

## Problem Set 3

We would like to distribute our favorite solution for each problem to the class as the official solution so please strive for clarity and elegance.

### Problem 1-1. Thermoforming

Consider the thermoformed part drawn in Figure 1 which was used to package last semester's hamburger yoyo. This part was unapologetically difficult to manufacture, and this problem will investigate some of its pitfalls.

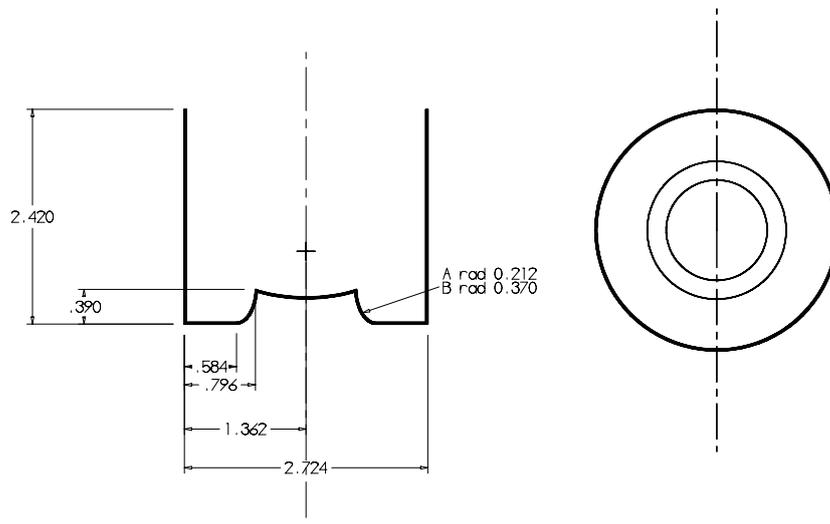


Figure 1: Thermoformed part

- (a) Compute the part's draw ratio. Is it reasonable?
- (b) The part was formed from a sheet of clear polystyrene with thickness 0.030 inches and dimensions 4 inches by 4 inches square. The part was vacuum-drawn with a clamp that enclosed an area of approximately 3.5" by 3.5". Assuming that the drawn part has uniform thickness, what is the wall thickness.
- (c) The part certainly did not have uniform thickness. Which areas of the part would you expect to be the thickest and why?
- (d) Recall that the formula for Euler buckling is

$$P_{cr} = \pi^2 EI / (kL^2)$$

where  $E$  is the modulus of elasticity,  $I$  is the moment of inertia  $L$  is the length, and  $k$  is a factor that takes the support conditions into consideration. Make reasonable assumptions and compute the buckling load that the part can take. Recall that  $I = \frac{1}{4}\pi(r_o^4 - r_i^4)$  for a tube with outside and inside diameters  $r_o$  and  $r_i$  respectively. Also, the modulus for standard polystyrene is  $3350N/mm^2$ . Comment on the appropriateness of the value you computed.

(e) What other problems does the part have?

### **Problem 1-2. Cutting model**

(a) Using the data from the first experiment in Monday's lecture, calculate the sheer angle  $\phi$  for the experiment. Show your calculations. The data for the experiment will be posted on the website.

(b) What is the chip velocity ( $V_c$ ) and sheer velocity ( $V_s$ ) from this experiment? Why does this make intuitive sense?

(c) Using the variables  $F_c$  and  $F_t$  (which would normally be measured experimentally using a dynamometer), determine the sheer strength ( $\rho_s$ ) of the material that we were cutting.

(d) Compute the power of the machine. Make assumptions about the motor efficiency, the energy lost to friction, noise, heat, and vibrations.

(d) Based on the drawing on page 15 of the Cutting notes (L6), I argue that the chip thickness  $t_c$  is the same dimension as the length of the shear plane. This would imply that  $t_c = t_0/\sin(\phi)$  which contradicts the equations from page 12. Explain what is wrong.

### **Problem 1-3. Process choice**

Describe how you would make a decision on whether to use thermoforming or injection molding for a part.

What is the difference between amorphous and crystalline plastics, and which ones are better for thermoforming?