MATERIALS SCIENCE & ENGINEERING

PhD Qualifying Exam – Spring 2018

DAY 1

Closed Book/Notes Exam

Thursday, February 1st, 2018

1:00-5:00 pm

EMS E250

Instructions

1. This part is a closed book/notes only
2. There are 6 problems in this part
3. Answer 5 problems only on separate answer books
4. Write the topic title on each answer book
5. Smart phones (devices) and laptops are not allowed

NOTE: NO ELECTRONIC SMART DEVICES ARE ALLOWED IN THE EXAMINATION ROOM
1. **Structures of Solids**

1. What are the indices for the directions indicated by the two vectors in the following sketch?

   ![Diagram of a crystal structure showing two directions indicated by vectors 0.4 nm, 0.3 nm, and 0.5 nm.](image)

2. The curve below shows an x-ray diffraction pattern for α-iron taken using a diffractometer and monochromatic x-radiation having a wavelength of 0.154 nm; each diffraction peak on the pattern has been indexed. Calculate the interplanar spacing for each set of planes indexed.

   ![X-ray diffraction pattern with peaks labeled (110), (200), and (211).](image)
2. Transport Phenomena

A very large block of AISI 52100 steel, with a 1 wt % carbon content, is heated in a furnace to a temperature of 1255K (in the austenite range). It was intended that the furnace atmosphere would have a carbon potential that would be in equilibrium with 1 wt% carbon in the steel. However, due to an error, the furnace atmosphere was set at zero carbon potential (i.e. the carbon content in the steel at equilibrium with the atmosphere is zero) and maintained at that level throughout the treatment. The error was discovered 9.65 hours later.

a. Sketch what the carbon composition profile in the block will look like after this treatment.

b. Write the applicable differential equation, the boundary conditions, and the solution for calculating the carbon concentration profile in the steel block.

c. Calculate the carbon content in wt% at a depth of 1 mm below the surface of the block after this treatment.

Data: The diffusion coefficient of carbon in austenite at this temperature is $2 \times 10^{-11} \text{ m}^2 \text{s}^{-1}$. Assume that the density of the steel does not change with carbon content.

Table of error function values:

<table>
<thead>
<tr>
<th>$z$</th>
<th>$\text{erf}(z)$</th>
<th>$z$</th>
<th>$\text{erf}(z)$</th>
<th>$z$</th>
<th>$\text{erf}(z)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.55</td>
<td>0.5633</td>
<td>1.3</td>
<td>0.9340</td>
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<tr>
<td>0.025</td>
<td>0.0282</td>
<td>0.60</td>
<td>0.6039</td>
<td>1.4</td>
<td>0.9523</td>
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<tr>
<td>0.05</td>
<td>0.0564</td>
<td>0.65</td>
<td>0.6420</td>
<td>1.5</td>
<td>0.9661</td>
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<tr>
<td>0.10</td>
<td>0.1125</td>
<td>0.70</td>
<td>0.6778</td>
<td>1.6</td>
<td>0.9763</td>
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<td>0.15</td>
<td>0.1680</td>
<td>0.75</td>
<td>0.7112</td>
<td>1.7</td>
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<tr>
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<td>0.80</td>
<td>0.7421</td>
<td>1.8</td>
<td>0.9891</td>
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<tr>
<td>0.25</td>
<td>0.2763</td>
<td>0.85</td>
<td>0.7707</td>
<td>1.9</td>
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<tr>
<td>0.30</td>
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<td>0.90</td>
<td>0.7970</td>
<td>2.0</td>
<td>0.9953</td>
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<td>0.95</td>
<td>0.8209</td>
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<td>0.9998</td>
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<tr>
<td>0.50</td>
<td>0.5205</td>
<td>1.2</td>
<td>0.9103</td>
<td>2.8</td>
<td>0.9999</td>
</tr>
</tbody>
</table>
3. **Thermodynamics**

A large batch of molten steel in a ladle contains 0.002 wt % oxygen. Vanadium is to be added in the ladle at 1560°C to make a product containing 1 wt % vanadium dissolved in the steel. To what extent must the oxygen content of the heat be lowered to prevent the loss of vanadium via oxidation during the alloying process? Describe in detail any assumptions you make and the defend the reasonableness of each assumptions.

Given: $2[V]_{\text{Fe, wt\%}} + 3[O]_{\text{Fe, wt\%}} = \text{<V}_2\text{O}_3>;$ \hspace{1cm} $\Delta G^\circ = -780,400 + 267.8T$ (J)

($T=$ Temp in K) \hspace{1cm} <solid> \hspace{1cm} [dissolved]
4. Phase Equilibria, Phase Diagrams

a. Determine the phases present, composition of each phase, and the relative phase weight fraction under equilibrium conditions of 780 °C and a bulk composition of 20 wt% Cu. Draw a sketch of the expected structure.

b. Assuming that same 20wt% Cu alloy was then cooled slowly from 780 to 778 °C, determine the phase present, compositions, and phase weight fractions of all constituents at 778 °C immediately after any applicable transformations occur. Draw a sketch of the expected structure.

c. Draw cooling curves (temp versus time) for 28.1wt%Cu and 50 wt% Cu compositions from a fully liquid condition to 500˚C.
5. Kinetics & Diffusion, Phase Transitions

Your employer (a petrochemical company) has a large steel pressure vessel (wall 0.3 m thick) which has contained high pressure hydrogen at temperatures of 400°C for a year. Your problem is to calculate the time the vessel should be held at temperature with the hydrogen pressure removed, so that 90% of the hydrogen can diffuse out. (The aim is to avoid hydrogen cracking on cooling) the following data is given:

\[ D_{H_2}^{Fe} = 0.05 \exp(-6000 \text{ (cal/mol)/RT}) \text{ cm}^2/\text{s} \]

Vessel diameter 3 m)

(a) Sketch the concentration profile through the wall at \( t = 0 \)
(b) Give a numerical estimate of the time to diffuse 90% of the gas
(c) Outline how a more exact calculation of the transient could be made.
6. Materials Processing (NO LONGER REQUIRED STARTING SPRING 2020)

Answer **ALL** parts:

1. Using a neat sketch, explain the relationship between the stress distribution on the tool face and the formation of built-up edge during the cutting process.

2. In a straight turning process of a 12” long cylindrical workpiece with a specific cutting energy of 2 hp/(in^3/min) and an initial diameter of 6” on a 8-hp (net power) lathe, the cutting time was measured to be 2 minutes. What is the depth of cut in the process assuming that the process used 75% of the machine tool power capacity? (ignore the effect of depth of cut on the average diameter of the workpiece)

3. Discuss the various effects of applying front tension and back tension of equal magnitudes, simultaneously, on the workpiece in a flat rolling process.

4. In a wire drawing process of a strain-hardening material with n = 0.2 what should the percentage of friction plus redundant work be, in terms of total work, so that the maximum reduction per pass is 50%?