Department of Mechanical Engineering
University of Saskatchewan

ME324.3 Engineering Materials

FINAL EXAMINATION (CLOSED BOOK)

Instructor:	I. N. A. Oguocha	**Date:**	17 December, 2004.
Time:	3 Hours		

Reading Time: 10 Minutes **Total Points = 683**

Apart from your calculator and ruler, only TWO free pages will be allowed.

This is a very busy examination. Do not waste time on extraneous statements or grammar. Go straight to the point(s).

You may be requested at any time to present your Student Card or Driving License.

Instructions: Answer ALL Questions. Show details of all your calculations.
Include units, where necessary, in all final answers. They are part of your answers.
All sketches must be labeled. No mark for unlabeled diagrams.

Question 1: (66 Points) **Points**

Figure Q1 (see Worksheet) shows the phase diagram for a binary alloy system between two metals Ni and Mo.

(a) Name the *terminal solid solutions* present. 4

(b) Name the *intermediate phases* present. 6

(c) Circle all the *three-phase equilibra* present (Use Worksheet). 8

(d) Name and write the reaction formulas for the equilibria named in (c). 16

(e) Sketch and label the *cooling curve* for alloy X. 12

(f) Sketch and label the microstructures for alloy X at positions (b), (c), (d) and (f). 20

Question 2: (86 Points) **Points**

(a) Consider a Fe-C alloy that undergoes the *austenite* → *ferrite* transformation. What is the maximum carbon content (in wt.%) for which this transformation can take place? Where do carbon atoms reside inside ferrite? 8

(b) Most steels have a higher carbon content than that in part (a). For an alloy with 0.77 wt.%C, what is the *engineering name* for this steel? 4

(c) Suppose you cool the steel in part (b) slowly, what is the name of the equilibrium phase transformation that occurs upon cooling from the austenite region? Write the equation of this reaction. What *phases* will develop? What is the common name given to this microstructure? 18

(d) Does the microstructure change if the carbon content is higher than 0.77 wt.%C (e.g. 1 wt.%C)? 5

(e) A AISI-SAE 10115 steel is slowly cooled from 900 °C to a temperature just slightly below 727 °C.

(i) What is the carbon content of this steel? 5

(ii) Is this steel a *hypoeutectoid*, *hypereutectic*, or *hypereutectoid* steel? 4

(iii) Calculate the wt.% *proeutectoid cementit*e present in the steel. 12

(iv) Calculate the wt% of *eutectoid cementite* present and wt.% *eutectoid ferrite* present in the steel. 30

Question 3 (128 Points)

(a) **Figure Q3(a)** shows the TTT diagram for a coarse-grained plain-carbon steel of eutectoid composition. Thin samples of the steel are austenitized at 850 °C and then subjected to the quenching treatments shown in the diagram. Describe the microstructure produced by each heat treatment. Note: For each treatment, state the ***microstructures*** (*phases and/or microconstituents*) and their ***relative amounts*** in the final material. 48

(b) A plain-carbon steel contains 10.86 wt% *eutectoid cementite*. What is the AISI-SAE number for this steel? 36

(c) Three plain-carbon steel specimens with 0.28 wt%C were austenitized at 1050 °C for 1 hour and subsequently subjected to the following schemes:

(1) Quenching
(2) Normalizing
(3) Annealing

(i) With the help of labeled simple *Temperature* versus *Time* diagrams, explain briefly the three heat treatments. Assume that all the samples were at room temperature before austenitization. 18

Points

(ii) Use **Table Q3(c)** in the Worksheet to explain the expected microstructure (phases, microconstituents and grain size) and mechanical properties (hardness, strength, impact toughness) of each of the three specimens. Use such terms as *very high*, *high*, *low*, *coarse*, *fine*, *medium* to qualify the mechanical properties and grain size. 26

Question 4 (120 Points)

(a) Distinguish between *hardness* and *hardenability*. 6

(b) How does austenite grain size affect the hardenability of steels? 4

(c) How is the hardenability of steels affected by the austenitizing temperature? 4

(d) The compositions of two steels are given below:

Steel A: 0.89 wt.%C, 0.29 wt.% MN, balance Fe
Steel B: 0.39 wt.%C, 0.56 wt.%Mn, 3.53 wt.% Ni, 0.74 wt.% Mo, balance Fe.

(i) Which steel will have the highest hardenability? Why? 6

Thin razor blades of each steel are heated to 950 °C and then quenched in cold brine solution.

(ii) Which blade will have the highest hardness? Why? 6

(iii) Which blade will probably crack, distort or warp after quenching? 4

(e) A 60-mm (2.4")-diameter steel rod of an SAE 4017 steel has been carburized to 0.68 wt%C at the surface and 0.42 wt.%C at 3 mm below the surface, and remains at 0.17 wt.%C at 7.5 mm below the surface. See **Figure Q 4(e)** in the Worksheet for the pertinent diagrams. 90

(i) Determine the hardness profile of the steel after water quenching.

(ii) What would the profile have been without carburizing?

Interpolate where necessary.

Use the Worksheet for extraction and tabulation of your data. Draw the profiles in the exam booklet.

Question 5 (96 Points) **Points**

(a) Which THREE of the following steels are suitable for *carburizing*? 12

Alloy	C	Si	Mn	P	S	Ni	Cr	Mo	Cu
A	0.15	0.20	0.65	0.045	0.045	4.0	1.20	0.25	
B	0.35	0.20	0.65	0.045	0.030				
C	0.17	0.07	0.92	0.014	0.033				
D	0.28	0.20	0.41	0.045	0.030	1.50	1.60	0.30	
E	0.20	0.30	1.88	0.018	0.022	0.03	0.04	0.02	0.04

(b) Which THREE of the following steels are suitable for *nitriding*? 12

Alloy	C	Si	Mn	P	S	Cr	Ni	Mo	V	W	Al
A	0.31	0.20	0.55	0.025	0.030	2.25		0.20	0.15		
B	0.18	0.40	0.80	0.025	0.030	1.5		0.80	0.30		1.1
C	0.45	0.20	0.65	0.045	0.045						
D	0.37	0.40	0.70	0.025	0.035	1.2		0.25			1.8
E	0.00	0.35	0.76	0.015	0.031	1.5	1.7	0.30	0.22		1.3

(c) Which THREE of the following steels are suitable for *selective hardening*? 12

Alloy	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Mg
A	0.45	0.20	0.65	0.045	0.045					
B	0.35	0.20	0.65	0.045	0.030	1.70	0.80	0.20		
C	0.17	0.07	0.92	0.014	0.033	0.04	0.01	0.01	0.03	
D	0.51	0.20	0.41	0.045	0.030					
E	3.5	2.8	0.88	0.018	0.022	0.20		0.08		0.05

(d) You are a mechanical Engineer-in-Training (EIT) in local manufacturing plant that fabricates a variety of potash ore-crushing, automobile and agro-machine components from steels. Your company uses carburization to meet the wear resistance requirements of its clients for these parts. However, due to unfavourable market situation, your company is cutting down on power consumption in the plant. One of the targeted facilities is your carburizing furnace, where you work currently under a senior engineer. Your manager is worried and wants to save money for the company. He proposes that you should reduce the carburizing temperature from 1000 °C to 900 °C, arguing that the carburizing time to get the same results will only be about 15% longer. You are not convinced. To prove that your supervisor is wrong you have to calculate the diffusion coefficient D at 900°C, then calculate the time required to reach the same wt.% C, C_x, which is 20% of the surface concentration (C_s), at a depth of 0.02 cm below the surface of the steel component. Assume, for the purposes of this analysis, that the carbon content of the steel is 12.1% of the surface carbon concentration (C_s). Is he really wrong? 60

Diffusion Data:

D of carbon into steel at 1000 °C = 2.98 x 10^{-7} cm^2/s

D_o of carbon into steel = 0.25 cm^2/s

Q for carbon into steel = 144.56 kJ/mol. Gas Constant R = 8.314 J/mol K

Solution of Fick's Second Law **Points**

$$\frac{C_s - C_x}{C_s - C_o} = erf\left(\frac{x}{2\sqrt{Dt}}\right) \quad \text{where } D = D_o \exp\left(-\frac{Q}{RT}\right)$$

Values of error function

y	erf (y)	y	erf (y)	y	erf (y)
0	0	0.5	0.521	1.3	0.934
0.05	0.056	0.6	0.604	1.4	0.952
0.10	0.112	0.7	0.678	1.5	0.966
0.15	0.168	0.8	0.742	1.6	0.976
0.20	0.223	0.9	0.797	1.8	0.989
0.25	0.276	1.0	0.843	2.0	0.995
0.30	0.329	1.1	0.880	2.4	0.999
0.4	0.429	1.2	0.910	∞	1.000

Question 6 (98 Points)

(a) A portion of Browne and Sharpe table of gauge numbers and wire diameters or sheet thickness, in inches, is shown in **Table Q6**. Two wires, A and B, of yellow brass with 0.070 mm average grain size had original gauge numbers of 0 and 2 in the annealed condition. Each was cold-drawn, such that its gauge number increased by 3. Using **Table Q6** and **Figure Q6**, determine the following:

(i) The initial and final diameters of each of the wires 12

(ii) The percent reduction in diameter 16

(iii) The percent reduction in area 16

(iv) The temper designation of as-cold drawn wires 6

(v) The yield strength (in psi) of the as-cold drawn wires. 8

(b) A particular design requires that we choose materials using a selection criterion $M = \frac{E^{\frac{1}{2}}}{\sigma^3}$. Determine the slope of the *selection line*. 10

(c) The material performance index for a light-weight telescope mirror support is given by 30

$$M = \frac{E^{\frac{1}{3}}}{\rho}.$$

Use **CES 4.0**, **Level 2**, to select FIVE materials that will serve this purpose.

<u>Question 7</u> (89 Points) **Points**

(a) State the FOUR conditions that are favorable for extensive substitutional solid solubility of one metal in another. 16

(b) What conditions, if any, favour interstitial solid solubility? 5

(c) Using the data presented in Table Q, determine if Mn (solute) and Mg (solvent) would be expected to exhibit *extensive solubility*, *partial solubility*, *zero solubility* or *interstitial solubility*. Justify your answer rigorously using calculations and analysis. 30

Element	**Atomic Weight**	**Crystal Structure**	**Atomic Radius (Å)**	**Valence**	**Electronegativity**
Mn	54.94	BCC	1.120	2+	1.5
Mg	24.32	HCP	1.604	2+	1.2

(d) What are the THREE basic heat treatment steps to strengthen a precipitation-hardening metal? 12

(e) Distinguish between *natural aging* and *artificial aging* for a precipitation-hardening alloy. 8

(f) Use a labeled ***strength*** versus ***time*** plot <u>only</u> (no grammar) to distinguish between *underaged*, *peak-aged* and *overaged* conditions in a typical aluminum-copper alloy. 18

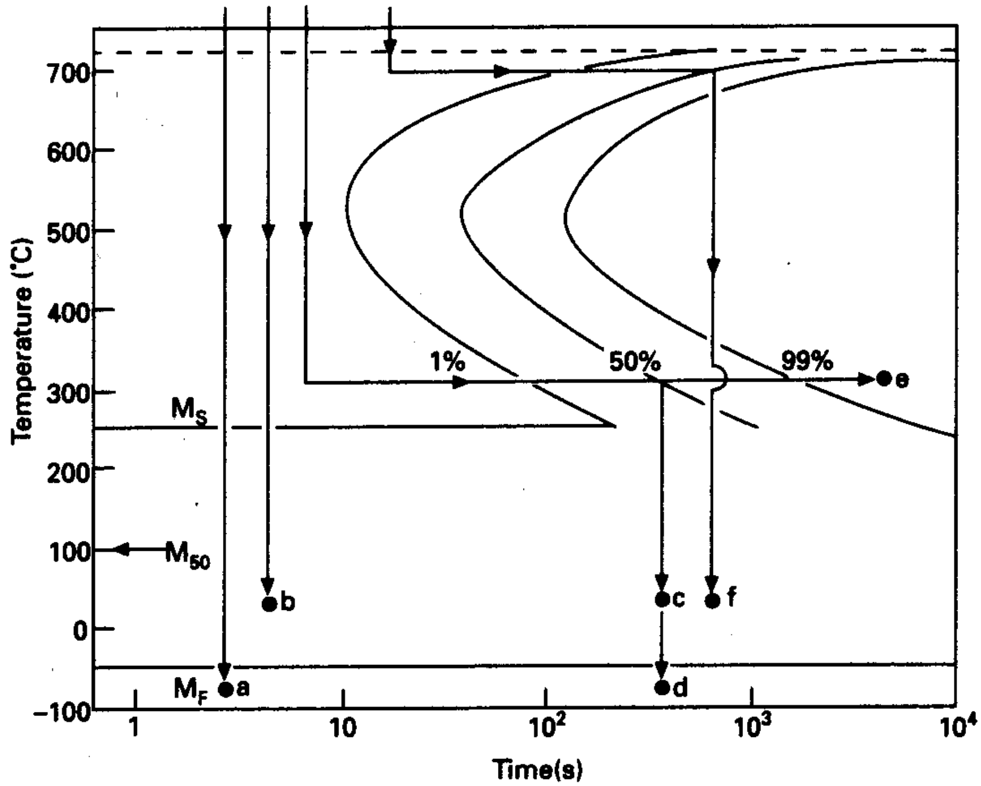


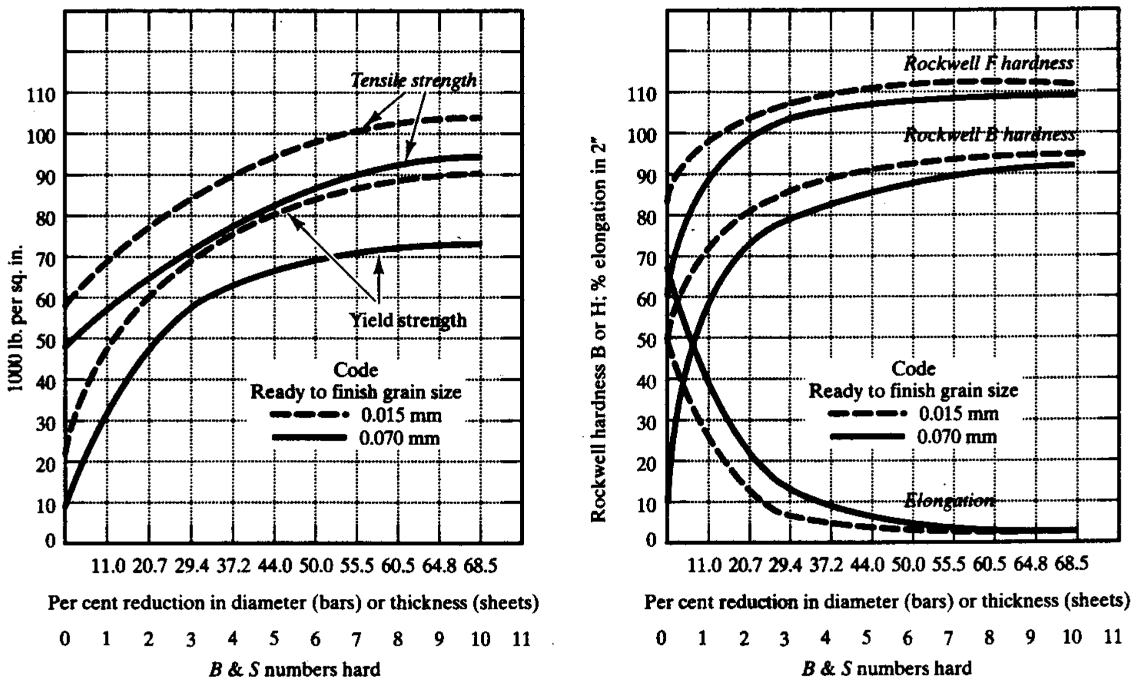
Figure Q3(a)

Table Q6

B&S Gauge Number	Wire dia. or sheet thickness, in.
0	0.324861
1	0.289297
2	0.257627
3	0.229423
4	0.204307
5	0.181940

Cold-worked tempers of wrought coppers and brasses.

Tempers-H	Increase in B&S Gauge Number	Temper Names	% Reduction in Diameter or Thickness
H00	Not specified	1/8-Hard	Not specified
H01	1	1/4-Hard	10.9
H02	2	1/2-Hard	20.7
H03	3	3/4-Hard	29.4
H04	4	Hard	37.1
H06	6	Extra hard	50.1
H08	8	Spring	60.5
H10	10	Extra Spring	68.6
H12	12	Special Spring	75.1
H14	14	Super Spring	80.3



Tensile strength
Yield strength
1000 lb. per sq. in.
110
100
90
80
70
60
50
40
30
20
10
0
Code
Ready to finish grain size
0.015 mm
0.070 mm
11.0 20.7 29.4 37.2 44.0 50.0 55.5 60.5 64.8 68.5
Per cent reduction in diameter (bars) or thickness (sheets)
0 1 2 3 4 5 6 7 8 9 10 11
B & S numbers hard
Rockwell F hardness
Rockwell B hardness
Elongation
Rockwell hardness B or H; % elongation in 2"
Code
Ready to finish grain size
0.015 mm
0.070 mm
11.0 20.7 29.4 37.2 44.0 50.0 55.5 60.5 64.8 68.5
Per cent reduction in diameter (bars) or thickness (sheets)
0 1 2 3 4 5 6 7 8 9 10 11
B & S numbers hard

Figure Q6

ME324 Final Exam Worksheet

Student Name **Student Number:**

Note: Return this worksheet with your answer booklets.

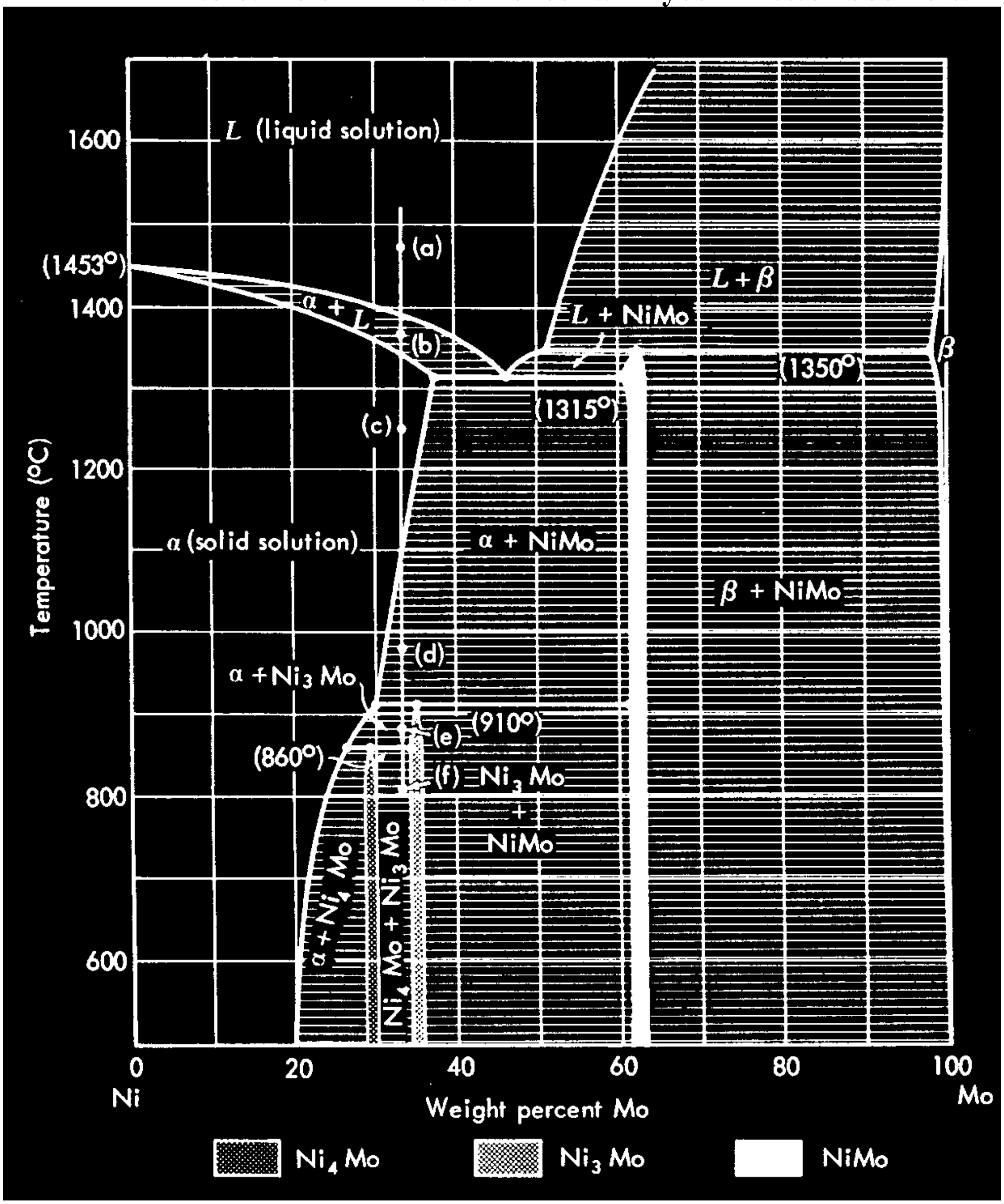


Figure Q1

Student Name **Student Number:**

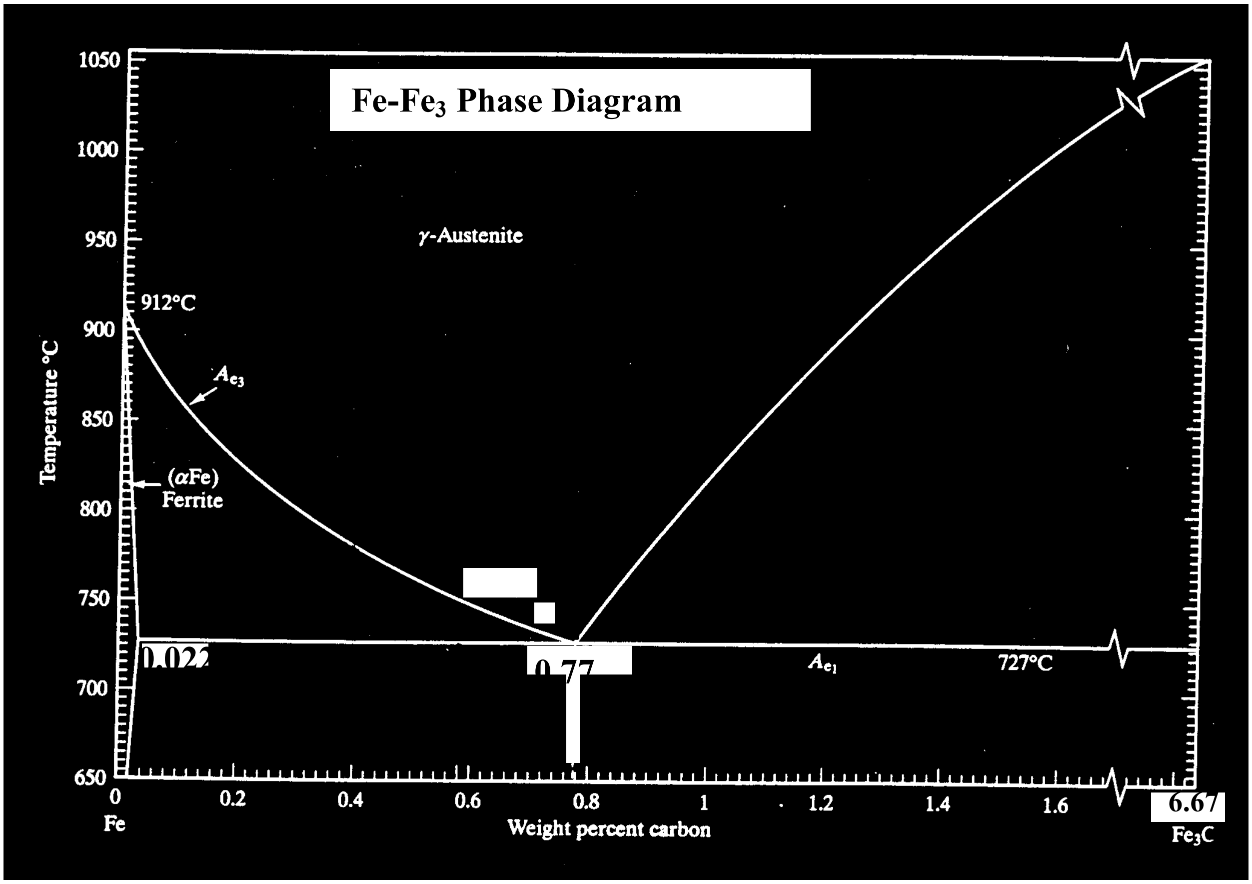


Table Q3(c)

Process	Microstructure	Hardness	Strength	Impact Toughness	Grain Size
Quenching					
Normalizing					
Annealing					

Student Name **Student Number:**

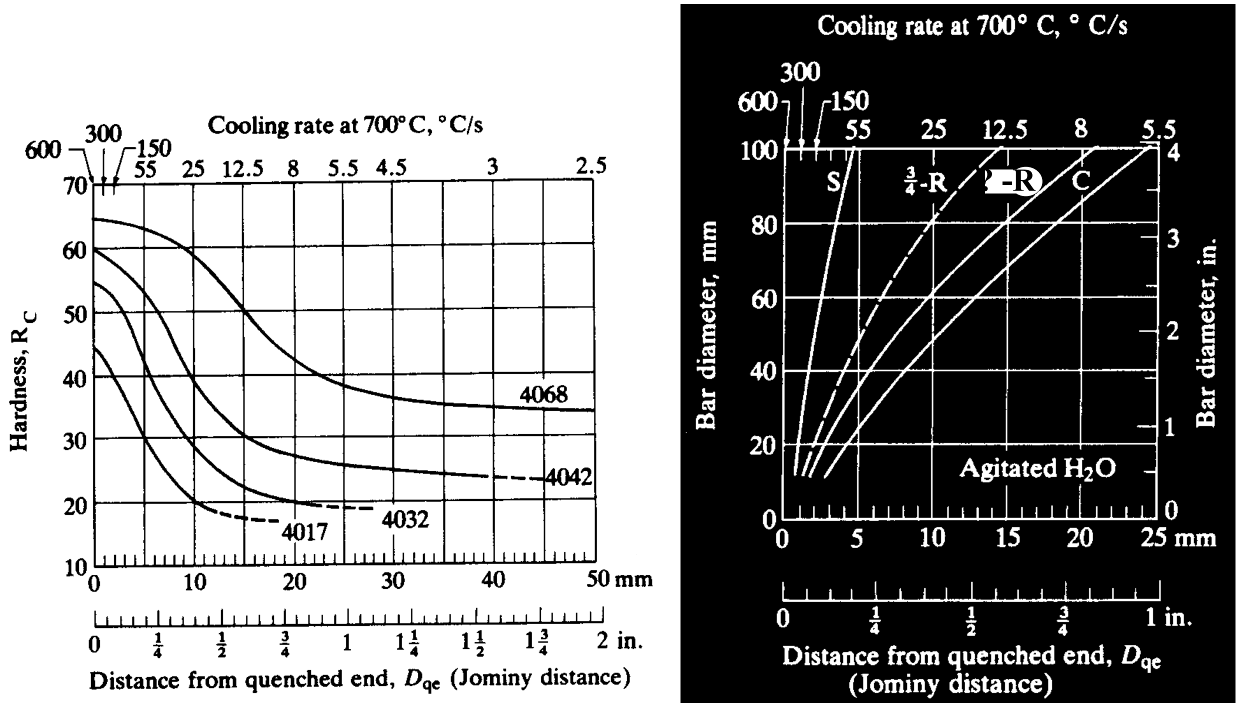


Figure Q 4(e)

		(a)		(b)	
Bar Position	**Jeq**	**%C**	**HRC**	**%C**	**HRC**
S					
3mm					
¾ R					
½ R					
Center					