Spring 2011 Manufacturing Qualifier Exam

Closed books
Closed notes

Work only **<u>three</u>** (3) of the four questions

List and justify all of your assumptions

Show all work

Question #1: Metal Machining

Consider a metal shaping operation carried out with a tool of zero rake angle.

(a) Derive an equation for the rate of heat generation in the shear zone in terms of the following quantities: cutting force (F_c), cutting speed (V), ratio of the undeformed chip thickness to the deformed chip thickness (r_c), and the coefficient of friction at the tool-chip interface (μ). Clearly state all assumptions you make in your derivation.

(b) Calculate the mean temperature rise in the shear zone given that 15% of the shear zone heat is conducted into the workpiece. The following quantities are given: specific cutting energy of the metal being cut (u_c) = 3 J/mm^3, $\mu = 1.0$, $r_c = 0.2$, density of metal (ρ) = 7200 kg/m^3, specific heat capacity (c) = 500 J/kg-K.

(c) What would be the temperature rise in the shear zone if the cutting speed (V) were tripled without changing the proportion of shear zone heat conducted into the workpiece?

Question #2: Polymer Processing

There are four (4) questions (A-D) that must be answered for this section. Several equations are listed at the end of the section.

A. Name the main three sections of the screw shown in **Figure a**. Fully describe the behavior/characteristics of the pellets within each Section.
   a. Section 1. Name__________________________

   b. Section 2. Name __________________________

   c. Section 3. Name__________________________

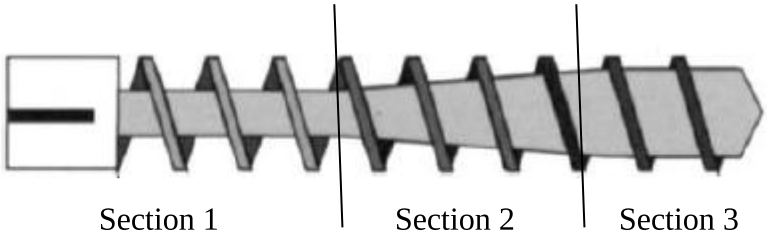


Figure a. Single flight extruder screw.

B. You need to schedule a production run to produce five colors (natural, black, light blue, yellow, and white) in polypropylene. Does the production order matter? If so, what order do you schedule the resins to be processed? In either case, why?

C. Polypropylene (PP) is being extruded in a 6” extruder equipped with a barrier flight in the metering section, having a barrel-to wall clearance of 0.05”, a channel depth of 0.35”, and a screw speed of 75 rpm, producing at a rate of 600 pounds/hour. Approximate the viscosity in the die land area of a sheet die that is 60” wide with a 0.125” opening. The density of PP is 0.91 g/cc, melt density is 0.75 g/cc, and the shear rate versus viscosity curve is given in **Figure b.** Helpful hints: g is grams, cc is a cubic centimeter and there are 454g/lb.

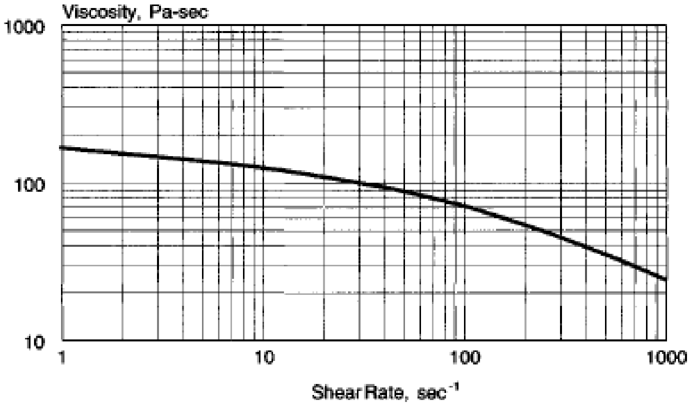


Figure b. Shear rate versus viscosity curve for PP.

D. Analyze the effect of geometry and material properties on flow through the channel of an extruder. Consider **1)** Newtonian flow and **2)** Power Law flow through flat and round channel geometries, as shown in **Figures c and d,** respectively. Assume that n = 0.4; $\frac{h}{2}$ = 1 mm; and D = 4 mm. How many times will the flow rate Q increase due to the channel height and the radius in each individual case (i.e., 1c, 1d, 2c, and 2d)? State all of your assumptions.

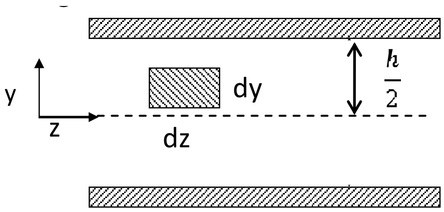


Figure c. Flat channel

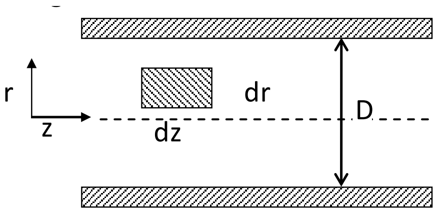


Figure d. Round channel

Equations:

Newtonian

1. Flat Channel $Q = \frac{\Delta P w h^3}{12\mu L}$, $\dot{\gamma} = \frac{6Q}{wh^2}$
2. Round Channel $Q = \frac{\pi \Delta P R^4}{8\mu L}$, $\dot{\gamma} = \frac{\pi D N}{60h}$

Power Law

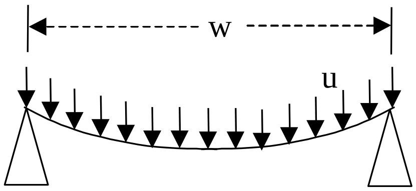
3. Flat Channel $Q = w\left(\frac{\Delta P}{KL}\right)^{1/n}\frac{2n}{2n+1}\left(\frac{h}{2}\right)^{\frac{(2n+1)}{n}}$
4. Round Channel $Q = \pi\frac{n}{3n+1}\left(\frac{\Delta P}{2LK}\right)^{1/n}R^{\frac{3n+1}{n}}$

Nomenclature

ΔP-pressure, Q-volumetric flow rate, w-channel width, μ-viscosity, L-length, $\dot{\gamma}$-shear rate, R-radius, N-screw speed in rev/min, K and n- power law constants

Question #3: Metal Rolling

A 3 feet wide 6061-O aluminum slab, which is known to exhibit a strength factor of 30,000 psi and a work-hardening exponent of 0.2, is rolled from an original thickness of 3 inches down to a final thickness of 2.8 inches. The rollers used in this process are made of stainless steel, with an elastic modulus of 27.6×10^6 lb/in^2, of 12 inch diameter. Each roller is simply supported by two small back-up rollers 36 inches apart. In this configuration, the lower roller experiences a loading condition similar to that shown in the following figure with a measured maximum roller deflection of 0.015 inch. If a 16 inch diameter roller were used, what would have been the maximum deflection? Note that the maximum deflection of a simply supported beam under uniform loading, u, is $y_{max} = \frac{5uW^4}{384EI}$.



u=uniform loading, lb/in
w=span, in
E=modulus of elasticity, lb/in^2
I=2nd moment of inertia
for bar with diameter of D, $I=\pi d^4/64$

Question #4: Sand Casting

A disk 40cm in diameter and 5cm thick is to be cast out of pure aluminum in a sand mold. The melting temperature of aluminum is 660°C and the pouring temperature is 800°C. Assume that the amount of aluminum to be heated will be 5% more than needed to fill the mold cavity.

a) Accounting for isotropic volumetric solidification shrinkage of 7% and isotropic volumetric solid contraction shrinkage of 5.6%, determine the volume of molten aluminum required to produce the part with the desired dimensions and the amount of heat that must be added to the metal to heat it to the pouring temperature, starting from a room temperature of 25°C.

b) The mold is top gated. The sprue bottom transitions into a horizontal runner leading into the gate at the mold cavity. The sprue bottom, runner, and gate all have the same diameter. While obeying the Reynolds number criterion, design a sprue/runner/gate system so that the following conditions are met: (a) the mold filling time does not exceed 45s; (b) the sprue bottom diameter is not less than 10mm; and (c) the sprue height is at least 15mm. The reservoir approximation may be assumed for the sprue top/pouring basin. No aspiration may also be assumed.

c) The constant “C” in Chvorinov’s rule for this situation is given as 600 s/mm^2. Determine the solidification time.

d) Cylindrical risers need to be designed for the part. The risers are as tall as the sprue (whose height was determined earlier) and have additional insulation that at least triples their solidification time relative to the casting. The tops of the risers are insulated so they do not transfer heat to the environment. The risers are on the runner so the bottom interface area of the riser can be ignored while considering the heat transfer area. Determine the minimum diameter of the riser that meets the above requirements.

Data for Aluminum are as follows:

Latent heat of fusion: 397 kJ/kg
Density: 2700 kg/m^3
Specific heat (solid aluminum): 938 J/kg K
Specific heat (liquid aluminum): 1050 J/kg K
Viscosity: 0.0015 N-s/m^2 around 800°C.