Musical Drum Prototype Structural Analysis Estimation Through Change in Infill Percentage

MAE 301 Final Project

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Experiment Performed: Thursday, April 16th, 2019 1pm MST

Report Due: Friday, April 26th, 2019

Notes:

The original plan for this project was to compare the behavior of the physical specimen in the experiment to the SOLIDWORKS model thereof. After researching 3D printing - particularly plastic extrusion - it was found that SOLIDWORKS has no effective method of demonstrating the behavior of 3D Printed material and that proper modelling of various percentages of 3D Printed infill would have to be performed using FEA. I do not know how to perform FEA at this time, and do not wish to butcher the modelling of a 3D printed structure by estimating its behavior in SOLIDWORKS.

Additionally: The statistical testing method was altered to better suit the data found - becoming a single tailed t test, for $\mu_1 > \mu_2$. Weights of the structures are included in the data shown, but were not utilized directly in analysis. Percentage Infill is a *rough* approximation of support structures per weight of total structure. This is especially true in samples as small as these, where small variations in weight - due to the overall small weight of these samples - can be difficult to measure, require precise measuring instruments (like the scales in the PSH Chemistry Labspaces), and may contain error due to printer errors - leftover printing supports, or accidental removal of specimen material when attempting to remove printing supports.

Executive Summary

The influence of percent infill on the strength of a cylindrical extruded part of height 4.375mm and diameter of 10mm was tested to represent a scaled down version of a short, hollow musical drum with a diameter of 16in and a height of 7in (model will be 1/40 the size of the original). This test will be used to determine the point at which additional internal drum supports would become redundant.

In this case, redundant refers to ratio of change in fracture strength over change in weight. The drum model will represent a multisensory drum to be used with children. As a result, this drum can include internal structures - as the sounds will be produced electronically - and it needs to be both strong and light. Testing will be confined to the midrange of infill - 30% - 60% - as this area should (logically) contain the point at which structures begin being redundant.

The drum topography was smooth and filament utilized remained the same throughout the experiment - standard, MakerBot PLA. The compressive strength of this design was tested on the SEMTE INSTRON Series IX version 8.25.00 testing machines with the assistance of Dr. Dallas Kingsbury. Each test was performed with the same force up to 5kN, as that is the maximum load the machine can apply, and a cross-heed speed of 2.0 mm/s.

It was hypothesize that the difference in distribution means of fracture strength for 30 and 40 percent infill would be larger that of the difference in distribution means for fracture strength of 50 and 60% infill. The structure strength was suspected to increase exponentially with increase in percent infill until, at an unknown point near 50%, the structure strength tends to a horizontal asymptote. The variation in fracture strength was assumed to not change with percent infill. A two sample student's T test with a pooled variance was used to test the hypothesis with a single tail alpha of 10%.

The results of the test, a p = .453, indicate that the null hypothesis cannot be rejected. This indicates that more testing is required to find a more precise ratio of supports to overall structure weight, but that the point where additional structures becomes redundant is likely within the range given, as was previously assumed. More samples need to be collected from all the ranges to be tested to ensure quality and consistency in the numerical results, as well as verify the validity of the chosen experimental method.

Introduction

Music Therapy has been shown to be an excellent method of treatment for Autism Spectrum and Sensory Disorders by the American Music Therapy Association[1]. “Researchers have discussed advanced music memory, responsiveness, and aptitudes within this population; more recent studies show that individuals with ASD (Autism Spectrum Disorder) may have a heightened musical aptitude and sensitivity to musical elements, yet similar skills of music perception as compared to typically developing peers”[1]. Dynamic Links, a music therapy center in Oakwood, Illinois describes music therapy as working the best when students receive feedback for multiple senses - not just auditory [2]. This is shown in the instruments the children prefer the most consistently - the cabasa, a handheld maraca-like object with metal beads that click together when rubbed but do fall out on occasion, and the ocean drum, a large, heavy drum with a clear head and beads that can be felt through the fabric on the bottom of the drum [2]. The Djambe Autism Therapy Drum development team at Arizona State University aims to construct a drum for use in these therapeutic sessions that integrates visual, haptic, and auditory feedback in a safer, more captivating drum than either of the previously described solutions.

An integral part of this drum will be its sturdiness and weight. This drum should withstand the pressure applied by chaotic small children but be lightweight enough for ease of transportation by the teacher without posing a threat to the safety of the children. This drum was estimated by 3D printed cylinders, extruded by a Makerbot Replicator+, set to scale of the final product of measurements - 16inch diameter and 7 inches in height, with measurements of 4.375mm in height and a diameter of 10mm [3]. The drum has a smooth topography and the filament used was PLA as it is the most highly used filament type in the Fulton 3D Print Lab, made for a simple testing process, and was recycled at the conclusion of the test. The effective strength of these 3D printed cylinders was tested in compression by an INSTRON Series IX version 8.25.00, up to a maximum load of 5kN until the sample’s material reached the elastic limit. This limit approximated the permanent fracture of internal support structures of the drum, and indicated the maximum force the drum can withstand.

The amount of support structures within a structure will change both the maximum amount of force it can withstand as well as the weight of the structure. Given the nature of 3D printing, the percent infill approximates the relative proportion of support structures to the overall structure of the drum. It is generally accepted within the 3D printing community that 30% infill exceeds the strength required for most non-load-bearing applications, and that between 30 - 60% the ratio of improved strength to added infill tapers off [4]. The difference in distribution means of fracture strength for 30 and 40 percent infill was hypothesized to be larger than that of the difference in distribution means for fracture strength of 50 and 60% infill. The structure strength will increase exponentially with increase in percent infill until, at an unknown point near 50%, the structure strength tends to a horizontal asymptote. (10% is much stronger than 5%, but 70% and 100% are practically identical in structure strength in compression.) The variation in fracture strength was assumed to not change with percent infill. The variation of each distribution is assumed to be a real number which will be approximated by the sample variance for all samples as each sample is the same structure design and filament type. As a result, a two sample student's t test was utilized with a pooled variance to test this hypothesis. In the event that the hypothesis will be rejected with a single tailed alpha of 10%, I will assume that the point at which additional supports become redundant will be close to 50% and will compare the change in fracture strength/ weight ratio of 40% to 50% to 30-40 and 50-60 to confirm which region of my interval this occurs in. If this can be rejected, it must be concluded that further testing needs to be performed to determine if the structure must have a higher support to structure ratio than 60%. The percentage infill required indicates the minimum support to weight ratio required to optimize the drum structure.

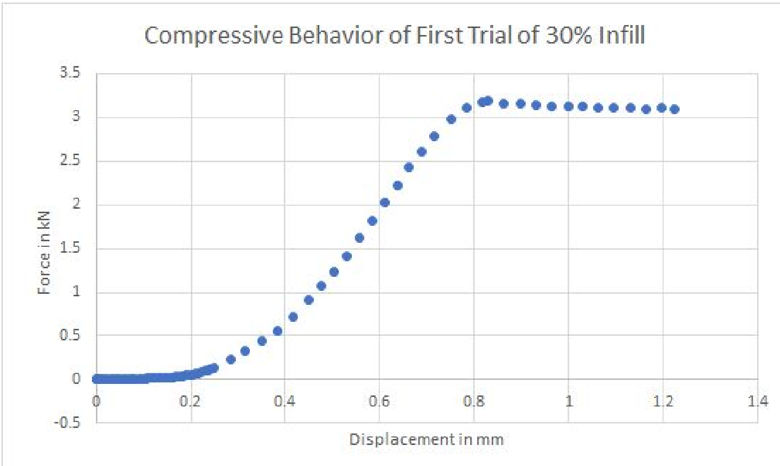
The inputs for this hypothesis test are the infill percentages, and the output is the corresponding elastic limit of each of these infill percentages. There is two trials for each infill percentage. While this is a pitifully small number of tests, 3D printing with the Fulton 3D Print Lab can be a time consuming process and this was an attempt to estimate the similarity of distribution means.

Procedures

A cylindrical specimen of measurements 4.375mm in height and 10mm diameter was loaded into the INSTRON Series IX version 8.25.00 for a manual compressive test without an extensometer and a cross-heed speed of 2.00000 mm/min. A inch square thin steel plate was placed atop the specimen to ensure equal distribution of force across the specimen. The simulations were ran until the computer software passed the elastic limit, when the specimen was unloaded but then permanently plastically damaged. Any further testing with such small samples simply squishes the plastic instead of crushing the structure itself.

The graphical results, outputted from the INSTRON Series IX with 3D Printed Samples of 30,40, 50, and 60% infill, standard infill pattern with two walls is shown below, with the ‘elbow’ like point indicating the compressive elastic limit. The elastic limit as shown is ‘xbar’ in the pooled variance t test to be ran. The standard deviation is calculated as the sum of the differences of each infill percentage from the other infill percentage it is paired with (30% and 40%, 50% and 60%).

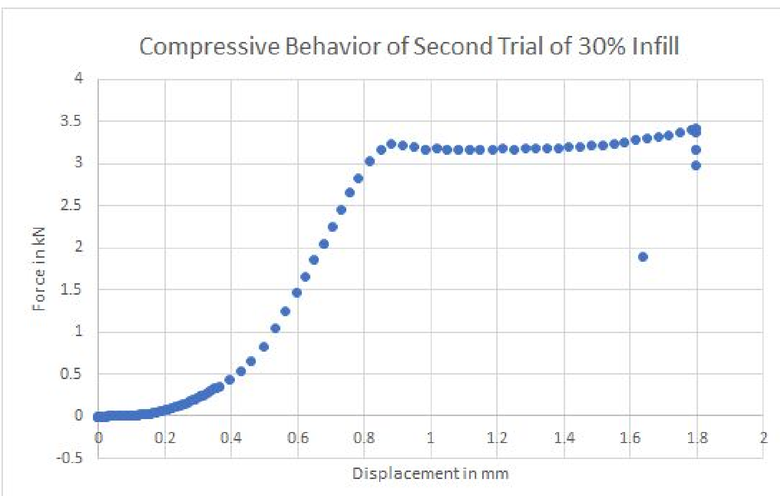
Graphical Results



30% Infill:

Weight = 0.308g

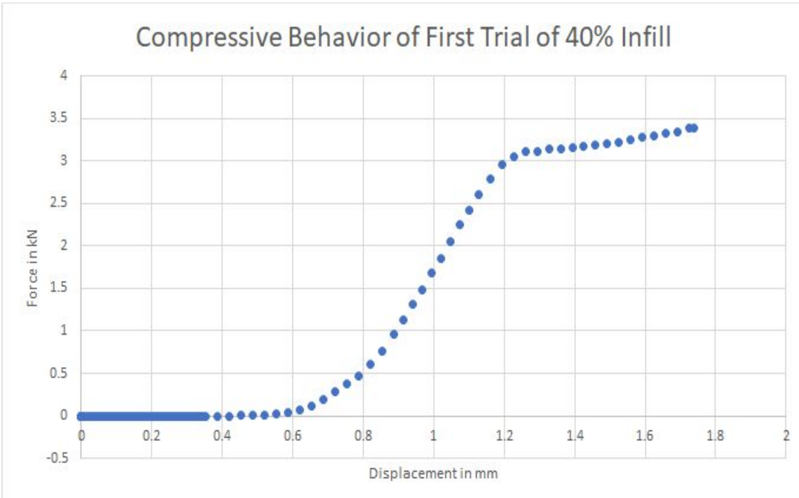
Elastic Limit: 3.1839kN



30% Infill:

Weight = 0.305g

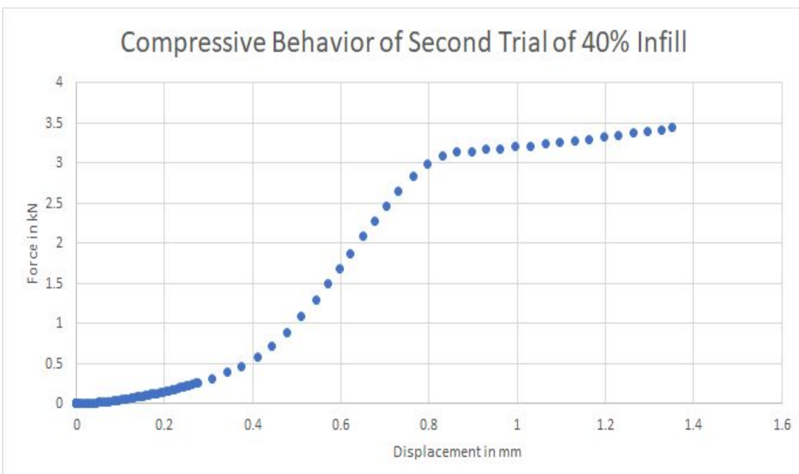
Elastic Limit: 3.2282kN



40% Infill:

Weight = 0.319g

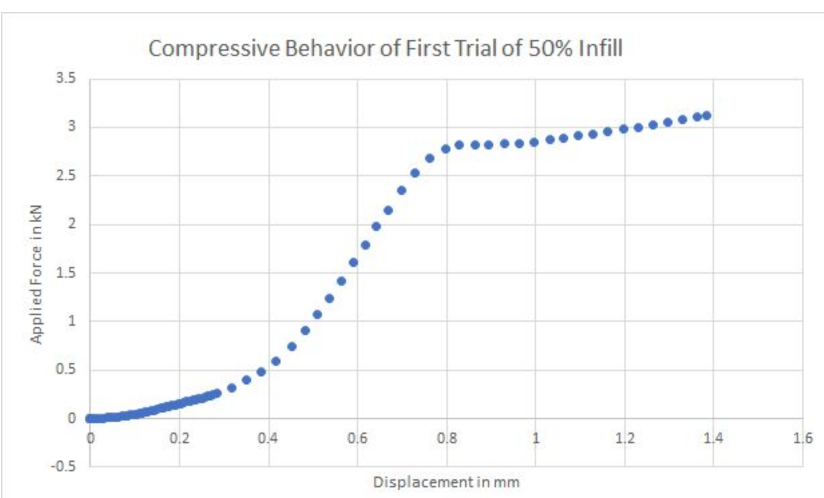
Elastic Limit: 3.0488kN



40% Infill:

Weight = 0.319g

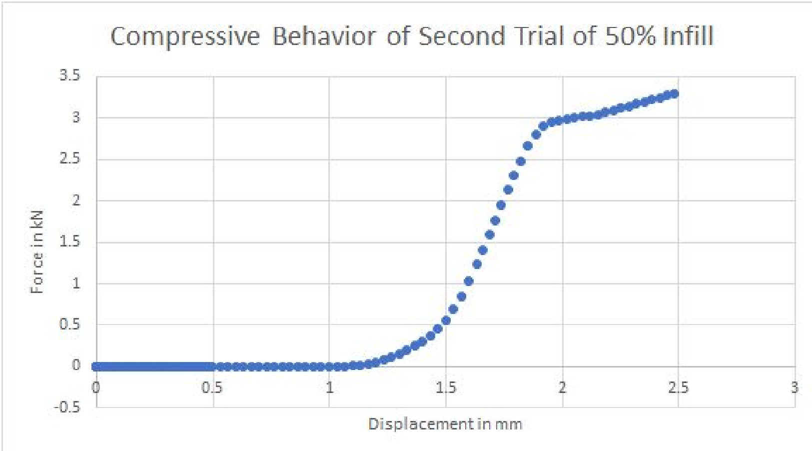
Elastic Limit: 3.08725



50% Infill:

Weight = 0.308g

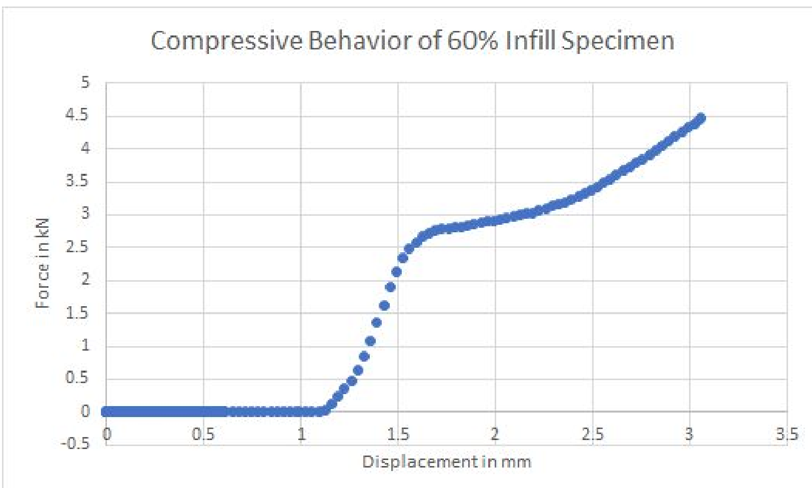
Elastic Limit: 2.9785kN



50% Infill:

Weight = 0.317g

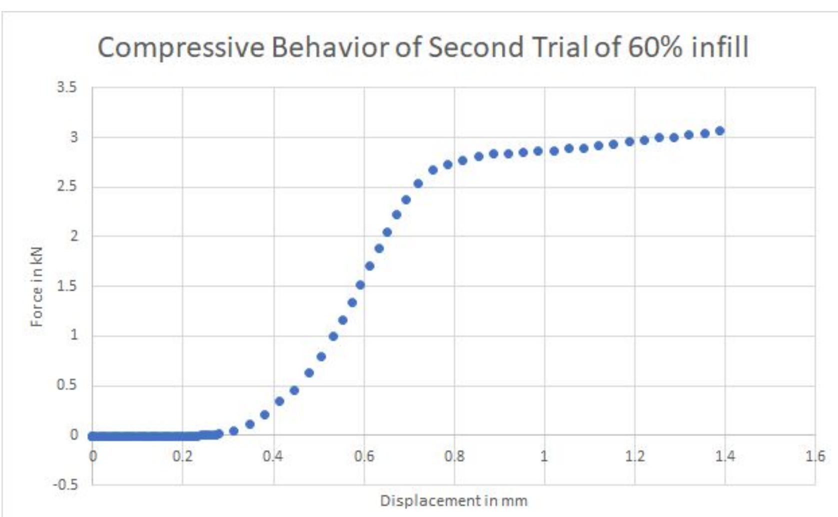
Elastic Limit: 2.78121



60% Infill:

Weight = 0.320g

Elastic Limit: 2.7248kN



60% Infill:

Weight = 0.320g

Elastic Limit:

2.7315kN

Analysis

Student's T Test:

$$T = \frac{(\overline{x_1} - \overline{x_2}) - (\mu_1 - \mu_2)}{\sqrt{Sp^2(\frac{1}{n_1} + \frac{1}{n_2})}} \text{ with } Sp = \frac{(n_1 - 1)s_1^{\,2} + (n_2 - 1)s_2^{\,2}}{n_1 + n_2 - 2} \text{ and } dof = n_1 + n_2 - 2$$

$\alpha = 0.10$

$n_1 = \textit{number of } 50\% \textit{ and } 60\% \textit{ infill trials}$ = 4

$n_2 = \textit{number of } 30\% \textit{ and } 40\% \textit{ infill trials}$ = 4

$\overline{x_1} = \textit{difference of average elastic strength for } 30 \textit{ and } 40\% \textit{ infill}$

$= \frac{3.1839+3.2282}{2} - \frac{3.0488+3.08725}{2} = 0.138025$

$\overline{x_2} = \textit{difference of average elastic strength for } 50 \textit{ and } 60\% \textit{ infill}$

$= \frac{2.78121+2.9785}{2} - \frac{2.7315+2.7248}{2} = 0.151705$

$s_1 \approx \textit{the sums of the differences in trials compared per percentage infill } (30\% \textit{ and } 40\%)$

$s_2 \approx \textit{the sums of the differences in trials compared per percentage infill } (50\% \textit{ and } 60\%)$

$$Sp = \frac{(n_1 - 1)s_1^{\,2} + (n_2 - 1)s_2^{\,2}}{n_1 + n_2 - 2} = \frac{3s_1^{\,2} + 3s_2^{\,2}}{6} = 0.02423$$

$$T = \frac{(0.138025 - 0.151705) - (\mu_1 > \mu_2)}{\sqrt{0.02423(\frac{1}{4} + \frac{1}{4})}} = 0.452574$$

Conclusions

Since this value p = 0.45257 is larger than a single tailed alpha of 10%, the null hypothesis cannot be rejected. This indicates that the logic behind this experiment may be valid - the assumption that the percentage of support structures in a cylinder decreases effectivity between 30-60 percent (or, as it was described earlier 'becomes redundant'.) More tests need to be run to fine tune the experimental procedure, with large numbers of samples that confirm the assumptions of the test. Ideally, this would continue to compare closer percentage values to narrow down the scope of the range to the precise percentage of structures needed in a drum to create a functional, sturdy, yet weight-effective solution. Given the time constraints on the Djambe Autism Therapy Drum Group, the drum design will continue with 40% percent weight support structures until more testing - both on the prototype itself and upon these 3D printed samples - can be performed.

References

[1] AMTA Strategic Priority Group on Music Therapy and ASD. (2015). FACT SHEET: Music Therapy and Autism Spectrum Disorder (ASD) [Pamphlet]

[2] Wilkins, A. (n.d.). Therapy at Dynamic Lynks. Retrieved from https://www.dynamiclynks.com/therapy

[3] Aguilera De Alba, L., Baye-Wallace, L., Dorf, A., Lederman, M., Lewis, R., Michaels, C., & Mowad, K. (n.d.). Djambe: Austism Music Therapy Drum esign Document [PDF]. Tempe: (Not Formally Published) EPICS at Arizona State University.

[4] Cain, P. (n.d.). Selecting the optimal shell and infill parameters for FDM 3D Printing. Retrieved from https://www.3dhubs.com/knowledge-base/selecting-optimal-shell-and-infill-parameters-fdm-3d-printing