

**Department of Materials Science and Engineering
Massachusetts Institute of Technology
3.044 Materials Processing – Spring 2012**

Exam II

Wednesday, May 2, 2012

The Rules:

- 1) No books allowed; no computers allowed; etc.
 - 2) A simple calculator is allowed
 - 3) Two hand written 3x5 index cards may be prepared as a crutch.
 - 4) Complete 5 out of the 6 problems. If you do more than 5 problems, I will grade the first 5 that are not crossed out.
 - 5) Make sure that you READ THE QUESTIONS CAREFULLY
 - 6) Supplementary materials are attached to the end of the test (eqns., etc.)
 - 7) WRITE YOUR NAME HERE:
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Problem #1: A Continuous Casting is Subjected to Scrutiny Following Some Concerns About the Stability of the Solidification Front

In this problem, you will explain the following statement:

If we continuously cast a thick section of a binary alloy, the solidification begins in a stable plane front mode, but later transitions into an unstable, dendritic growth mode.

Part A:

Even though the solid and liquid have about the same 'k' (thermal conductivity), the resistances, or conductances, of these two components are different. Compare the thermal conduction in the liquid and solid of a continuously-cast alloy for the early stages of casting, when we are still in the mold.

Part B:

Compare the conductances of the solid and liquid at a much later time, when we are out of the mold and solidification is almost complete.

Part C:

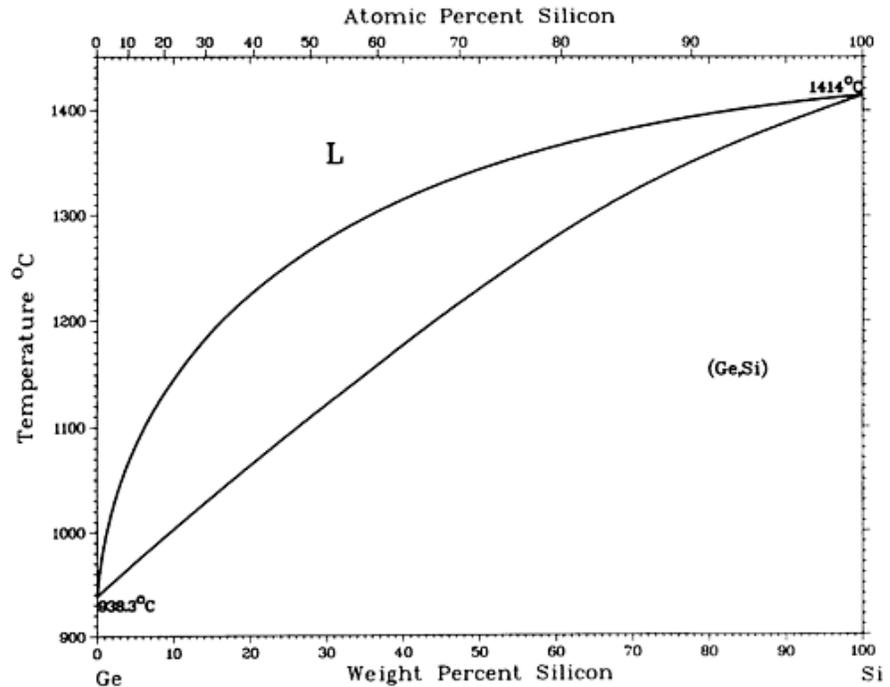
Explain how the conditions in the early (Part A) and late (Part B) stages of casting lead to stable and unstable solidification, respectively.

Problem #2: Solidification: Inside, Outside, Upside Down

Here is a phase diagram for a binary alloy of Ge-Si. We are going to solidify a dilute alloy, say Ge-10 at% Si.

I would like you to show me how this solidification problem is different from all those we have seen in class, by drawing some pictures of the composition profile as the alloy solidifies.

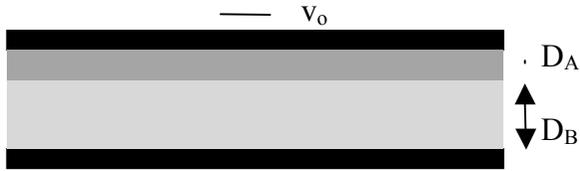
Assume that mixing/diffusion in the liquid is rapid, but nonexistent in the solid.



Please draw three pictures of the composition profile, at at least three times/temperatures. One near the beginning of the solidification ($T = T_1$ near the liquidus), one at an intermediate time ($T = T_2$), and one near the end of solidification ($T = T_3$ near the solidus). Please make your charts as QUANTITATIVE as possible; label every quantity you can.

Problem #3: Go With the Co-Flow

Imagine our classical two-parallel-plates-in-shear situation, but now there is not a single fluid between the plates, but two immiscible fluids...



The fluids, call them A and B, in general have different properties, and different dimensions, D . The bottom plate is fixed and the top one is moving at a fixed velocity v_0 .

Part A:

Describe the analogous problem in heat transfer.

Part B:

Draw the steady-state flow profile for this system; state any assumptions you make about the properties of the two liquids (which must NOT be the same).

Part C:

Identify any sets of conditions in which you can neglect one of the two fluids.

Part D:

Describe what you could do to guarantee mixing of these two liquids; what is the specific mathematical condition you would need to achieve?

Problem #4: How Neglectful Can We Be?

For each of the following problems, there are two driving forces for fluid flow. For each problem, do the following:

1. Write down the two driving forces,
2. Write the mathematical quantities you would need to compare the two forces (the units should match).
3. Write the conditions under which you can neglect the first, under which you can neglect the second, and under which you can neglect both

Part A: Parallel plates being sheared, oriented at an angle θ from horizontal

Part B: A vertically oriented pipe, pressurized at the top

Part C: A vertically oriented pipe, pressurized at the bottom

Problem #5: Laminar, Laminar, Laminar, Turbulent

Consider a transient flow problem: we have parallel plates separated by 1 cm, and we will shear a film of water between them beginning at time $t = 0$. The velocity of the upper plate (relative to the bottom, fixed, plate) is 1 m/s. Water properties: $\mu = 10^{-3}$ Pa-s, $\rho = 1000$ kg/m³.

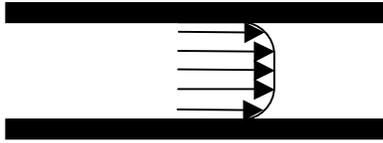
Part A: Before we think about the transient problem, let's think about the steady state, a long time after $t = 0$. Convince yourself (and me) that there will be turbulent flow.

Part B: In light of your answer to part A, draw a schematic of what you think the average flow profile might look like in the steady state. Explain your drawing in one sentence or less

Part C: Now let's talk about the transient problem. Draw a series of flow profiles for this system as a function of time. Please draw at least a few pictures at various dimensionless times ranging from $\tau = 0$ to 1. Include in your pictures something that indicates where and when turbulence develops.

Problem #6: Snubbed

Here is a picture of a flow profile in a pressurized tube:



The profile is NOT parabolic; it is “snubbier” than would normally be expected from our classical laminar flow analysis.

Question: In the absence of any other information, can you explain why the flow profile is not parabolic?

Explain several possible answers to this question, in each case explaining how the stated answer would lead to a “snubbier” flow profile

Answer A: Turbulence.

Answer B: Temperature effects.

Answer C: The fluid is not Newtonian.

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