Applying flexural and tensile stresses to 3D printed samples of varying infill orientations and densities

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Introduction

The purpose of this research project was to determine how infill density, filament variety, and orientation of a 3D printed sample on the build plate affect the strength and elasticity of an object. These factors can also affect the time and cost of printing, both of which are important considerations when making an object. In Anton's (2017) study, researchers examined Fused Deposition Modeling (FDM), a variant of Additive Manufacturing (AM) in which a heated nozzle extrudes a molten filament into layers. Acrylonitrile butadiene styrene (ABS) and polycarbonate (PC) parts were tested for shear, flexural, and tensile strength. In this research project, tensile tests and three point bend (flexural) tests were used to quantify object strength. The two filaments used in Anton's (2017) study were selected for this project in addition to two alternative filaments. Due to its efficiency, commercial availability, and potential to produce parts that are comparable in strength to their conventionally produced counterparts, the FDM subsection of AM has rapidly increased in popularity over the last few decades, making it an important area of research.

Methods and Materials

Four different filaments were used with an Ultimaker 2 3D printer including ABS, polylactic acid (PLA), PC, and colorFabb woodFill (wood fiber/PLA blend). For tensile testing, SketchUp© was used to model dogbone samples, a shape characterized by two rectangular ends for gripping and a reduced width midsection that takes the majority of the load. These samples were constructed in compliance with ASTM D638 standards (Osborn, 2014). For flexural testing, 5.00 × 0.25 × 0.25 inch rectangular prisms were created. The SketchUp© files were then exported and converted to printer instructions using Cura. In Cura, two different variables were independently manipulated: orientation on the build plate with respect to the infill grid (0°, 23°, 45°, and 90° shown in Figure 1) and infill density (25%, 50%, 75%, 100%). Due to time constraints, 45° was the only tested orientation for PC and woodFill samples. Tensile tests were performed on an Instron 3345 (Figure 2), which uses the Instron Bluehill® software to calculate values for stress and strain. Three point bend tests were performed on a Vernier Structures and Materials Tester (Figure 3) in which a connected LabQuest® device recorded force and displacement; this raw data was later used to generate stress vs. strain curves, to determine Young's modulus (E), yield strength, and ultimate flexural strength. Data collection ended at sample failure in all tests.

Methods and Materials (cont.)

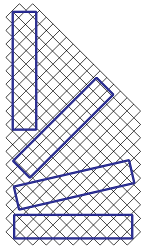


Figure 1: Diagram of 0°, 23°, 45°, and 90° orientations with respect to infill grid (bottom to top).

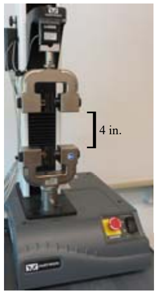


Figure 2: Instron 3345 Machine

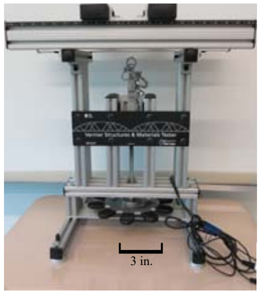
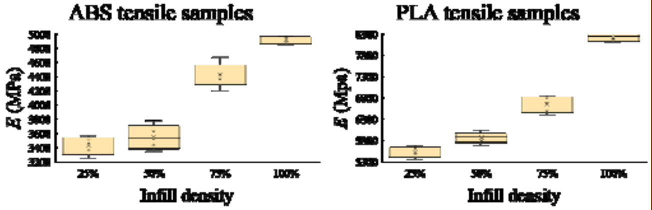
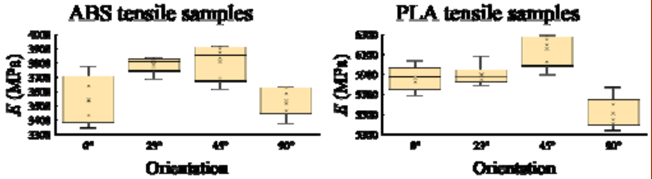


Figure 3: Vernier Structures and Materials Tester

Results



Graph 1 (above-left) and Graph 2 (above-right): Density effects on Young's modulus for ABS and PLA; five samples were tested for all densities.



Graph 3 (above-left) and Graph 4 (above-right): Orientation effects on Young's modulus for ABS and PLA; five samples were tested for 0° and six for the others.

45° Tensile Test Comparisons			
Filament Variety	Young's Modulus (MPa)	Ultimate Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
ABS	3805 (+114/-187)	39.70 (+1.97/-1.70)	65.41 (+3.59/-4.04)
PLA	6152 (+137/-257)	60.43 (+3.95/-3.61)	115.2 (+9.4/-11.4)
PC	4325 (+58/-104)	58.54 (+5.74/-7.34)	157.6 (+3.6/-4.4)
woodFill	3923 (+389/-390)	27.25 (+4.29/-2.79)	49.96 (+5.51/-7.64)

Table 1: 45° tensile test means of six ABS, six PLA, five PC, and four woodFill samples. Parenthetical values are distance between the mean and upper/lower bounds.

Results (cont.)

Using a one-way ANOVA test, modulus means of 25%, 50%, 75%, and 100% samples were compared from ABS flexural tests, ABS tensile tests, PLA flexural tests, and PLA tensile tests. All four tests had a p-value of less than 0.001, indicating a statistically significant difference in the elasticity between the various infill densities. One-way ANOVA tests for pairwise comparison were performed on the data from Graph 1 and Graph 2 to determine significance between each pair of modulus means; all were significant ($p < 0.01$) except for ABS 25% and 50%. For differing orientations, the results yield no apparent optimal angle for all filament varieties and data was typically inconsistent between tensile and flexural tests. Graph 3 and Graph 4 show how the orientation effects on Young's modulus for both ABS and PLA had little trend with the exception of 45° infill having the greatest Young's modulus. When comparing 45° tensile tests shown in Table 1, PLA had the greatest Young's modulus while ABS had the lowest. For ultimate tensile strength, PC was the greatest and woodFill was the least.

Conclusion

The results of this project indicate important effects that infill density and orientation have on the elasticity and strength of a 3D printed part. Both of these properties are important to evaluating a design when engineering or prototyping. Regarding Table 1 where all four filaments are compared, 45° PC samples would be most effective for maximizing load taken as they had the greatest ultimate tensile strength. 45° ABS could be used to maximize elasticity as its Young's modulus was the smallest, a trait indicative of a more flexible object. With the greatest Young's modulus, 45° PLA could be most useful for creating stiffer parts. The 45° woodFill overall yielded the weakest results all around, so other than being purely a decorative piece, this filament lacks any use for engineering.

References

Anton, J., et al. (2017). Experimental characterization of the mechanical properties of 3D-printed ABS and polycarbonate parts. *Advancement of Optical Methods in Experimental Mechanics*, *3*, 89-105. doi:10.1007/978-3-319-41600-7_11

Osborn, N. (2014). Standard test method for tensile properties of plastics. *ASTM International*. doi:10.1520/D0638-14