Manufacturing Systems and Materials Processing Qualifying Exam

Student No.:_______________________

Closed Notes, Closed Book, No Cellphones, Only Calculator Allowed. (Example Problems)

1. Use the space below to describe the most probable material(s) and process(es) used to produce the 10 products or components shown on this and the next three pages. You will get partial points if you simply give a general answer like 'plastics', 'metals', 'casting', or 'machining'. You will receive more points if you give more specific answers like: "The product (specify what it is) is generally made of stainless steel," "It is a polymer composite part with long fiber reinforcement," and "The most probable process for this mass-produced component will be injection molding. However, if only a small quantity is needed, then 3D printing will be a more economically viable process." If you don't know the exact name of the material or process(es), try to describe, in words or sketches, what is required for the material and how the item is made.

Example: *Shampoo Bottle Caps with A Living Hinge*

Example answers:

(Wrong answer) The shampoo bottle caps are made by the CNC process with a lightweight metal.

(Poor answer) The shampoo bottle caps are made by a plastics processing method.

(Good answer) The shampoo bottle caps are made by injection molding of a thermoplastic resin that can be bent over and over again.

(Best answer) The shampoo bottle caps with a living hinge are made by injection molding of a polypropylene (PP) resin as PP is the best material for living hinges and can be bent numerous times without failure.

1. Football Helmet Shell

shampoo bottle cap

cell phone covers

Injection molding

Polycarbonate (PC)

Head: High carbon Steel, Die Casting

Handle: FRP, Injection Molding

2. Hammer

Injection Molding

PET

3. Two-Liter Soda Bottle

Die casting

Ni-alloy

4. Boeing 787 Dreamliner Fuselage

Injection Molding

Polycarbonate

5. Car Bumper Fascia

2. Using the space below for texts and/or figures, describe the pros and cons in terms of product features, part quality, production time, and cost of production between additive manufacturing and the following manufacturing processes: CNC, injection molding, and die casting.

Die Casting

- **Pros**:
  - **Product Features**: Can produce complex shapes with good dimensional accuracy.
  - **Part Quality**: High-quality surface finish and excellent mechanical properties.
  - **Production Time**: Fast production rates suitable for high-volume runs.
  - **Cost of Production**: Cost-effective for large volumes due to the high-speed production process.
- **Cons**:
  - **Product Features**: Limited to non-ferrous metals and specific part designs.
  - **Part Quality**: Risk of porosity and internal defects, which can affect strength and durability.
  - **Production Time**: Long lead times for die creation and initial setup.
  - **Cost of Production**: High initial tooling and setup costs, making it less viable for low-volume production.

Injection Molding

- **Pros**:
  - **Product Features**: Can produce parts with complex shapes, fine details, and consistent quality.
  - **Part Quality**: Excellent surface finish and high repeatability.
  - **Production Time**: Very fast for high-volume production, making it ideal for mass production.
  - **Cost of Production**: Low cost per unit for large production runs after the initial mold investment.
- **Cons**:
  - **Product Features**: Design changes are difficult and costly once the mold is created.
  - **Part Quality**: Initial defects in the mold can affect all subsequent parts.
  - **Production Time**: Long lead time for mold creation and setup.
  - **Cost of Production**: High upfront costs for mold design and manufacturing.

CNC Machining

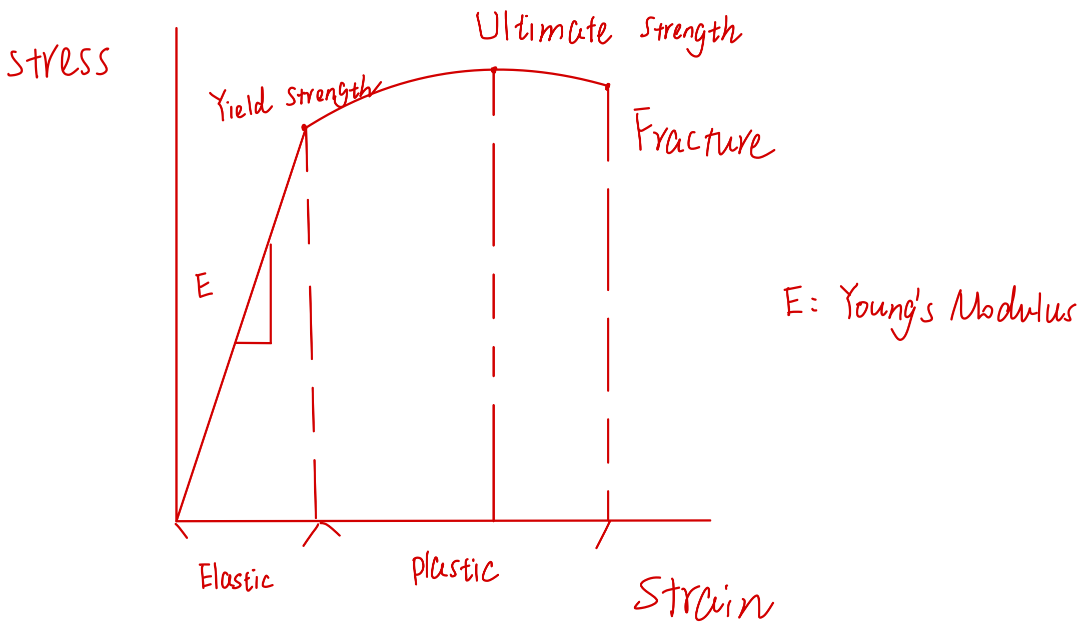
- **Pros**:
  - **Product Features**: High dimensional accuracy and ability to produce complex shapes with tight tolerances.
  - **Part Quality**: Excellent surface finish and mechanical properties.
  - **Production Time**: Suitable for both low and high-volume production with quick turnaround for individual parts.
  - **Cost of Production**: Cost-effective for low to medium production volumes. No need for expensive molds.
- **Cons**:
  - **Product Features**: Limited by the subtractive nature of the process; intricate internal features are challenging.
  - **Part Quality**: Material waste is higher due to the subtractive process.
  - **Production Time**: Longer setup times for initial programming and tool changes.
  - **Cost of Production**: Higher initial setup costs and less efficient for very high-volume production compared to injection molding.

2. Using the space below for texts and/or figures, describe the pros and cons in terms of product features, part quality, production time, and cost of production between additive manufacturing and the following manufacturing processes: CNC, injection molding, and die casting.

Additive Manufacturing (3D Printing)

- **Pros**:
  - **Product Features**: Can produce complex geometries and intricate designs that are difficult or impossible with traditional methods.
  - **Part Quality**: Good for prototypes and custom parts with specific design requirements.
  - **Production Time**: Quick for prototyping and small production runs as no molds or tools are required.
  - **Cost of Production**: Lower initial costs as it doesn't require expensive molds or tooling. Suitable for small batches and custom parts.
- **Cons**:
  - **Product Features**: Typically limited by layer resolution, which can affect the smoothness and detail of the final product.
  - **Part Quality**: Generally lower mechanical properties compared to traditional methods due to the layer-by-layer construction.
  - **Production Time**: Slower for large-scale production compared to injection molding and die casting.
  - **Cost of Production**: Higher cost per unit for mass production due to slower production speeds and material costs.

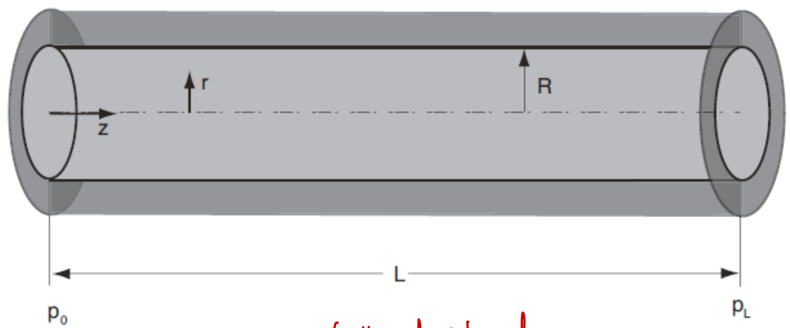
3. Draw a typical tensile test stress vs. strain curve and indicate several important mechanical properties you can obtain from the curve. In addition, please describe the main difference between toughness and ductility.



Difference Between Toughness and Ductility:

- **Toughness**: The ability of a material to absorb energy and plastically deform without fracturing. It is a measure of the amount of energy a material can absorb before failure. Toughness is represented by the area under the entire stress-strain curve.
- **Ductility**: The ability of a material to undergo significant plastic deformation before rupture or fracture. It is quantified by the strain at fracture (total elongation) and is indicated by how much the material can stretch or elongate.

4. Tube flow is encountered in several material manufacturing processes. Let's assume that the flow inside the tube is steady, fully developed, and is axis-symmetric. Furthermore, it has no entrance effects, the gravitational force is negligible, and the fluid is a Newtonian fluid. Based on the momentum equation in the z direction, simplify it and then solve for the velocity profile, $u_z(r)$ and the volumetric flow rate, Q.



$u_r = u_\theta = 0$

Steady State   fully developed

$$\rho\left(\cancel{\frac{\partial u_z}{\partial t}} + \cancel{u_r\frac{\partial u_z}{\partial r}} + \cancel{\frac{u_\theta}{r}\frac{\partial u_z}{\partial \theta}} + \cancel{u_z\frac{\partial u_z}{\partial z}}\right) =$$

axis-symmetry   g force negligible

$$-\frac{\partial p}{\partial z} + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_z}{\partial r}\right) + \cancel{\frac{1}{r^2}\frac{\partial^2 u_z}{\partial \theta^2}} + \cancel{\frac{\partial^2 u_z}{\partial z^2}}\right] + \cancel{\rho g_z}$$

fully developed

$$\partial P/\partial z = \mu\left[1/r\ \partial/\partial r\left(r\,\partial u_z/\partial r\right)\right]$$

$$\partial/\partial r\left(r\,\partial u_z/\partial r\right) = r/\mu\ \partial P/\partial z$$

$$r\,\partial u_z/\partial r = \tfrac{1}{2} r^2/\mu\ \partial P/\partial z + C_1 \quad ①$$

$$\partial u_z/\partial r = \tfrac{1}{2} r/\mu\ \partial P/\partial z + C_1/r$$

$$u_z = \tfrac{1}{4} r^2/\mu\ \partial P/\partial z + C_1 \ln r + C_2 \quad ②$$

① $r = R,\ u_z = 0$ $C_2 = R^2/4\mu\ \partial P/\partial z$

② $r = 0,\ u_z = 0$ $C_1 = 0$

$$u_z = \partial P/\partial z\ 1/4\mu\ (R^2 - r^2)$$

$$Q = \int_0^R 2\pi r\left(\partial P/\partial z \cdot 1/4\mu\ (R^2 - r^2)\right)dr$$

$$= \partial P/\partial z\ \pi R^4/8\mu$$