categories, provide example of prototype and working parts that underwent failures due to issues in these categories, and provide context to these failures including probable causes and solutions.

2. Print failure categories, cases, and possible remedies

The cases of these failures in 3D printing come from various academic and personal projects completed in the Materials Science & Engineering Department at the University of Washington and in a private setting.

2.1. Category one – design deficiencies

Issues in product and prototype design are common and usually require iteration to resolve these issues. In many cases of early prints this is limited to a combination of material and structural issues in design. 3D printing using FFF is naturally anisotropic, meaning that the individual fused layers will be bonded together weakly compared to the direction parallel to the build surface [2].

Shown in **Figure 1**, small amounts of stress applied to the edges of the highlighted areas caused cracking and breaking along the unfavorable direction of deposition. The design lacked any kind of transitions between the segments of these parts, and as a result the areas acted as stress concentrators. This and the issue of part anisotropy are common causes of failure due to part designs not taking them into account. In the case of the wing box, the design was changed to add fillets to round out the sharp edges of the part. This reduced stress concentrations and was kept until the final iteration. Other proposed solutions included changing print parameters to have a higher infill and using stronger material that was less prone to cracking. These methods of resolution have their merits and are more suited to other situations. Fillets were chosen in this case as they add minimal weight to an aircraft and do not require expensive material to be used in a prototype.

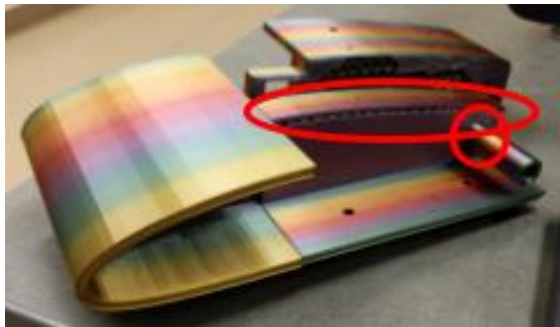


Figure 1. Failed prototype of a wing box printed from PLA; a structure meant to hold the wings of an unmanned aerial vehicle in place while transferring the force associated with wing loading throughout the structure of the vehicle. Failure occurred along a layer of the print about a stress concentrator.

2.2. Category two – suitability for chosen application

3D printing is one of the major novel technologies that is expected to contribute to the next industrial revolution [3]. 3D printing is, however, still a developing and niche manufacturing method. The key to developing successful 3D parts is choosing it as the correct methods and materials of manufacture for the chosen application.

One case where the choice in material caused inadequacies in the final product is shown in **Figure 2**. In the hopes of taking advantage of the acoustic properties of carbon fiber [4], the nylon-6 and carbon fiber chop composite by Markforged was used to create a cello. Unfortunately, the nylon substrate of the composite was too pliable, leading to



Figure 2. 3D printed from a nylon-6 and carbon fiber chop composite; this cello has noticeable bending takes place under the tension of the strings

the entire instrument bowing under the tension of the strings. The original design from an open source digital design website intended for the components to be printed from Acrylonitrile Butadiene Styrene (ABS) or PLA, which are comparatively stronger and stiffer than nylon-6.

Another 3D printed part that failed is seen in **Figure 3**. These parts were designed to split the flow of the filter pump of an above ground pool. In this case, 3D printing was not a suitable manufacturing method. This part was printed at 100% infill and printed in an orientation such that the strongest directions would correspond with the direction of hoop stresses imposed by internal pressure. Despite this, the internal pressure caused the layers to come apart enough to cause leaks and delamination between 3D printed layers. Without post processing steps to fuse together the 3D printed layers, it seems as though 3D printing using the FFF method is not suitable for this application.

2.3. Category three – print parameters

Printing parameters in this context are being defined as the aspects of the additive manufacturing process that can be directly controlled in either the slicer settings or can be tuned during the print. They usually vary between various materials, parameters usually including print temperature, build plate temperature, print speed, and part cooling. Various failures can arise from materials being printed with unfavorable print parameters.



Figure 3. 3D printed from orange PLA, this hose adapter failed in multiple places, resulting in spouts of water coming out of small cracks created by internal water pressure.



Figure 4. A part printed from clear PETG at an unnecessarily high temperature causing surface defects such as stringing and burrs.

Low print temperatures will not allow the material to melt as effectively. It will lower the flow rate of the material through the extrusion nozzle and possibly cause blockages, clogs, and jams. This almost invariably needs to be fixed by taking the hot end assembly apart and removing excess material by hand. High print temperatures are not favorable either. As seen in **Figure 4**, there are a high number of surface defects in the form of stringing and burrs. While these can be removed during post-processing, it can be avoided by changing printing parameters. Every 3D printer will have a different orientation of heating element with respect to geometry and distance to the melted material and the thermistor. Every printer will have an ideal print temperature where material flows as intended but hardens soon after leaving the nozzle. This can also be achieved through part cooling. Having a small fan blow on the material as it prints cuts down on these surface defects as well.

Another common failure sometimes caused by unrefined printing parameters is part warping during a print. More common in high temperature materials like ABS, part warping can be caused by many print parameters [5]. Warping is usually caused by rapid temperature change, which will cause the part's adhesion to the build plate to fail allowing the part to warp further. A heated build plate can mitigate this temperature difference and maintain the shape of the part by making it less likely for the part to peel off the build plate. This can also be done by printing a bed adhesion structure such as a brim, raft, or skirt depending on your slicer. An example of a warped part can be seen in **Figure 5**.



Figure 5. A warped green PLA dog bone that warped severely without a heated bed. The length and width (shown) are slightly angled, but the depth (not shown) warped to be about 30% thinner than designed.

3. Conclusions

Additive manufacturing is still a novel technology in a developing field. It will still be a time before 3D printing takes part in the next industrial revolution and changes the global manufacturing climate. At this point in the development of the technology, to start 3D printing in academia or otherwise is an undertaking of materials, electronic, and design engineering.

Research, development, and experience is required to successfully 3D print using the FFF manufacturing methods. It requires careful design work, materials knowledge, and manufacturing experience to determine if 3D printing is the appropriate manufacturing method to be used. For an amateur printer, these things only come with time and patience.

Further research and development into 3D printer manufacturing and standard printing practices and operating procedures is difficult. There are many processing methods that fall under the umbrella term of additive manufacturing that creating uniformity in tooling and processing is difficult. Many organizations such as ASTM committee F42 are working towards “The promotion of knowledge, stimulation of research and implementation of technology through the development of standards for additive manufacturing technologies” [6]. Through research and standards such as these, 3D printing will become more accessible to average consumers and common issues like those described above will be more easily remedied than with only the knowledge and experience that comes with continued manufacturing.

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Conflict of Interest

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