Spring 2019 Manufacturing PhD examination.

Closed book, closed notes.

Attempt only three (3) of the four (4) questions.  If you do all four (4), the faculty will only grade the first three.

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Question #1 – Polymer Processing

The GT Factory will be making 500 million low density polyethylene (LDPE) peanut butter jars per year using two operations: 1) injection mold parisons and then 2) blow mold the parisons into peanut butter jars in a separate machine. The parisons are produced four (4) at a time. Each parison is 100 mm in diameter and 1 mm thick. The work week is 80 hours (two shifts). There are 50 weeks of production in one year. The properties of the LDPE and the temperature profile are given in the table below.

a) What is the clamping force, if the injection pressure is 100 MPa?
b) What is the cooling time?
c) How many parts that can be produced in one year by one machine, if injection molding is the limiting factor (rather than the blow molding machine)? For injection molding, the injection, packing, holding, opening, and closing times adds up to 3.8 seconds per cycle.
d) How many machines will be needed to meet the production demand?

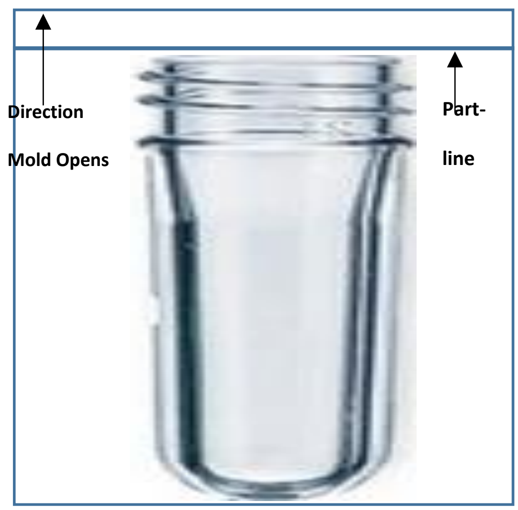


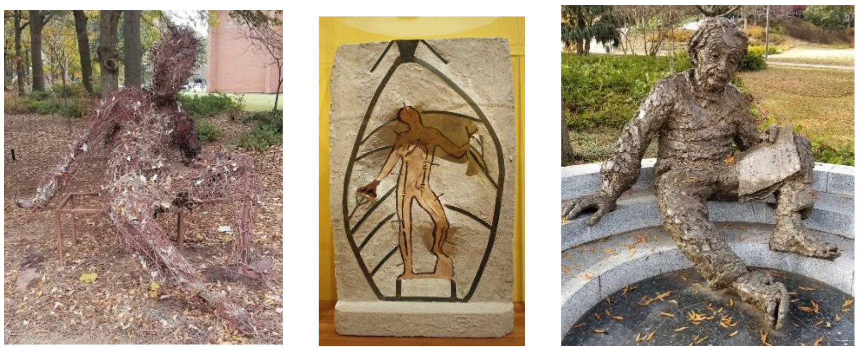

Figure 1. Parison, image not to scale.


Figure 2. Peanut butter jar, image not to scale.

| Property | Value |
|---|---|
| Density - ρ | 920 kg/m3 |
| Hardness (Rockwell R) - H | 60 |
| Ultimate tensile strength - UTS | 13 MPa |
| Young's modulus - E | 0.21 GPa |
| Specific heat capacity - c | 2,200 J/kg-C |
| Thermal conductivity - k | 0.3 W/m-C |
| Glass transition temperature - Tg | 110 C |
| Injection temperature - TM | 210 C |
| Ejection temperature - TE | 75 C |
| Mold temperature - TW | 35 C |

## Question #2 – Casting

Consider the lost wax casting of the Einstein statue on campus as shown below.



Armature (left), investment (center), completed statue (right)

The statue is 3 meters in height and has a wall thickness of 3 mm.

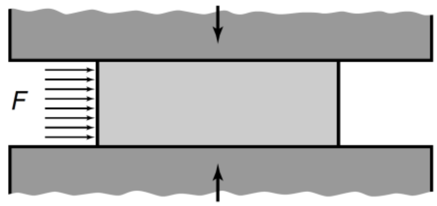
a) Should this be a mold that is bottom-gated or top-gated? Why is the type that you selected better for this product?
b) If the top of the pouring basin is 1 m above the top of Einstein's head, what should the diameter of the bottom of the sprue be?
c) If the bottom of the pouring basin is 0.75 m above the top of Einstein's head, what should the diameter of the top of the sprue be?
d) Assume that the statue can be modeled as a hollow cylinder with an outer diameter of 1 m, and, for this part of the question is bottom-gated. If you want the mold to fill within 30 seconds, how many circular gates, each in diameter equal to the wall thickness, should there be?

| **Solids @ 25ºC** | | | |
|---|---|---|---|
| | Specific heat (Cp) | Density (ρ) | Thermal conductivity (k) |
| | (kJ/kg-ºC) | (kg/m3) | (W/m-ºC) |
| Sand | 1.16 | 1500 | 0.6 |
| Copper | 0.385 | 8960 | 394 |

| **Liquids** | | | | |
|---|---|---|---|---|
| | Melting point | Latent heat of solidification($H_f$) | Specific heat (Cp) | Viscosity (μ) |
| | (ºC) | (kJ/kg) | (kJ/kg-ºC) | (mPa-s) |
| Copper | 1083 | 220 | 0.52 | 4.0 |

Question #3 – Open Die Forging

Assume that the workpiece shown in the figure below is being pushed to the right by a lateral force F while being forged between flat dies.




(a) Make a sketch of the die-pressure distribution for the condition for which F is not large enough to slide the workpiece to the right.

(b) Make a similar sketch, except that F is now large enough so that the workpiece slides to the right while being compressed.

(c) Derive an expression for the lateral force F applied to the workpiece when is starts sliding to the right (assume plain strain compression, h is the workpiece height, w is its width and l is its dimension into the third, not shown, direction).

Question #4 – Machining

Consider an orthogonal metal cutting operation carried out with a high speed steel tool. The following data are given:

| |
|---|
| Density of workpiece material ($\rho$) = 7800 kg/m$^3$ |
| Specific heat of workpiece material (c) = 470 N.m/(kg °C) |
| Cutting speed (V) = 3 m/s |
| Resultant force ($F_r$) = 2400 N |
| Undeformed chip thickness ($t_0$) = 0.2 mm |
| Deformed chip thickness ($t_c$) = 0.4 mm |
| Friction angle ($\beta$) = 20° |
| Width of cut (w) = 6 mm (measured into the plane in figure below) |
| Rake angle ($\alpha$) = +10° |

Calculate the following quantities and state all assumptions you make in arriving at your answers:

a) Shear plane angle ($\varphi$), and average shear strain
b) Shear force ($F_s$), friction force at the tool-chip interface ($F_f$), shear plane power ($P_s$) and friction power ($P_f$)
c) Average shear plane temperature if the ambient temperature is 20°C. Assume 10% of the shear plane power is conducted into the workpiece.