PhD Qualifying Exam - Manufacturing
Spring 2018

Attempt <u>only three</u> of the four problems below. Clearly show all of your work. List all relevant assumptions.

1. A casting is being produced out of pure aluminum metal in a *top gated* sand mold. The metal level in the pouring basin is 254 mm above the top level of metal in the mold, and the runner is circular with a 10 mm diameter. Pure aluminum has a density of 2700 kg/m^3 and a viscosity of approximately 0.0015 N-s/m^2 around 700°C.

   First, determine the following:
   a. The velocity and rate of the flow of the metal into the mold.
   b. Whether the flow is turbulent or laminar.
   c. What, if any, corrective action is required.

   Next, for the sprue described above, determine the following:
   d. The runner diameter needed to ensure a Reynolds number of 20000.
   e. The time it will take for such a runner to fill a 2.5x10^6 mm^3 casting.

   Now, provide your analysis (quantitative and qualitative) on the impact of this filling time on the castability of the component.

   f. Is the casting process expected to proceed flawlessly or are some difficulties or concerns expected? Explain.

   Next, assume that the mold is bottom-gated. The casting has a square cross-section of 150 mm per side and a height of 100 mm.

   g. Derive the equation for the mold filling time and use it to determine the filling time for this mold using the original runner diameter. Assume the sprue is frictionless.

   Finally, you are to estimate the time for the casting to solidify. The constant "C" in Chvorinov's rule for this situation is given as 3 s/mm^2. The mold can be broken safely and the casting retrieved when its solidified shell is at least 25 mm thick. You should assume that the casting cools evenly.

   h. Determine the time that must transpire after pouring the molten metal before the mold can be broken. Provide justification for your analysis.

2. For a cylindrical OD plunge grinding operation with a CBN wheel grinding 52100 steel hardened to 60 HRC, please do the following:

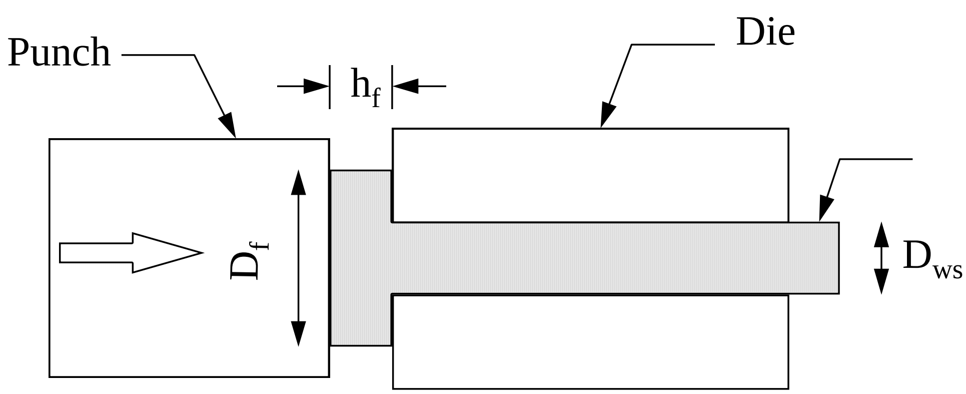
    a. Derive the mathematical relationship for the theoretical power needed to grind. Feel free to include any parameters that you feel are necessary to fully describe the process.

    b. Define and discuss the production rate of this process.

    c. What limits the production rate of this process? Is this limitation constant? What causes this limitation to change? Please provide all necessary mathematical relations to support your discussion.

    d. How would you control the grinding to maximize its production rate?

3. Heading is an operation (also known as upset forging) that is commonly used to produce heads in nails, bolts, and other fasteners. One such heading operation for a steel nail is depicted in the figure below. The true stress-true strain curve of steel is given as $\sigma_t = 1015(\varepsilon_t)^{0.17}$ MPa. The coefficient of friction (μ) at the die-workpiece and punch-workpiece interfaces is 0.1. The diameter of the steel wire stock (D_{ws}) used to produce the nail is 4.75 mm. The desired final diameter (D_f) and thickness (h_f) of the head of the steel nail are 7.125 mm and 4 mm, respectively. (Note: In the figure below, the punch is shown at the end of its travel; the workpiece is held firmly in the die while the head is being formed)



Heading (Upset Forging)

(a) Determine the length of workpiece stock that must project out of the die in order to produce the desired head geometry.

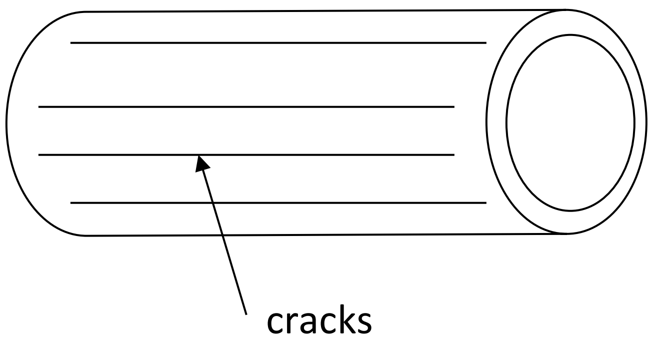
(b) Calculate the force the punch must exert to form the head. List and justify all assumptions you make in arriving at the answer. Relevant equation for die pressure in upset forging is given below.

(c) If the true strain at fracture of the nail material is known to be 0.85, will the head of the nail develop surface cracks on its circumference during the heading operation described in the problem? Justify your answer with appropriate calculations.

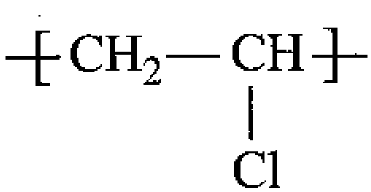
Instantaneous die pressure of a cylinder in open die forging:

$$p = Ye^{2\mu(r-x)/h}$$

4. You are the chief engineer at a polymer extrusion company. One of your manufacturing engineers has brought you a piece of extruded hollow tube. When subjected to either internal pressure or external force, the tube cracks axially through its thickness (see figure). The tube has an outer diameter of 25 mm and an inner diameter of 23 mm, and is made using the extruder and die shown below. It is made from PVC (polyvinyl chloride), which is a semi-crystalline, thermoplastic polymer with a melting point of 212°C and a glass transition temperature of 87°C. The manufacturing engineer is at a loss as to what is causing the problem and how to solve it.



PVC monomer

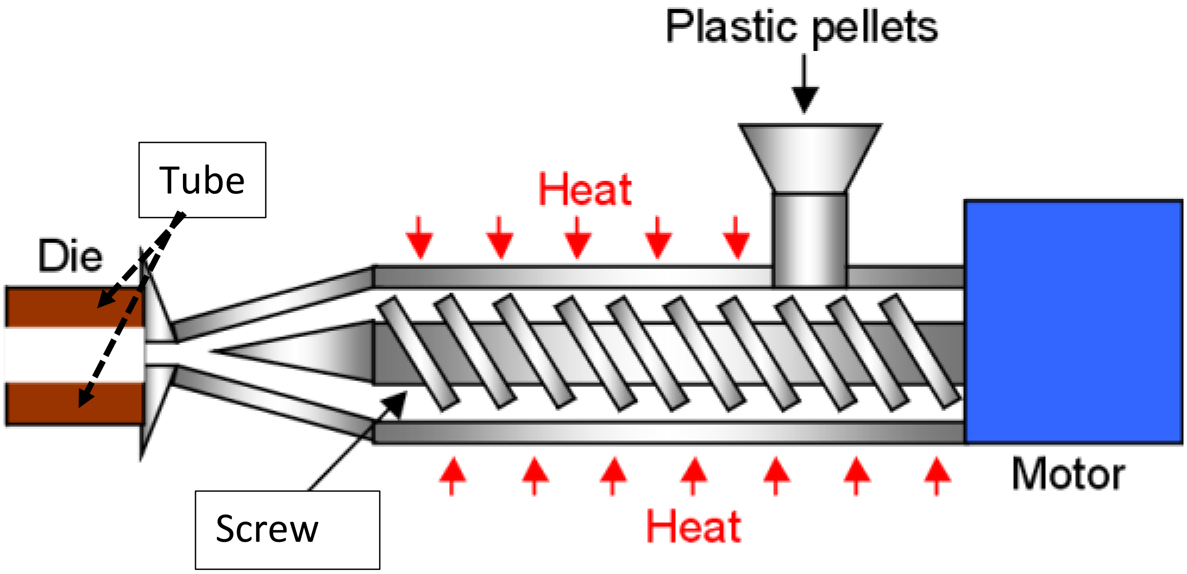


Answer the following three questions:

a) What is causing the problem?
b) What are some solutions to the problem?

The die required to make this tube is an annulus (ring).

c) Develop an equation for the polymer flow from this die (Q_{die}).



Screw equation

$$Q_{screw} = w * \left[\frac{v_z \mathrm{H}}{2} - \frac{H^3}{12\mu}\frac{\mathrm{d}p}{dz}\right]$$

Round die equation

$$Q_{die} = \frac{\pi R^4}{8\mu}\frac{\Delta p}{L}$$

Rectangular die equation

$$Q_{die} = \frac{H^3}{12\mu}\frac{\Delta p}{L}$$

Other equations

$$v_z = v_{screw}\cos\theta$$

$$v_{screw} = \frac{\pi DN}{60}$$

$$dz = \frac{l}{\sin\theta}$$