Active Prosthetic

% Infill Analytical Analysis

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Introduction

In order to determine the most efficient and durable way to manufacture the prosthetic arm, the percent infill of material needs to be evaluated. By examining the percent infill, the durability of the arm can be maximized. In order to pick an optimum percent infill, the volume of a segment of 3D printed material with varying percent infills will be used to calculate the weight the segment can withstand under yield strength. The weight will be compared to the yield strength to visualize a fracture point. This process will be repeated with different percent infills to determine the one that lasts the longest before fracture. This analysis is important in order to help reduce funding by lowering the mass of the 3D printed part, as well as ensure the arm is lightweight and durable.

Walk-Through Analysis

The first step of this analysis was to pick a material. A common printing material is Polylactic Acid (PLA), so this material was used in the analysis. A Matlab code, attached in Appendix A, allows for easy interchangeability of the material properties. This section will show by-hand calculations to acquire the same result the Matlab code can get.

The modulus of elasticity (E) and the density (ρ) of PLA were researched in order to begin the analysis [1]. The found modulus was 3.5 GPa and the found density was 1.3 g/cm^3. The force was set at 22.2 N because the hand needs to withstand a minimum of 5 pounds. The cross sectional area was estimated to be 45.6 cm^2, and this value can be manipulated depending on the diameter of the arm being manufactured. Using equation 1, the stress was calculated using these inputs.

$$\sigma = \frac{F}{A} \tag{1}$$

Using the calculated stress of 4868.4 Pa and the found modulus of elasticity reduced to Pascals, equation 2 was used to calculate the strain which was found to be 1.3909e-6. .

$$\sigma = E\varepsilon \tag{2}$$

The dimensions of the tested segment were set using a thickness of 1.2 mm, which is standard for the nozzle used for 3D printing. Figure 1 shows a diagram of the rectangular segment and the dimensions used. The percent infill (p_{infill}) varied between 0.05 and 1 in increments of 0.5. In this section, the steps will be shown for a percent infill of 0.15. Using this value and the dimensions, the volume calculated using equation 3 was 167.143 cm^3. These dimensions were picked because the cross sectional area of the rectangular section was approximate to the resulting circular cross sectional area. A rectangular shape could be assumed for these calculations because if a differential section of the curved surface of the arm was taken, the differential would also be rectangular.

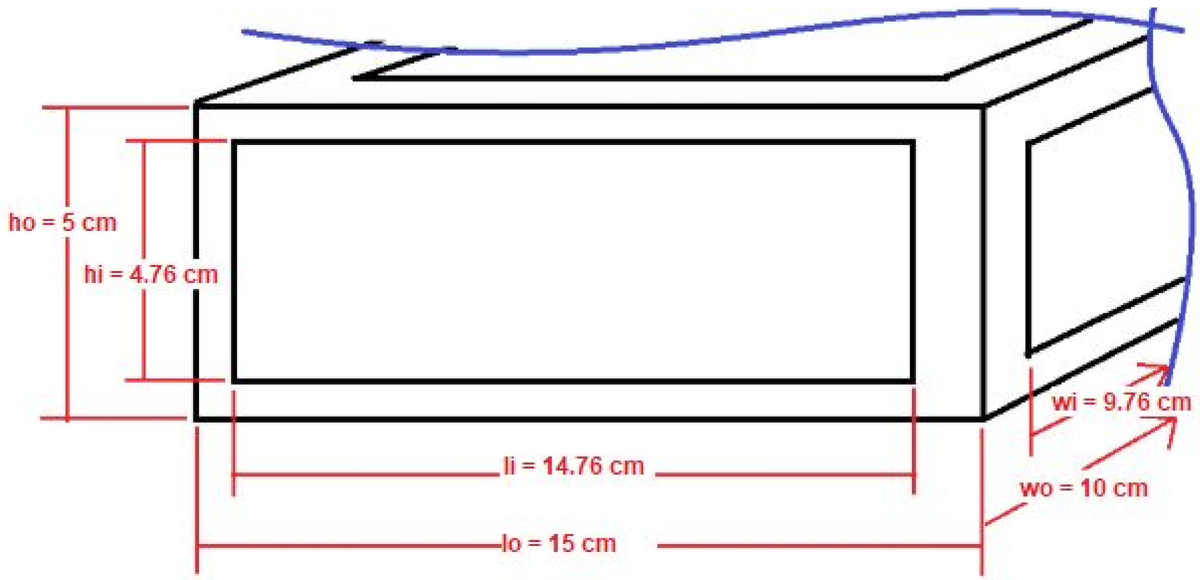

Figure 1: *Segment Schematic*

$$V = l_o w_o h_o - l_i w_i h_i (1 - p_{infill}) \tag{3}$$

Taking this volume and the calculated density, the mass is found using equation 4. This mass was 217.285 grams.

$$m = V\rho \tag{4}$$

Using mass and the gravitational constant, the weight was found to be 212940.1 gcm/s^2 or 0.021294 N using equation 5.

$$W = mg \tag{5}$$

Using equation 6 to calculate the yield strength at 0.2% offset from the original stress-strain graph as demonstrated in figure 2, the resulting yield is 9.7363 N/m^2

$$\sigma_y = 0.002\varepsilon E \tag{6}$$

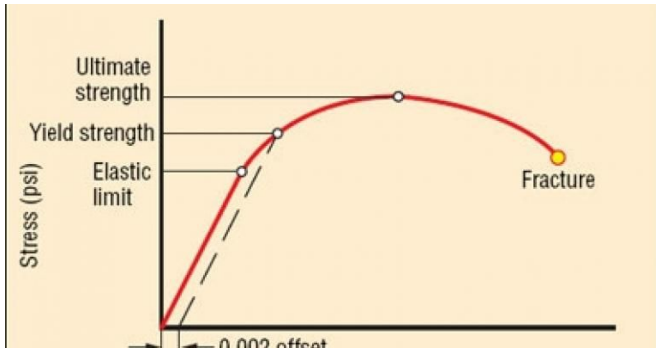

Figure 2: *Stress-Strain Curves [2]*

The weight was then compared to the yield strength times the area in order to make the units equal to each other, shown in equation 7.

$$W = \sigma_y A \tag{7}$$

The resulting yield strength times area is 0.044 N. This means the weight needs to be less than 0.044 N in order to resist permanent deformation under stress. This process was repeated for the other percent infills.

Results

The total range of percent infills calculated were 0.05 to 1 in increments of 5%. Table 1 displays the Matlab outputs using the corresponding percent infill inputs. When each of these answers were compared to the yield strength, 40% was the optimal percent infill. This is due to the fact that 0.043 is less than 0.044 and the next percent infill of 0.45 resulted in 0.0475 which is greater than 0.044. Any percent infill above 40% will cause the 3D printed material to permanently deform, which breaks engineering and customer requirements. Moving forward in prototyping, a percent infill of 40% will be used to manufacture the arm.

Table 1: *Resulting Weights*

% Infill Input	Weight (N)
0.05	0.01256
0.1	0.01693
0.15	0.02129
0.2	0.02566
0.25	0.03003
0.3	0.0344
0.35	0.03877
0.4	0.04313
0.45	0.0475
0.5	0.05187
0.55	0.05624
0.6	0.06061
0.65	0.06497
0.7	0.06934
0.75	0.07371
0.8	0.07808
0.85	0.08245
0.9	0.08681
0.95	0.09118
1	0.09555

Nomenclature

E = Modulus of Elasticity (GPa)
ρ = density (g/cm^2)
F = force (N)
A = cross sectional area (cm^2)
σ = stress (Pa)
ε = strain (unitless)
W = Weight (N)
m = mass (kg)
g = gravitational constant 9.81 m/s^2
V = volume (cm^3)
l_o = length outside (cm)
w_o = width outside (cm)
h_o = height outside (cm)
l_i = length inside (cm)
w_i = width inside (cm)
h_i = height inside (cm)
p_{infill} = percent infill (%)

References

[1] MakeitFrom, "Other Material Properties" *Polylactic Acid.* [Online]. 2018. Retrieved: https://www.makeitfrom.com/material-properties/Polylactic-Acid-PLA-Polylactide

[2] Machine Design. *"Motion System Design".* 2018. [Online]. Retrieved: https://www.machinedesign.com/technologies/motion-design-101-stress-strain-curves

Appendix A: Matlab Code

```
close all; clear all; clc;
% Material: PLA
E = 3.5*10^(9); %Pa %Modulus of Elasticity
rho = 1.3; %g/cm^3 %density

g = 980; %cm/s^2 %gravitational constant
F = 22.2; %N %Use input force
A = 45.6*10^(-4); %m^2 %User Input Cross-Sectional Area
l_o = 15; %cm %outer length
w_o = 10; %cm %outer width
h_o = 5; %cm %outer height
l_i = 14.76; %cm %inner length
w_i = 9.76; %cm %inner width
h_i = 4.76; %cm %inner height
p_infill = 0.15; % percentage. User Input 0.05 : 0.5 : 1

format long
stress = F/A; %N/m^2
Strain = stress/E; %unitless
V = l_o*w_o*h_o - l_i*w_i*h_i*(1-p_infill); % cm^2 %volume
m = V*rho; %g %mass
W = m*g; %gcm/s^2 %calculated weight
W1 = W/(1000*100); %kgm/s^2 %N %Weight
yield = 0.002*E*Strain; %N/m^2 %yield strength
compare = yield*A;
fprintf('Stress = %5.4g, Stain = %5.4g, Volume = %5.4g, Mass = %5.4g, Weight = %5.4g',
stress, Strain, V, m, W1)
fprintf('\n The weight must be less than %5.4g',compare)
```