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MECHANICAL STRENGTH OF 3-D PRINTED FILAMENTS

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Abstract- Fused deposition modeling (FDM) printers are becoming more frequent in everyday use. These types of 3D printers are extremely useful for rapid prototyping. Fused deposition modeling printing melts the printing material and extrudes it through a nozzle. The material is laid out in a layer by layer fashion until the object is completed printing. Two common types of filament used in FDM printing are Polylactic Acid (PLA) and Acrylonitrile butadiene styrene (ABS). Some properties that can change the strength of 3D printed piece are things such as infill percentage, layer height, print orientation, extruding temperature, and build speed to name a few. Infill percentage and print orientation were tested to determine the mechanical strength of the material. The infill percentage varied from 20%-100% by increments of 20%. The goal of this project was to analyze the mechanical strength of PLA being printed in various orientations and infill percentages.

Keywords: Fused deposition modelling, 3d printing, tensile
Strength.

I. INTRODUCTION

3D printing is ideal for medical applications. It can print complex shapes. It has comparatively low material costs and it is quick to print components. As a more readily available method for materials, it is important for the properties of its products to be further researched . There has been concerns about the reproducibility of 3D printed parts. This can be corrected with more data regarding 3D printed materials. Others have documented on 3D printed parameters , changing its water solubility , affects after sintering
.However, few have addressed the print orientation and infill concerns. This work details the reproducibility of their properties, documenting their several of their mechanical properties.

A method of 3D printing called Fused Deposition Modeling (FDM) was used to print the testing pieces in this experiment. Filament is fed through a heating element melting the material into an anamorphous state. It is extruded through a nozzle and deposited on a heated platform. The extruder put a layer by layer pattern creating the finished product. As each layer is printed, orientation determines the direction of infill. A change in infill direction will cause stress and strain concentrations to be transferred within the material differently. This investigation only looks at the honeycomb infill pattern which is the default setting of the Makerbot Replicator 2X. Polylatic Acid (PLA) was used because of its popularity in 3-D printing and its biological applications inside the body.

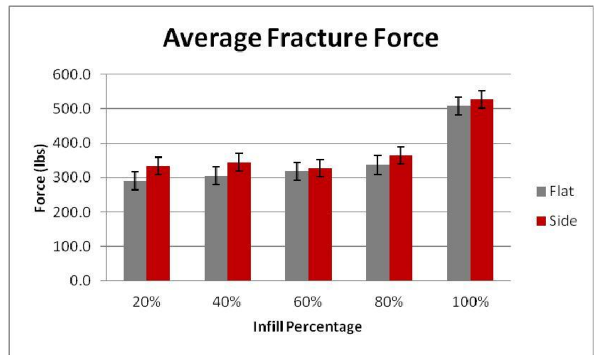


Fig. 1. Average fracture force of both orientations. There is a linear trend from 20%-80% then a rapid increase from 80%-100%. Consistently the side orientation had a higher fracture force than the flat orientation with the strongest fracture force 530.9 lbs.

II. METHODS

All of the pieces were printed using a Makerbot Replicator 2X. Multiple testing pieces were printed at the same time to avoid possible discrepancies that can arise between printing at different times. Each print job consisted of 3 piece printed simultaneously with all of the same settings for a total of 30 pieces printed. The setting used were as follows: extruder temperature was at 220°C, heating platform was 60°C, extruding speed 40mm/s, traveling speed 60 mm/s, 0.15 mm layer height, nozzle size 0.4 mm, and 2 shells. The angle at which supports were needed was changed from the default 45° to 63° to allow more support material. Acetone was used to clean the building platform of any leftover residue or oils from anyone previously handling the platform. The printer was covered in order to eliminate rapid cooling of the material during the printing. Problems such as thermal warping at the corners can occur if the material is cooled too quickly during the print. Three different orientations were printed with the layers parallel to the x, y, and z-axis. For prints done parallel to the y and z-axis support material was needed. The support material was carefully removed in order not to deform the specimen. Needle nose pliers and miniature wire cutters were used to remove the support material. All sample pieces were stored in a thermally insulated container to avoid fluxuations in temperature and to help reduce the amount of moisture absorbed by the PLA.

The tensile testing machine used for testing required us to design and use an adapter in order to test the specimens shown in Figure 2. Metal plates were placed on both sides of each end of the specimen. 1 inch sections of 10-32 threaded rod with wing nuts were used to secure the specimen into the machine.

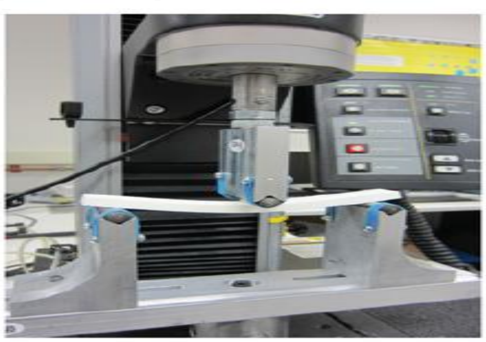
Strength of 3D printed materials

A. Common FDM printed materials:

FDM based 3D printing relies on fusing sequential layers of material extruded from a small nozzle to form the overall part geometry. Due to this process, the available materials are currently limited to thermoplastics although additional materials with additives and blends are being investigated. shows the strength of the raw bulk materials most commonly used in FDM. These materials are used in the popular Stratasys and Makerbot brand FDM printers. As a comparison, three additional materials are shown in 1including two common casting urethanes and a common two-part Epoxy resin . It is important to note that these are bulk properties and do not represent the properties of the material when 3D printed through FDM.

B. Strength of materials printed :

The FDM printing method deposits fibers/beads of thermoplastic in two-dimensional layers, building up the layers on top of each other to form the desired part geometry. The layering and direction of the fibers introduces an anisotropic effect that greatly influences the overall strength of the 3D printed part . Numerous researcher have shown that FDM printed materials show an approximate 45% decreases in modulus when compared to the bulk material . Smith et al. also showed a 30–60% decrease in ultimate tensile strength based on part orientation when comparing the FDM printed test samples with the bulk material properties . Careful tuning of the printer parameters including extrusion rates, bead sizes, and temperatures can also be performed to improve part strength although these techniques are still bounded by anisotropic behaviors and the bulk properties of the printed thermoplastic.



Two metal plates on either side to protect the specimen from the wing nuts and help distribute the load evenly. The specimen was then placed under tensile strength until failure.

Fig. 2. Flat Orientation print at 80% infill undergoing tensile testing.

Fill composition technique:

By utilizing hollow voids and channels printed internally to the components as molds for casting materials, complex internal reinforcing structures can be made that provide an increase in part strength and stiffness. Although the bulk material properties of common casting materials including urethane and epoxy do not far exceed those of the bulk 3D printed material, as their properties are isotropic when molded and therefore do not exhibit the same orientation preferences as 3D printed materials. The process of strengthening a 3D printed part with the fill compositing technique is illustrated. Each of the three methods will be discussed in the following sections.

A. Placing hollow voids within the part:

the original design of the proximal link of a robot finger. There are three methods for introducing hollow voids within the printed part. The first and simplest method is to print the part using a sparse infill technique. As long as the sparse infill is porous enough to allow resin to fill the cavity, the resin will take up the hollow volume in the part. The simplicity of this method is that all modification can be done in the 3D printer slicing software and no changes to the original part geometry are required. The second way to modify the part is to make the internal portion of the component completely hollow. The external walls of the part act as a mold to internally cast the stronger resin material. This technique can be thought of as using FDM 3D printing to create a mold where the mold remains to provide the detailed outer geometry. Factors related to the specific printer including overhang angle, unsupported span length, and minimum wall thickness all relate to the necessity for support structures. Using both a Stratasys uPrint and Stratasys Fortus-250m, the authors have successfully printed overhangs at a 30 degree angle from horizontal and unsupported horizontal spans of up to 3mm without the need for support material. A 0.6 mm wall thickness.

B. Casting resin material into voids :

The modified parts are printed with internal hollow sections and the detailed external geometry provided by the 3D printer. A 1mm hole is drilled into the component to access the hollow cavity(s). a syringe is used to inject resin into the void. The injection site should be chosen to allow for the epoxy or other casting material to set without leaking out the infill hole. Since air may become trapped in the internal voids, it is sometimes preferred to create multiple fill ports or tiny vent holes.

C. Final part features:

In the finished part, hardened resin provides structural reinforcement to the component from the inside. All external geometries of the original part are unchanged. The process can be compared to investment casting where the component provides the mold for the internal reinforcing cast structure or even overmolding where a thin plastic layer covers a strong internal structure.

Expected Strength Improvement of Fill-Composite Parts :

The proposed technique creates a composite component that can leverage the added strength of the injected resin. The cross-section of the constructed samples can be analyzed to determine the effect of the added resin on the overall bending strength. Using the flexure strength properties of ABS (53.0 MPa) and Epoxy Resin (97.2 MPa) . we can calculate the bending moment at failure using standard beam bending equations for each of the types of fill compositing described in the previous section. The cross-sections and associated beam stress profile for hollow filled samples and resin filled channels as compared to a standard solid printed ABS beam when subjected to three-point bending. The geometry is identical
to the tested samples described in the following section. The results indicate that, for this geometry, we can expect a 25% improvement in capable bending loads through using the complete hollow filled with epoxy resin and a 5% improvement in strength with the epoxy filled resin channel geometry.

III. Results and Discussion

The average fracture force of each specimen at varying infill percentages. The weakest specimen for both orientations was at 20% infill. The flat orientation had a steady increase from 20%-80% and a large jump from 80%-100%. The side orientation had a slight increase from 20%-80%, however, there was a drop at 60%. The causes of this are still under investigation. The 100% infill in both orientations showed a large increase in strength from 80%. The flat orientation had an increase of 66% strength and the side orientation had an increase of 69%. We believe that the lack of empty space and increased surface adhesion maybe contribute to this increase in strength. An additional experiment testing 80%, 85%, 90%, 95%, and 100% is planned to investigate the increase in strength. The side orientation had a consistently higher average fracture force than the flat orientation. The exact cause of this is currently unknown; however, we believe this to be due to the default printing pattern used by the Makerbot. Further testing is required.

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