NAME Solution
UNIVERSITY OF CALIFORNIA
CE 60
Fall 2011

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CE 60 PROPERTIES OF CIVIL ENGINEERING MATERIALS
FIRST MIDTERM EXAMINATION
October 4, 2011

Question 1 [/ 8]

a) Atomic arrangements

i) Alumina can have two different *atomic arrangements*. Could the atomic arrangement reveal if Alumina is amorphous or crystalline? **[✓ Yes]/No** (Circle and explain).

Amorphous → Short Range Order

Crystalline → Long Range Order

ii) Does the face centered cubic (FCC) crystal structure contain the same number of slip planes as a hexagonal closed packed crystal (HCP) structure? **Yes/[✓ No]** (circle);

iii) Are the slip planes in HCP **[✓ high atomic] or low atomic density slip planes**? Circle

b) Questions dealing with Phase Diagrams.

i) The host and the alloying element have same crystal structures and similar atomic radii (i.e. a difference less than <10%). What type of Phase Diagram would you expect? **[✓ Complete solid solution], limited solid solution, no solid solution phase diagram**? (Circle)

ii) The composition in a two phase regime is equal to the composition of the alloy. **True/[✓ Wrong]** (circle).

iii) Do alloys in a complete solid solution phase diagram exhibit a lamellar microstructure at room temperature? **Yes/[✓ No]** (circle).

iv) At the eutectic point in a phase diagram, how many phases are in equilibrium? 3

Question 2 [/8]

a) Why is the nucleation rate so small in close vicinity to the melting temperature? Circle the appropriate answer/answers:

1 i) due to [✓ low driving] force for transformation
ii) due to low probability of clustering of atoms
iii) due to small critical size of nuclei

1 b) Which energy is being enhanced when the system is undercooled? The [✓ **Volume free energy (ΔGv)**] or the **Surface free energy (ΔGs)**? (Circle)

1 c) Which energy is being reduced when going from homogeneous to heterogeneous nucleation? The **Volume free energy** (ΔGv) or the [✓ **Surface**] **free energy** (**ΔGs**)? (Circle)

1 d) Can homogeneous nucleation occur during phase transformation from one solid S1 to another solid S2**? Yes/**[✓ **No**](circle)

1 e) What effect does high undercooling have on the growth rate? Will it **increase/**[✓ **decrease**] the growth rate? (Circle)

1 f) A phase transformation revealed an amorphous material at room temperature. Which Phase transformation/s did most likely occur? [✓ **Liquid to Solid**]**; Austenite to Ferrite**; **Austenite to Martensite**; **Austenite to Pearlite**? (Circle).

2 g) Martensitic Phase transformations occur in Steel, Ni-Ti alloys and in pure Iron. Which one will lead to low toughness? Martensitic phase transformations in [✓ **Steel**]**/ Ni-Ti alloys/ pure Iron**?
(circle and explain in detail).

Steel: Martensite → bct cryst. structure → less dense slip planes

→ very distorted lattice due to Carbon being quenched in

Question 3 [/24]

The phase diagram and TTT diagrams for this question are on pages 4 & 5

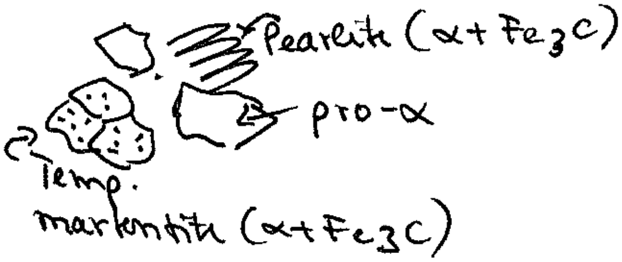
a) Indicate the composition/ compositions that produces 100% Pearlite at room temperature in the Phase Diagram on page 4. 0.8% C

b) What is the amount of Carbon that can be dissolved (i.e. max. solubility) in
   i) Ferrite 0.02%
   ii) Cementite 0%

c) A steel alloy with composition X1 was heat-treated in three different ways. Heat-treatment #1 revealed coarse grained pro-eutectoid ferrite, coarse grained pearlite and martensite at room-temperature.

   i) Show schematically the quench-hold-quench cycle this alloy must have undergone to create this type of microstructure in the appropriate TTT diagram on page 5.

   ii) That same alloy was reheated to around 400C. After quenching back to room temperature what will be the microstructure of that steel? Draw the microstructures and include the phases associated with these microstructures.



   iii) To improve the yield strength alloy composition X1 was heat treated differently and these are the various heat-treatments:
   Heat-treatment #2: revealed **fine** grained pro-eutectoid ferrite and **fine** pearlite
   Heat-treatment #3: revealed **fine** pearlite and bainite
   Which of the two heat-treatments above reveal a higher yield strength? **Heat-treatment #2** or [✓ **Heat treatment** #3]? Please circle and explain briefly.

   Finer grain size due to bainite

   iv) Show both heat-treatment ~~#1~~ #2 and ~~#2~~ #3 as quench-hold-quench cycles in the appropriate TTT diagram (tip: may require more than one quench cycle).

d) Two specimens (S1 and S2) with same alloy composition of 1.2% C were investigated. Both specimens revealed fine grained pro-eutectoid cementite and martensite at room temperature

   i) Show the quench-hold-quench cycle of the two specimens that would reveal this type of microstructure in the appropriate TTT diagram below.

   ii) S1 and S2 revealed the same microstructure, however, when the martensite of S2 was indented, it revealed a higher hardness compared to the martensite of specimen S1. As you recall from the lab, the indentation size reveal the hardness of the microstructure. Which of the two specimens had the smaller indentation size in its martensite: **specimen S1 or** [✓ **S2**]? (circle)

iii) Since both specimen had the same alloy composition, what was the difference in heat-treatment between S1 and S2 to reveal a difference in the hardness of martensite? (Please explain in great detail and illustrate schematically using the Phase Diagram below).

Alloy composition of 1.2% C was cooled to different Temp. within 2-phase regime ($Fe_3C + \gamma$) prior to quenching cooled to T_1: will reveal higher carbon content in martensite after quenching

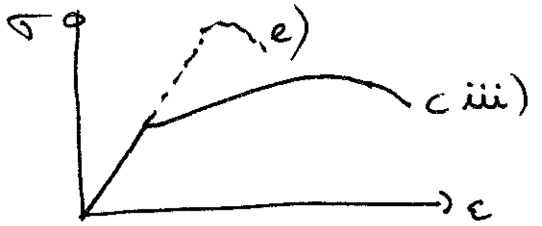
iv) Do you expect a difference in weight% of pro-eutectoid cementite in the two specimens due to the difference in heat-treatment? [✓ Yes]/No? (circle).

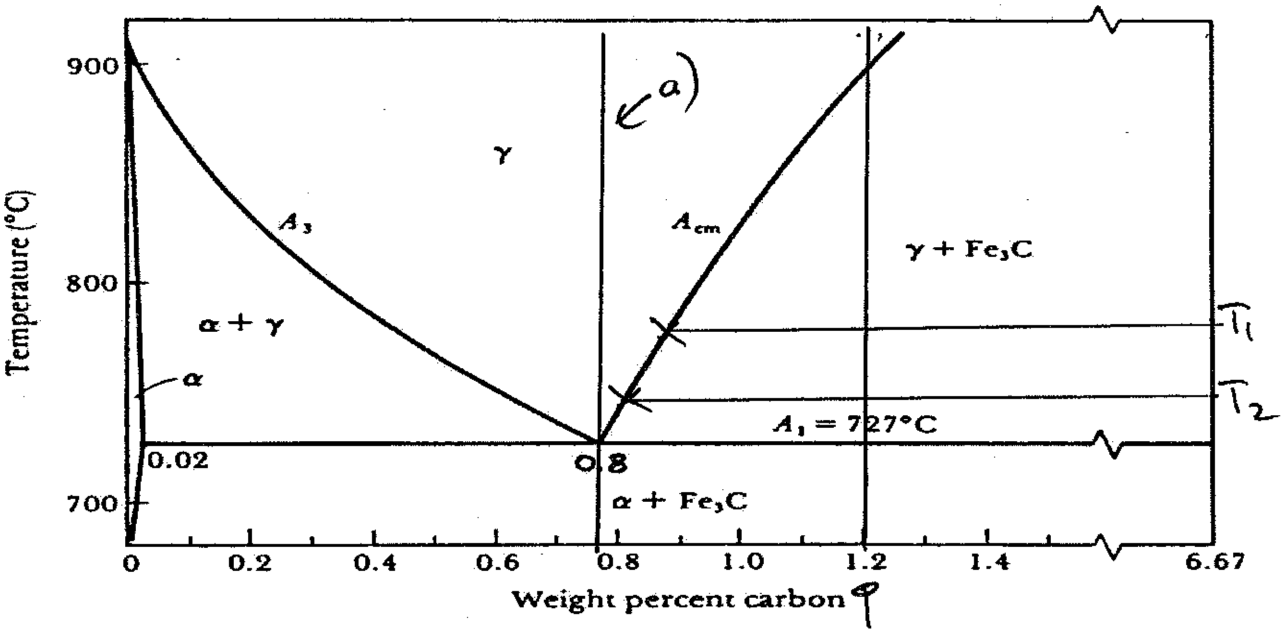
e) An alloy with 1.2 wt%C was cooled from austenite to room temperature and revealed fine grained pro-eutectoid cementite and fine pearlite. How much pearlite would form just below the eutectic Temperature?

γ transforms into Pearlite $\Rightarrow$ $\gamma = \dfrac{6.67-1.2}{6.67-0.8}$

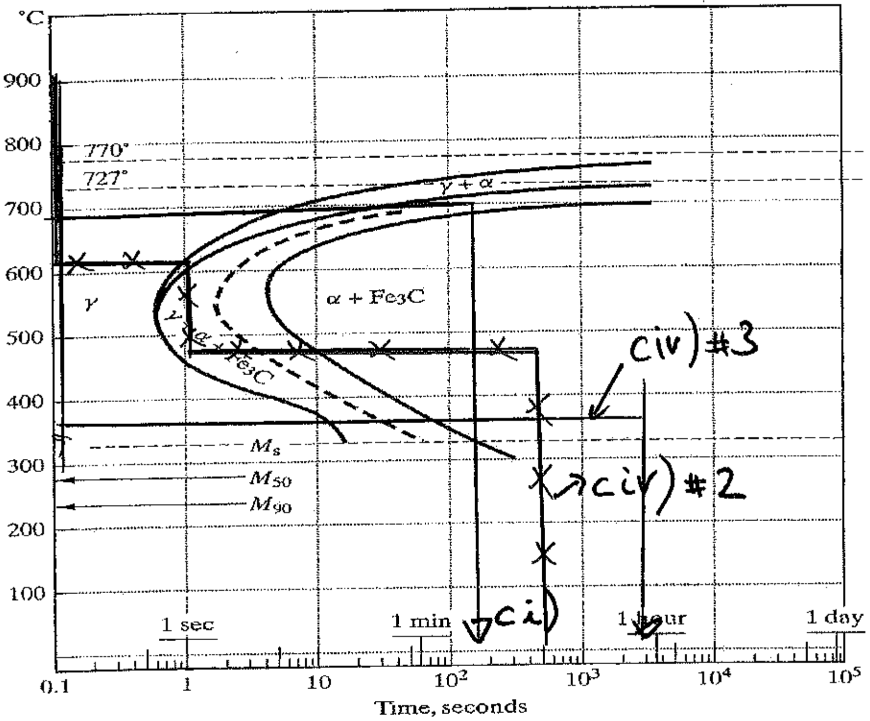
$\Rightarrow$ 93% Pearlite

f) Draw the stress strain curves of the steel in (e) above and the steel discussed in c (iii) (with heat-treatment#2) into **the same stress strain diagram.**

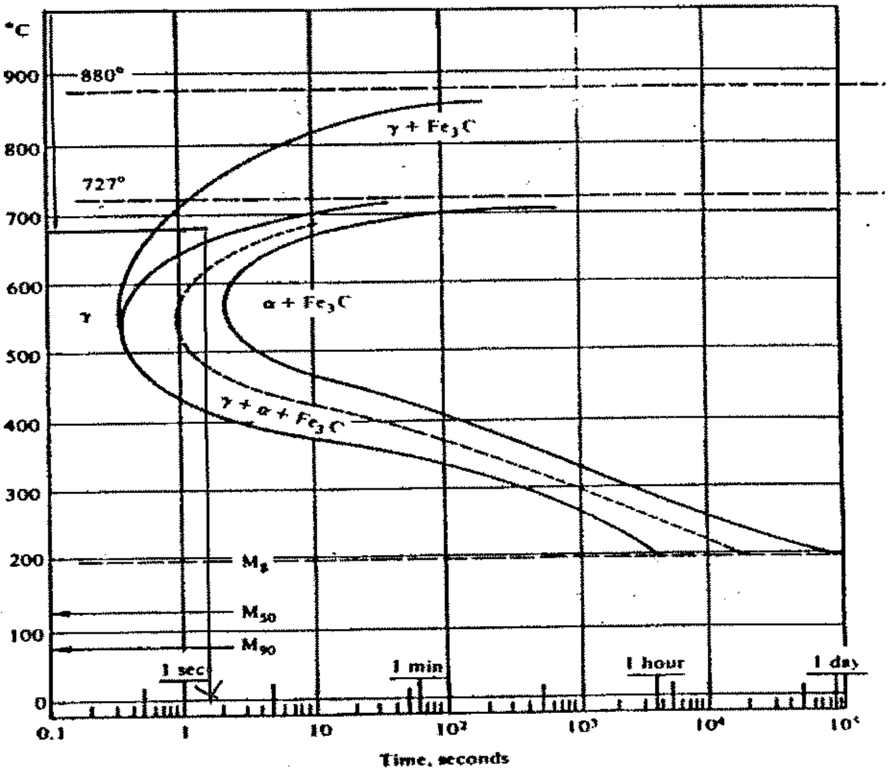




The eutectoid portion of the Fe-Fe$_3$C phase diagram.


°C
900
800
700
600
500
400
300
200
100
770°
727°
γ + α
γ
α + Fe3C
γ + α + Fe3C
Ms
M50
M90
c iv) #3
→ c iv) #2
c i)
1 sec
1 min
1 hour
1 day
0.1
1
10
10²
10³
10⁴
10⁵
Time, seconds

di)


°C
900
800
700
600
500
400
300
200
100
0
880°
727°
γ + Fe3C
γ
α + Fe3C
γ + α + Fe3C
Ms
M50
M90
1 sec
1 min
1 hour
1 day
0.1
1
10
10²
10³
10⁴
10⁵
Time, seconds

Question 4 [/10]:

The engineering stress strain curve of an aluminum alloy is shown below with some experimental data.

i) At the yield strength the specimen length was 8 inches. What was the initial length of the specimen? (the gage length before testing was 2" and at yield strength 2.01") .

$L_f = L_0 + \Delta L$

$= L_0 + \varepsilon \cdot L_0$

$\Rightarrow L_0 = L_f / (1+\varepsilon) = 7.96''$

$\varepsilon = \frac{\text{change in gage length}}{\text{init. gage length}} = \frac{\text{change in total length}}{\text{init. length}}$

ii) After reaching 38 ksi and a strain of 0.02, the alloy was unloaded. Determine the elastic recoverable strain mathematically.

$\varepsilon_{el} = \sigma / E = \frac{38\,\text{ksi}}{6700\,\text{ksi}} = 5.7 \cdot 10^{-3}$

$E = \frac{35\,\text{ksi} - 15\,\text{ksi}}{0.005 - 0.002} = 6700\,\text{ksi}$

$E = 35\,\text{ksi} / 0.005 = 7000\,\text{ksi}$ (ok)

iii) After unloading (in ii) the alloy was reloaded and revealed a higher yield strength compared to the initial yield strength shown in the figure below. Please explain why the yield strength has increased.

due to strain / work hardening

# of disloc. increases during strain hardening $\Rightarrow \perp - \perp$ interaction

iv) What is the ductility of the alloy? (initial diameter of the specimen was 0.4 inches; the final diameter measured after failure is 0.35 inches)

ductility: $\frac{A_f - A_0}{A_0} = \frac{d_f^2 - d_0^2}{d_0^2} = 0.23 \Rightarrow 23\%$

stress (ksi)	strain
15	0.002
35	0.005
38	0.02
40	0.06