

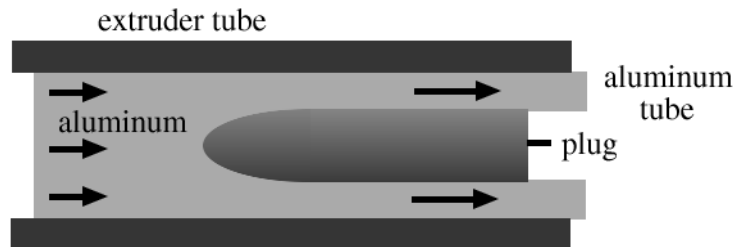
3.044 Problem Set 7

Deformation Processing, Evaporation

Due Friday April 29, 2005

1. Extrusion of a tube (30)

A seamless polymer or metal (*e.g.* a magnesium alloy or aluminum as shown below) tube is made by extruding the solid through the cylindrical die pictured in cross-section below. (The central plug is held in place by a “spider” whose details are not significant for this problem.)



You may assume “flow” of the solid is steady-state and incompressible, that the plug and tube are long enough to establish fully-developed flow in the annulus between them, and that gravity is *not* an important driver for the flow.

- On a single (large) graph, sketch the shear stresses and velocity profiles you would expect to see in the annulus (with the same maximum velocity) assuming the solid behaves like a:
 - Newtonian fluid
 - Pseudoplastic fluid
 - Bingham plastic

Label features of curves as appropriate. (15)

- Based on what you know of their stress-strain behavior, which of the above do you think will be closer to the actual behavior of an extruded solid metal? (7)
- Briefly describe the structure and properties of the resulting extruded tube: will the grain size be larger or smaller than before extrusion? Will the metal be weaker or stronger, and why? (8)

2. Sintering rates and stages (20)

- For cadmium chloride (CdCl_2), Stage I sintering is dominated by evaporation and condensation. Is there any densification associated with this process? Why or why not? (7)
- At a certain temperature, $100\mu\text{m}$ CdCl_2 powder begins Stage II and starts to densify in 10 hours. Assuming the Stage I to Stage II transition happens at a certain neck/particle radius ratio x/r , how long will it take $50\mu\text{m}$ powder to start to densify in Stage II? (13)

3. Evaporation of alloying elements from titanium (50)

Previously you used k'' and continuous flow behavior to determine the effectiveness of electron beam melting at removing volatile impurities. Now you will calculate the k'' values themselves, and apply the analysis to the alloying elements aluminum and vanadium. Assume average surface temperature is 1750° C.

Clausius-Clapeyron equation form for pure element vapor pressure (in torr):

$$\log_{10} \bar{p}_v = -\frac{A}{T} + B + C \log_{10} T + DT$$

Henry's law for a dilute solute i (i =Al, Cd, etc.) with activity coefficient γ_i , mole fraction X_i :

$$p_{vi} = \gamma_i X_i \bar{p}_{vi}$$

Important constants:

Element	A	B	C	D	Activity coeff γ
Al	16540	12.36	-1.023	—	0.0640
Cd	5819	12.29	-1.257	—	?
Pb	10130	11.16	-0.985	—	?
Ti	23200	11.74	-0.66	—	1*
V	26900	10.12	0.33	-2.65×10^{-4}	1
Zn	6670	12.00	-1.126	—	?

*When close to $X_i = 1$, use Rault's law $p_{vi} = X_i \bar{p}_{vi}$.

Source: E. Brandes ed. *Smithells Metals Reference Book* (6th edition), Boston: Butterworth & Co., 1983.

- Use the Clausius-Clapeyron and Langmuir equations to calculate the vapor pressures and evaporation rates of pure aluminum and vanadium at the average surface temperature. (10)
- Assuming dilute solution in titanium, calculate the reaction rate coefficient of each of these, using a titanium melt density of 4.1 g/cm³. (10)
- Of these two alloying elements, which will increase in concentration and which will decrease during electron beam melting? (10)

For the remainder of the problem, the goal is to deposit a coating of titanium with 6 wt% aluminum and 4 wt% vanadium.

- If the beam focuses on a single spot 1" in diameter (instead of scanning over the whole pool), what will the shape of the vapor plume will look like (flux vs. angle, calculate cosine power n)? (10)
- What should the composition of the melt pool be to achieve this composition at the substrate? (10)