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MAE 301: Final Project

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Print Temperature and Orientation Analysis of 3D Printed Objects

Executive Summary:

This project entails the study of print temperature and print orientation, and their effects on the structural integrity of 3D printed parts. It is the belief that as the temperature of the extruder is raised, better adhesion will be achieved between the layers of the part. Also, the part will exhibit a larger stress capacity as it is able to distribute the applied load evenly across its cross-sectional area. This was, in essence, the hypothesis tested for this project. The test samples used during the project were created using a Monoprice Mini V2 3D printer with PLA filament. In order to obtain consistent results from each test, the samples tested were the ASTM D638 Type IV Dog Bone Tensile Sample, obtained user Lmpeeke from Thingiverse.com. This is the industry standard for tensile testing various materials. The test samples were printed in two different orientations, flat on the print bed and laying upright on their side. Overall, forty samples were created, twenty for each orientation. To study the effects of print temperature on the samples, the extruder temperature was varied during printing at increments of 10°C for five prints of each orientation. The final temperature range for the samples was 180-210°C. Once printing was complete, the samples were taken to ASU's Urban Systems Engineering building were tensile testing equipment is located. Tensile tests were performed on each sample to obtain stress and elongation data, and these tests were run until the samples failed. The collected data was then analyzed, and the maximum stress values were pulled from each sample's run to observe any trends. After the data had been analyzed using MATLAB, no significant differences were found between the means for either print temperature or orientation. However, there did appear to be an increasing trend with the temperature data, suggesting that the original hypothesis was proven to be true.

Introduction:

Three-dimensional printing, while being initially created almost 40 years ago, has only recently grown in popularity and understanding of its capabilities. This is largely due to people, such as Dr. Adrian Bowyer, who set out to make 3D printing cheaper and more commercially available with the RepRap open-source initiative (All That 3D, 2018). This allowed for many others to join in researching all the different aspects of 3D printed parts and devices. From that time on, much data has been collected regarding the structural strength of parts created in this fashion.

In this project, material extrusion temperature was the primary point of study, but orientation was also studied. Upon researching this topic, it was found that there are currently temperature boundaries set up for various materials, but these are only to help produce quality prints in terms of appearance. Only a small number of studies have been done regarding the affect of print temperature on tensile strength of 3D printed parts. The main difference between those studies and this one is the printer used to create the parts. For this project, the printer used was a Monoprice Mini Version 2, which is considered to be on the lower end of the spectrum when considering costs and quality. It has a 0.4mm extruder head, 120x120x120mm print area, and when coupled with a slicing software such as Cura, produced by Ultimaker, can produce decent quality models and parts. It currently retails for $189.99, according to the company website (Monoprice, 2019). This project would also test the ability of this printer to create components that had the same structural capabilities as its more expensive counterparts.

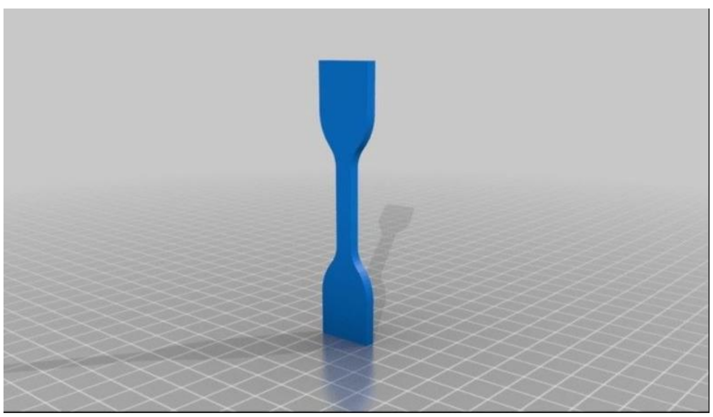
The testing samples were found in doing research on this type of material testing. Through the open-source website, Thingiverse.com, a contributor by the username of Lmpeeke created a model of an ASTM D638 Type IV Dog Bone Tensile Sample (Peeke, 2018). This model was created using a drawing sheet from Data Point Labs and this is a commonly used model in tensile testing analysis studies. The shape of the object lends itself very well to studying the effects of axial loading as it concentrates the stresses placed on it by a testing machine into the center, or gauge, section of the component.

Finally, the hypothesis for this project states that when the print temperature of a 3D printed part is raised and the part is printed so that all of the material lines are parallel to the applied load, then the part itself will be able to withstand higher loads than other orientations and lower print temperatures. This will be determined when data is collected from the tensile tests, parsed to obtain only the maximum stress that each part underwent, and then compared using a two-way ANOVA test to compare the sample mean values.

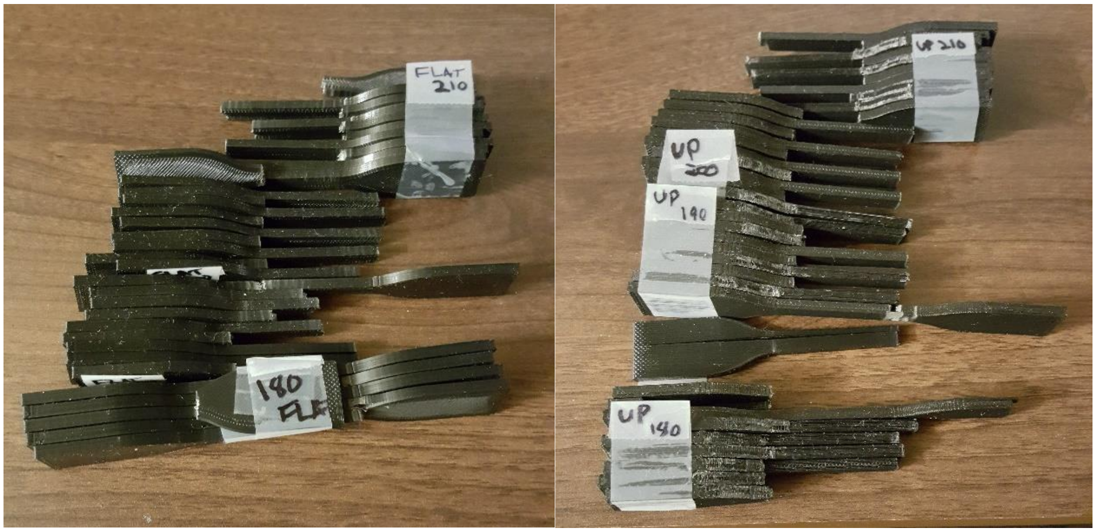
Procedures:

The procedure used for creating the sample data is as follows. First, the test samples were printed on the MP Mini V2 printer in batches of 5, in order to avoid possible variations from print to print for each set. Each printed group was then labeled and separated by orientation and temperature at which the parts were printed. They were then taken to the lab, where each sample was placed in a tensile testing machine and increasing load was placed on it until the part broke. This method was adjusted, as necessary, for some parts as they ended up not completely separating but did break to the point that they could not carry anymore load. More information regarding this fracturing will be shown and discussed in the results. Once all forty samples were tested and the data was gathered, it was analyzed to find the maximum stress that each sample underwent during the test. These values were then placed into a new matrix, with each column representing the orientations and the rows comprising the temperatures studied. This new matrix was then run through a two-way analysis of variance in order to measure the whether there was any interaction between the factors being studied.

Results:



The picture above is a 3D rendering of the test samples used for this project. As one can see, it is narrow in the center portion to create a stress concentration and focus the point of failure so that one can observe the failure in real time. The following picture shows the tensile testing machine used for the testing.



Following testing, this was the result of the samples. Preliminary observations of the samples showed that, for both orientations, at 180°C, the samples tended to stretch after failing due to the orientations of the fibers. For the samples that had been printed upright on their sides, it was interesting to see that the sample tended to split upon receiving its maximum load and would continue to hold a smaller load until completely failing. The samples that had been printed flat on the print bed would mostly follow what one would expect from this kind of testing, where upon reaching the maximum load the sample would catastrophically fail.

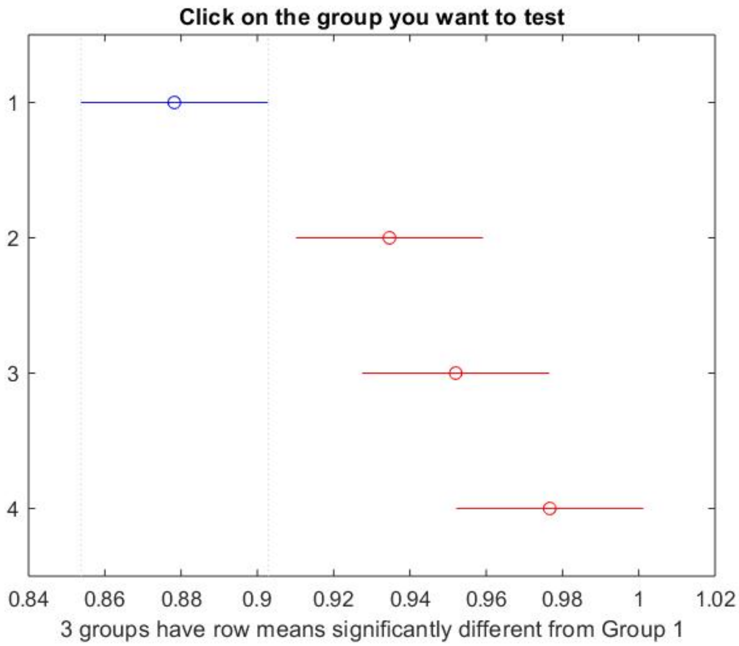
After collating the maximum loads that each sample took, they were inputted into MATLAB and run through a two-way ANOVA test. This was the results of that test.

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	0.00146	1	0.00146	0.89	0.3525
Rows	0.05247	3	0.01749	10.67	0.0001
Interaction	0.00983	3	0.00328	2	0.134
Error	0.05246	32	0.00164		
Total	0.11622	39			

As can be seen in the table above, the F-statistic between the two orientations is fairly low, leading to the realization that there is not much difference in stress capacity between these two orientations, and thus would lead one to believe that the hypothesis could be rejected. However, the F-statistic between the rows is rather large, with a very small p-value. This warrants further investigation as it could hold true that higher temperatures yield stronger parts.

In order to investigate this claim further, a comparison of the sample means was run to see what kind of variations were occurring between the temperature differences.



As can be seen in the table above, the reason for such a large F-statistic was due to the group of 180°C samples having a significantly smaller sample mean than the other temperatures. This, along with the plot of the rest of the sample means, does follow what was hypothesized, that as the temperature was raised, the parts would exhibit better load carrying abilities. Yet, it should be noted that the means are not significantly different enough to show much difference in the strengths of the parts.

Conclusion:

Based upon the analysis of the collected data, it is safe to say that the hypothesis of raising the print temperature of a 3D printed part to increase the strength of said part can be rejected. As seen in the above analysis, while the sample means do show a tendency for the parts to retain more load before breaking, the variance between the sample means is not large enough to say with certainty that the hypothesis holds completely true.

This tendency can also be seen in the test for orientation as a factor in the strength of these parts. The sample means were not significantly different enough to say that one orientation is better than the other, which, again, means the null hypothesis can be rejected.

Works Cited

All That 3D. (2018, August 09). The History of 3D Printing. Retrieved May 2, 2019, from https://www.allthat3d.com/3d-printing-history/

Monoprice. (2019, April 16). Monoprice MP Select Mini 3D Printer V2, Black. Retrieved May 2, 2019, from https://www.monoprice.com/product?p_id=21711

Peeke, L. (2018, October 1). ASTM D638 Type IV Dog bone Tensile sample. Retrieved April 5, 2019, from https://www.thingiverse.com/thing:3131427