Department of Mechanical Engineering
University of Saskatchewan

ME324.3 Engineering Materials

FINAL EXAMINATION (CLOSED BOOK)

Instructor:	I. N. A. Oguocha	**Date:**	16 December, 2005.
Time:	3 Hours	**Place:**	Room 1B71, Engineering

Reading Time: 10 Minutes **Total Points = 640**

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 labelled. No mark for unlabeled diagrams.

Question 1 (75 Points)

		Points
(a)	Answer the following questions with respect to solidification of pure metals.	
	(i) Name the TWO steps involved in the transformation.	4
	(ii) Name the TWO energies involved in the transformation.	4
	(iii) Distinguish between an *embryo* and a *nucleus*.	6
(b)	**Fig. Q1-1** shows a cooling curve for an Al-Si alloy. Using this diagram determine:	
	(i) The *pouring temperature.*	3
	(ii) The *superheat*.	4
	(iii) The *liquidus* temperature.	3
	(iv) The *eutectic* temperature.	3
	(v) The *freezing range*.	4
	(vi) The *local solidification time*.	4
	(vii) The *total solidification time*.	4
	(vii) The composition of the alloy (**Fig.Q1-2** in the **Worksheet** will be handy here).	6
(c)	Calculate the number of atoms in the nucleus of lead when it homogeneously solidifies at 247 °C from the liquid state. The latent heat of fusion is 23.2 kJ/kg, the density is 11.35x 10^3Kg/m^3, the equilibrium melting point is 327 °C, and γ_{sl} = 33 x 10^{-3} J/m^2. Lead is FCC with a lattice parameter of 4.9489Å. Assume a sphere model.	30

Question 2 (80 Points)

		Points
(a)	Use **Fig.Q2-1** in the **Worksheet** to determine the minimum austenitizing temperatures for the following AISI steels: 1095 and 5320.	8
(b)	The amount of *phases* and *microstructures* existing in the metastable Fe-Fe_3C alloy system varies with carbon content.	
	(i) Use **Fig.Q2-2** (see **Worksheet)** to illustrate how the wt% of *ferrite* (α) and *cementite* (Fe_3C) vary with carbon content at room temperature. Use straight lines to join your points.	12
	(ii) In **Fig.Q2-3** (see **Worksheet)**, show how the wt% of *primary ferrite*, *pearlite*, and *ledeburite* vary with carbon content. Use straight lines to join your points.	18
(c)	A 1.1 wt.% C *hypereutectoid steel* is cooled slowly from the austenite region to slightly below the A_1 transformation temperature. Using the Fe-Fe_3C phase diagram in **Fig. Q2-1**, determine:	
	(i) Temperature at which the primary phase begins to form	4
	(ii) What is this *proeutectoid phase* and where does it form?	6
	(iii) The mass fraction of austenite and its composition at 750°C	12
	(iv) The mass fraction of pearlite just below 727°C	10
	(v) The mass fraction of cementite in the microstructure.	10

Question 3 (74 Points)

		Points
(a)	Distinguish between AISI 43VB40 and AISI 4340H steels.	6
(b)	Name TWO *carbide-forming* elements in steels	4
(c)	Name TWO *ferrite-stabilizing* elements in steels	4
(d)	Name TWO *austenite-stabilizing* elements in steels	4
(e)	State FOUR reasons why cast irons are used widely as engineering materials.	8
(f)	The chemical compositions of FIVE different cast irons are given in **Table Q3-1**.	
	(i) Determine the *carbon equivalents* of these irons. Enter your results in the **Worksheet**.	20
	(ii) Based on the results of your calculations in (i), name the iron(s) that will show a hypereutectic microstructure.	6
	(iii) Based on the results of your calculations in (i), name the iron(s) that will show a hypoeutectic microstructure.	6
	(iv) Use a labelled sketch to show how the tensile strength of 2.0-inch diameter specimens of these irons will vary with carbon equivalent.	8
(g)	State, giving reason(s) which iron would:	
	(i) most likely solidify into white iron when cast	4
	(ii) be most suitable for high-temperature applications (*Hint*: high *graphitization* favours high temperature service).	4

<u>Question 4</u> (100 Points)

		Points
(a)	Answer the following questions with respect to steel.	
	(i) What effect does an increase in carbon content of steels have upon the nose of the TTT curve?	5
	(ii) What is the effect of an increase in the percentage of alloys on the position of the nose of the TTT curve?	5
	(iii) What does the addition of cobalt do to the nose of the TTT curve?	5
(b)	Six drill rods (4-mm diameter) of AISI 1080 steel receive the sequences of heat treatments shown in **Fig. Q4-1**. Use **Table Q4-1** in the **Worksheet** to answer questions (i) to (iii).	
	(i) Indicate the phase(s) that will be present after each heat treatment.	20
	(ii) Name the room temperature microstructure(s) and the percentages present for each heat treatment.	24
	(iii) Name the heat treatment process undergone by drill rods 1, 2, 4, 5 and 6.	15
	(iv) Which of the heat treatment processes will produce the hardest rod.	3
	(v) Which of the treatments will the give softest rod?	3
	(vi) Which of the heat treatments will be most suitable for generating the highest hardness and lowest defect density in a 20-inch diameter bar of AISI 1080 steel?	5
(c)	**Fig.Q4-2** shows the CCT diagrams for hypoeutectoid and hypereutectoid steels with the right-hand end of the M_s lines specially marked (dotted oval). Explain why the M_s line of the hypoeutectoid steel bends down while that of the hypereutectoid steel bends up within the marked region.	15

<u>Question 5</u> (97 Points)

		Points
(a)	Arrange in order of decreasing cooling rates FIVE quenchants used for heat treatment of steels.	10
(b)	State THREE differences between *martensitic* and *diffusive* transformations in steels.	12
(c)	A plain-carbon steel was held at a temperature for five hours and then quenched to room temperature. The as-quenched specimen was found to contain 50vol% *ferrite* and 50vol% *martensite* and the microhardness on the as-quenched martensite was 870 VHN. Assume for this analysis that the densities of ferrite and martensite are the same and the hardness of ferrite ~ 90 VHN. Using this information answer the following questions. **Figs. Q5-1**, **Q5-2, Q5-3** and **Q5-4** will be handy.	
	(i) Determine the temperature at which the steel was held and the AISI designation of the steel.	25
	(ii) If we consider the resulting microstructure to be a <u>composite material</u> composed of ferrite and martensite, determine its hardness.	10
	(iii) Specify a heat treatment sequence to convert the ferrite-martensite microstructure to 100% martensite. Indicate the temperature and time involved.	15
	(iv) Determine the hardness of the as-quenched martensite obtained in (iii) and the tempered hardness. Hence, determine the *tensile strength* in the *as-quenched* condition.	25

<u>Question 6</u> (119 Points)

		Points
(a)	List the SIX MAIN classes of engineering materials following Prof. Ashby's nomenclature.	15
(b)	You are asked to select materials for the frame of a mountain bike. Name FIVE essential properties you would consider.	10

(c) A particular engineering design demands that we select materials based on two materials selection indices, M_1 and M_2, where:

$$M_1 = \frac{E^{\frac{1}{2}}}{\sigma^{\frac{1}{3}}} \text{ and } M_2 = \frac{\sigma^{\frac{1}{2}}}{C_m \rho}$$

		Points
(i)	Determine the slope of the selection line for M_1.	12
(ii)	Determine the slope of the selection line for M_2.	12
(iii)	Using CES EduPack (Level 2), select FIVE materials that satisfy materials selection index M_1.	30
(iv)	Using CES EduPack (Level 2), select FIVE materials that satisfy materials selection index M_2.	30
(v)	List all the materials that satisfy the two selection criteria.	10

<u>Question 7</u> (95 Points)

		Points
(a)	State FOUR main precautions you would take when performing a Jominy end-quench (hardenability) test in order to ensure accurate and reproducible results.	12
(b)	What is the relationship between austenite grain size and hardenability of steels?	6
(c)	Why does the hardenability of steels increase with increasing austenitizing temperature?	8
(d)	How is the hardenability of steels affected by cobalt?	5

(e) Jominy hardenability curves for three unknown steels are shown in **Fig Q7-1**. Based on this figure and your knowledge of hardenability:

(i) Which curve relates to the steel of greatest hardenability? 4

(ii) Which curve relates to the steel of highest carbon content? 4

If a 15mm-diameter bar of **steel A** water quenched from the austenitizing temperature

(iii) What would be the microstructure at the centre of the bar? 4

(iv) What would be the microstructure at the mid-radius of the bar? 8

(v) What would be the microstructure about 2mm from the surface? 4

(f) A company is bidding for a contract to produce 20,000 clevis blocks or chain adaptors in aerial lifts (cherry pickers). The machine drawing for this component is shown **Fig. Q7-2**. Specifications call for a hardness of 40 HRC at the indicated point in order to prevent excessive wear. Otherwise, the choice of the material is left to the manufacturer, cost being the only consideration. The only steel on hand is SAE 1050 and a quick decision as to which steel to use is required. The only possibilities are the steels shown in **Fig. Q7-3**. A model of the clevis block is machined from the SAE1050 steel and heat treated according to the anticipated production need. The hardness measured at the located point is found to be 30 HRC. 30

(i) Which steel(s) will qualify for this application? <u>Show full details of your work in order to earn full mark.</u>

(ii) What is cooling rate (°C/s) at the point. (**Fig. Q7-4** will be handy) 10

END OF EXAM

Formulas

$$\Delta G_v = \frac{\Delta H_v \Delta T}{T_o} \qquad \Delta G_v = \frac{L_v \Delta T}{T_m}$$

$$r^* = -\frac{2\gamma}{\Delta G_v} \qquad \Delta G^* = \frac{16\pi\gamma^3}{3(\Delta G_v)^2}$$

$\Delta T = T_o - T$; T_o = equilibrium transformation temperature; T_m = melting point

For solidification, $\Delta H_v = L_v$, where L_v is the latent heat of fusion per unit volume.

Tensile Strength in MPa = 3.45 HB

<u>Table Q3</u>

Cast Iron (CI)	%C	%Si	%Mn	%P
CI-1	3.5	1.2	0.8	0.1
CI-2	3.3	2.2	0.5	0.3
CI-3	3.6	1.8	0.5	0.8
CI-4	3.0	5.0	0.5	0.1
CI-5	3.3	0.6	0.5	0.1

Carbon Equivalent Formula: $CE = \%C + \frac{\%Si + \%P}{3}$

Figures

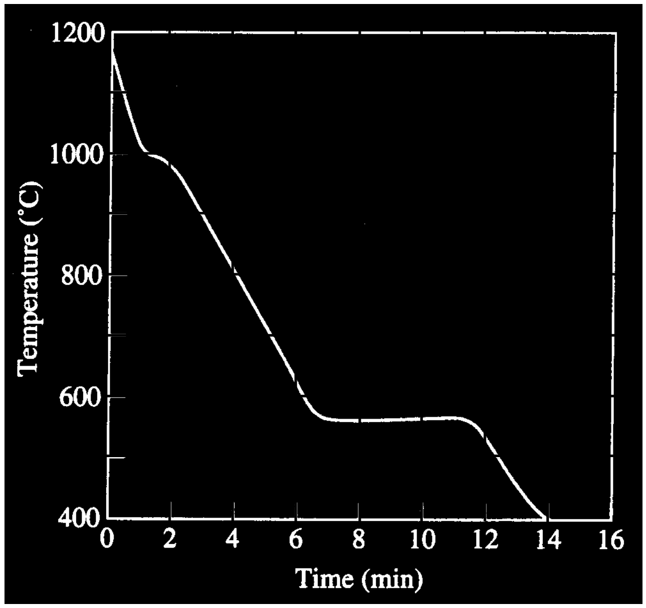


Fig. Q1-1

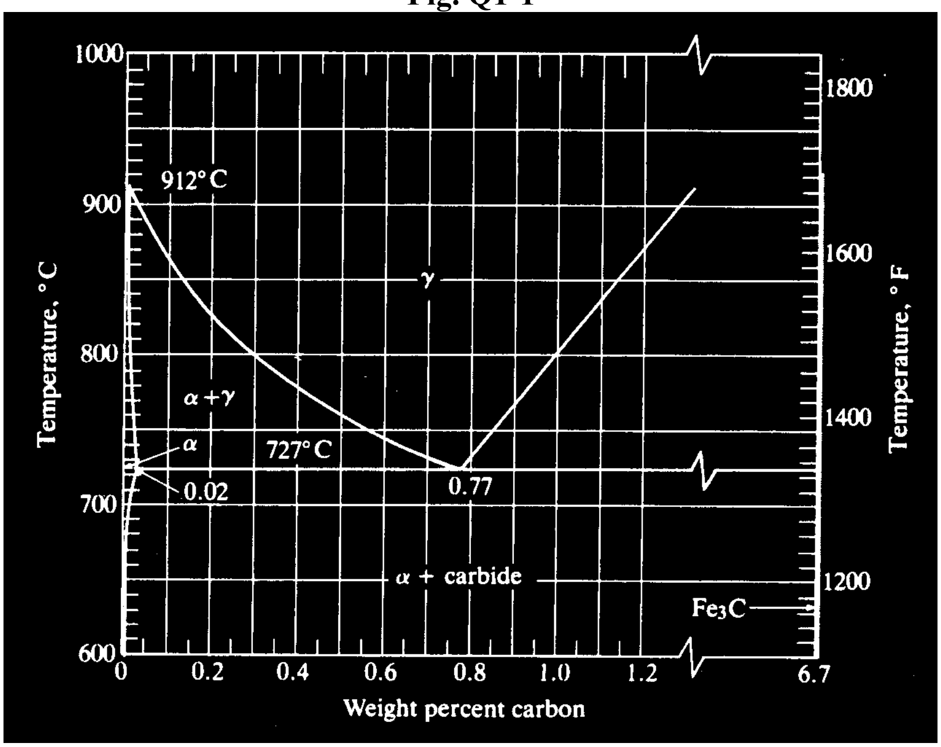


Fig. Q2-1

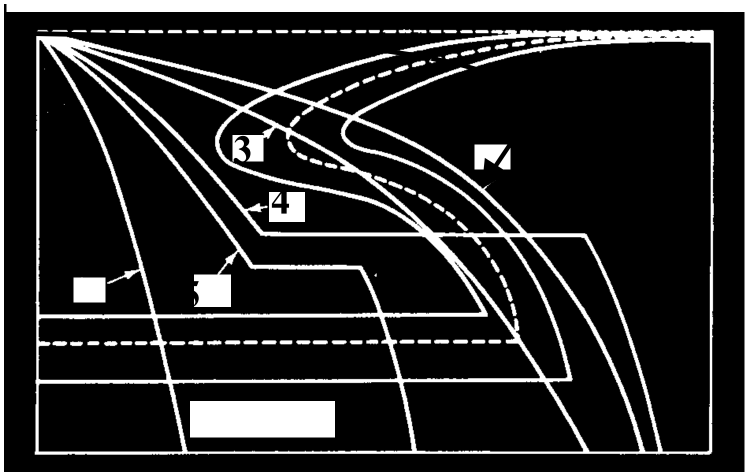
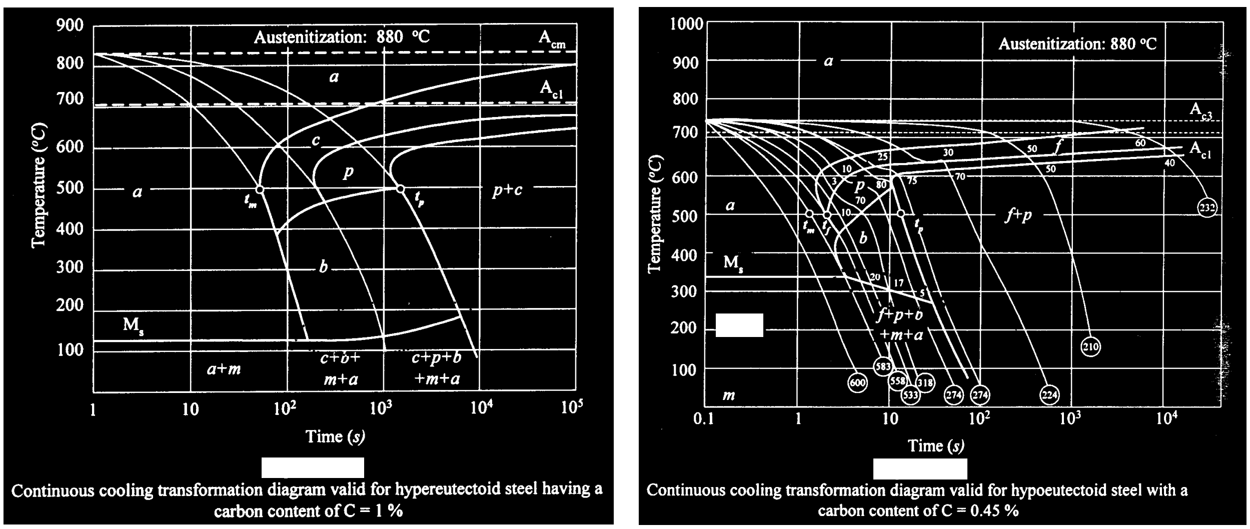


Fig. Q4-1



Continuous cooling transformation diagram valid for hypereutectoid steel having a carbon content of C = 1 %

Continuous cooling transformation diagram valid for hypoeutectoid steel with a carbon content of C = 0.45 %

Fig. Q4-2

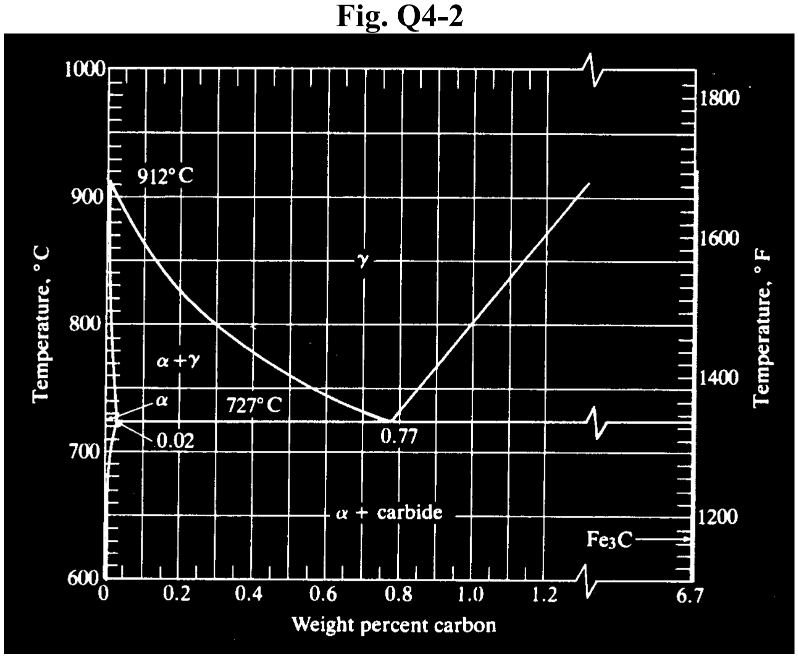
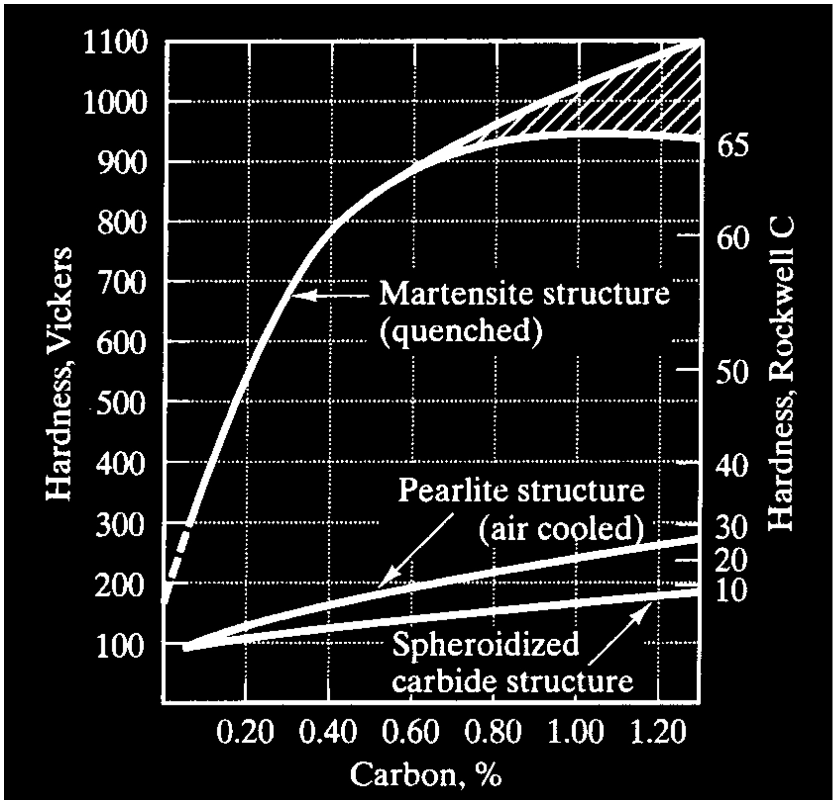
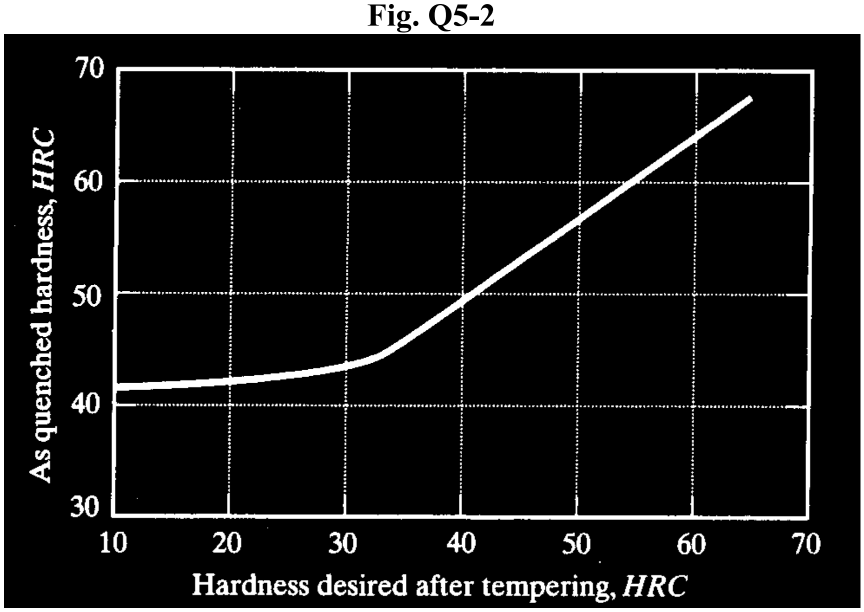


Fig. Q5-1



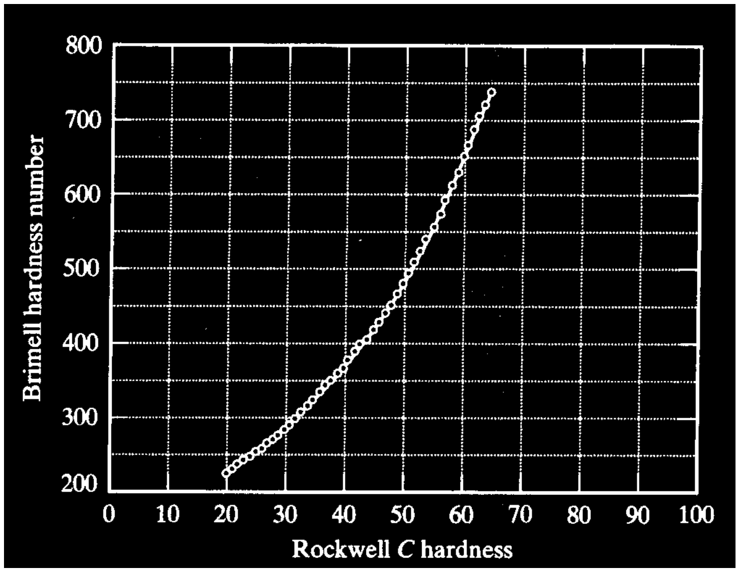
Hardness of ~100% as-quenched martensite, pearlite, and spheroidized microstructures as a function of carbon conetnt

Fig. Q5-2



As-quenched hardness of steel as a function of the desired hardness (in HRC) after tempering.

Fig. Q5-3



Relationship between HRC and BHN for steel.

Fig. Q5-4

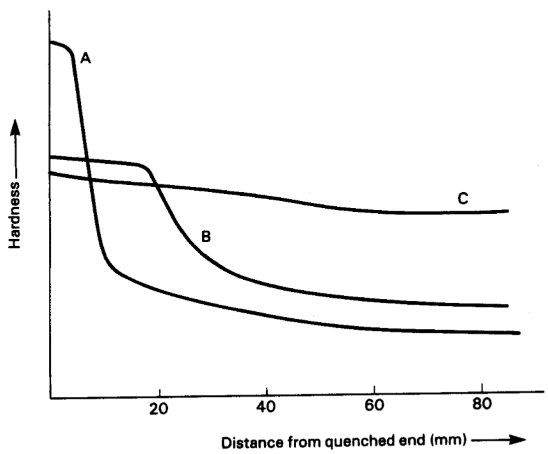


Fig Q7-1

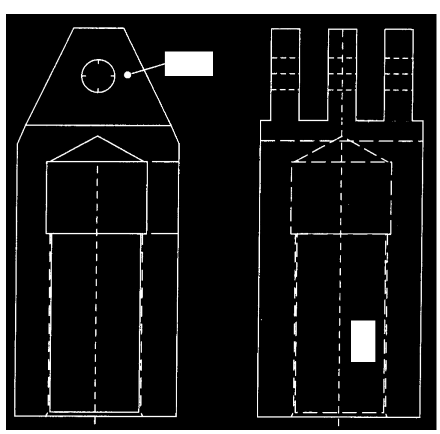


Fig Q7-2

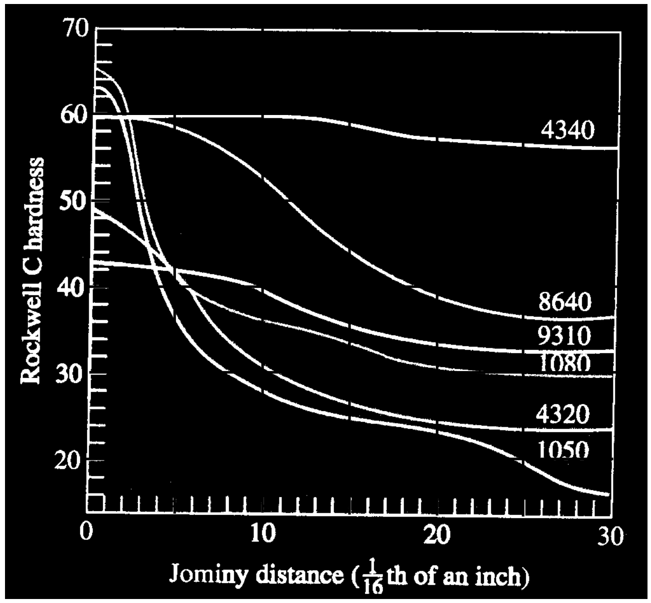


Fig Q7-3

Water Quench

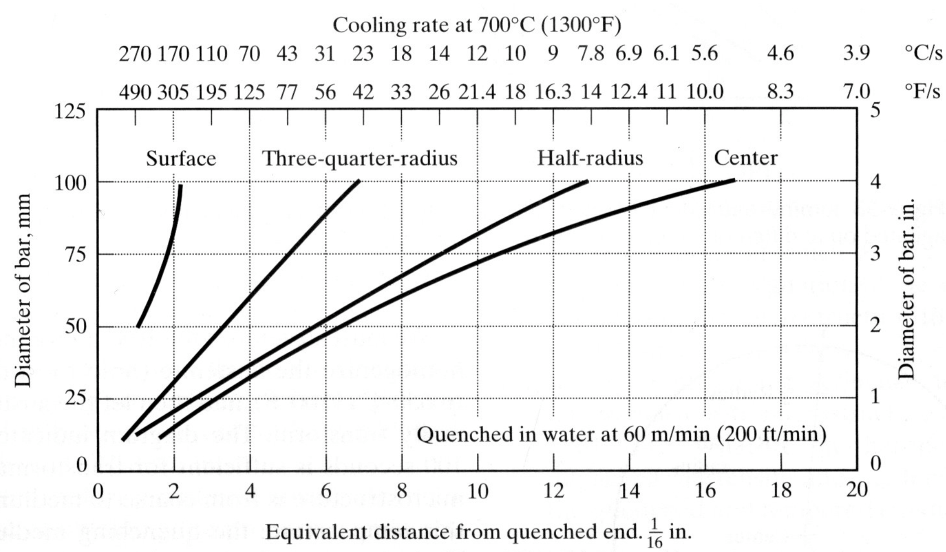


Fig Q7-4