

CME 300 Properties of Materials

Homework 5 October 20, 2011

Callister:

4.5 For both FCC and BCC crystal structures, there are two different types of interstitial sites. In each case, one site is larger than the other, and is normally occupied by impurity atoms. For FCC, this larger one is located at the center of each edge of the unit cell; it is termed an octahedral interstitial site. On the other hand, with BCC the larger site type is found at $0\frac{1}{2}\frac{1}{4}$ positions—that is, lying on $\{100\}$ faces, and situated midway between two unit cell edges on this face and one-quarter of the distance between the other two unit cell edges; it is termed a tetrahedral interstitial site. For both FCC and BCC crystal structures, compute the radius r of an impurity atom that will just fit into one of these sites in terms of the atomic radius R of the host atom.

For FCC $a = 2\sqrt{2} R$ and the site is occupied by $2R + 2R'$ where R' is for the interstitial atom.

$$\text{So } R' = (\sqrt{2}-1)R$$

For BCC $a = 4R/\sqrt{3}$. The interstitial site is in a tetrahedral site meaning that it is centered on 4 equidistant lattice atoms, two of which are the two nearest corner atoms, the center atom and a center atom from another unit cell. A right triangle can be drawn from the corner atom, the interstitial site and the center of one of the edges having sides of $a/2$ and $a/4$ and a hypotenuse of $R + R'$. So, $(R+R')^2 = a^2 (1/4 + 1/16) = R^2 (4 + 1)/3$, using the quadratic formula,

$$R' = (2R \pm \sqrt{(20R^2/3)})/(4R^2/3)$$

9.47 (a) What is the distinction between hypoeutectoid and hypereutectoid steels?

(b) In a hypoeutectoid steel, both eutectoid and proeutectoid ferrite exist. Explain the difference between them. What will be the carbon concentration in each?

a) Hypoeutectoid has pearlite domains encased in ferrite while hypereutectoid has pearlite domains encased in cementite.

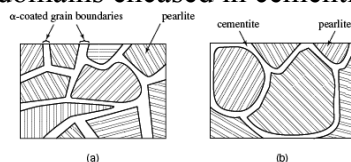
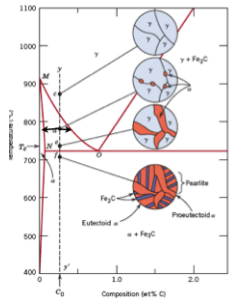


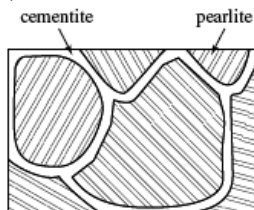
FIGURE 8.3. Schematic representation of (a) a hypoeutectoid microstructure of steel at room temperature containing primary α and pearlite microconstituents (the latter consisting of two phases, i.e., α and Fe_3C); (b) a hypereutectoid microstructure of steel. Note that the primary phases in both cases have "coated" the former grain boundaries of the austenite.

b) The eutectoid ferrite has the eutectoid composition, 2.14 mass percent carbon. This is present in the pearlite lamellar structure. The proeutectoid ferrite has a composition that depends on the position in the phase diagram where the liquidus line was crossed. The tie line to the ferrite phase determines the composition of this ferrite phase.



- 9.50** Consider 3.5 kg of austenite containing 0.95 wt% C, cooled to below 727°C (1341°F).
- What is the proeutectoid phase?
 - How many kilograms each of total ferrite and cementite form?
 - How many kilograms each of pearlite and the proeutectoid phase form?
 - Schematically sketch and label the resulting microstructure.

- Eutectoid composition is 0.77 wt. % carbon so this is a hypereutectoid steel. The proeutectoid phase is the cementite that precipitates at the grain boundaries.
- The austenite first forms a proeutectoid cementite of $(0.95-0.77)/(6.7-0.77) = 0.030$ fraction of the sample (0.11 kg proeutectoid cementite). The remaining 3.39 kg of austenite separates at the eutectoid composition of $(0.77-0.022)/(6.7-0.022) = 0.112$ fraction cementite (0.38 kg) and the remainder ferrite (3.01 kg). So the total cementite is 0.49 kg and ferrite is 3.01 kg.
- 3.39 kg of pearlite forms and 0.11 kg of proeutectoid phase.
- This is similar to the figure in the book,



- 9.54** The mass fractions of total ferrite and total cementite in an iron-carbon alloy are 0.91 and 0.09, respectively. Is this a hypoeutectoid or hypereutectoid alloy? Why?

$0.91 = (x-0.22)/(6.7-0.22)$ so $x = 6.1$ mass % carbon. This is hypoeutectoid.

9.63 For an iron-carbon alloy of composition 3 wt% C-97 wt% Fe, make schematic sketches of the microstructure that would be observed for conditions of very slow cooling at the following temperatures: 1250°C (2280°F), 1145°C (2095°F), and 700°C (1290°F). Label the phases and indicate their compositions (approximate).

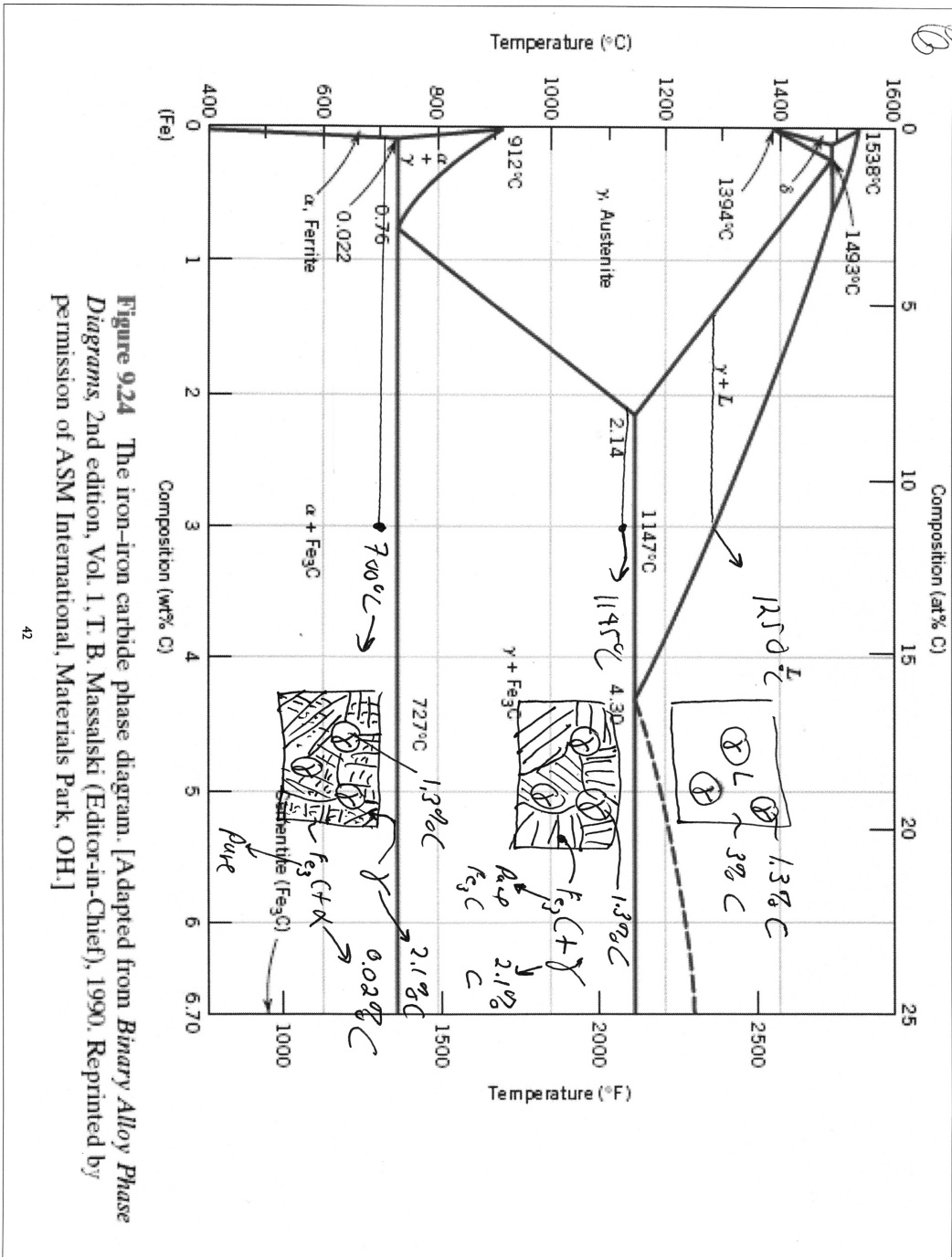


Figure 9.24 The iron-iron carbide phase diagram. [Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

9.66 A steel alloy is known to contain 93.65 wt% Fe, 6.0 wt% Mn, and 0.35 wt% C.

(a) What is the approximate eutectoid temperature of this alloy?

(b) What is the proeutectoid phase when this alloy is cooled to a temperature just below the eutectoid?

(c) Compute the relative amounts of the proeutectoid phase and pearlite. Assume that there are no alterations in the positions of other phase boundaries with the addition of Mn.

a) 690°C from Figure 9.34

b) α -Ferrite at about 0.02 wt. % Carbon

c) $(0.35-0.22)/(0.76-0.35) = 0.80$ fraction pearlite (80%).

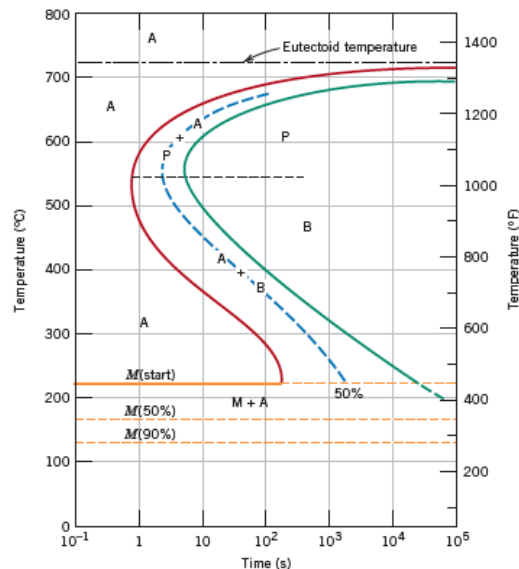
10.16 Briefly cite the differences between pearlite, bainite, and spheroidite relative to microstructure and mechanical properties.

Table 10.2 Summary of Microstructures and Mechanical Properties for Iron–Carbon Alloys

<i>Microconstituent</i>	<i>Phases Present</i>	<i>Arrangement of Phases</i>	<i>Mechanical Properties (Relative)</i>
Spheroidite	α Ferrite + Fe ₃ C	Relatively small Fe ₃ C sphere-like particles in an α -ferrite matrix	Soft and ductile
Coarse pearlite	α Ferrite + Fe ₃ C	Alternating layers of α ferrite and Fe ₃ C that are relatively thick	Harder and stronger than spheroidite, but not as ductile as spheroidite
Fine pearlite	α Ferrite + Fe ₃ C	Alternating layers of α ferrite and Fe ₃ C that are relatively thin	Harder and stronger than coarse pearlite, but not as ductile as coarse pearlite
Bainite	α Ferrite + Fe ₃ C	Very fine and elongated particles of Fe ₃ C in an α -ferrite matrix	Hardness and strength greater than fine pearlite; hardness less than martensite; ductility greater than martensite
Tempered martensite	α Ferrite + Fe ₃ C	Very small Fe ₃ C sphere-like particles in an α -ferrite matrix	Strong; not as hard as martensite, but much more ductile than martensite
Martensite	Body-centered tetragonal, single phase	Needle-shaped grains	Very hard and very brittle

10.18 Using the isothermal transformation diagram for an iron–carbon alloy of eutectoid composition (Figure 10.22), specify the nature of the final microstructure (in terms of microconstituents present and approximate percentages of each) of a small specimen that has been subjected to the following time–temperature treatments. In each case assume that the specimen begins at 760°C (1400°F) and that it has been held at this temperature long enough to have achieved a complete and homogeneous austenitic structure.

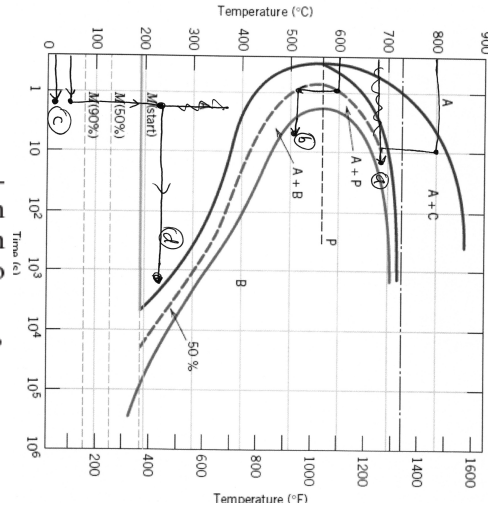
- (a) Cool rapidly to 350°C (660°F), hold for 10^3 s, then quench to room temperature.
- (b) Rapidly cool to 625°C (1160°F), hold for 10 s, then quench to room temperature.
- (c) Rapidly cool to 600°C (1110°F), hold for 4 s, rapidly cool to 450°C (840°F), hold for 10 s, then quench to room temperature.
- (d) Reheat the specimen in part (c) to 700°C (1290°F) for 20 h.
- (e) Rapidly cool to 300°C (570°F), hold for 20 s, then quench to room temperature in water. Reheat to 425°C (800°F) for 10^3 s and slowly cool to room temperature.
- (f) Cool rapidly to 665°C (1230°F), hold for 10^3 s, then quench to room temperature.
- (g) Rapidly cool to 575°C (1065°F), hold for 20 s, rapidly cool to 350°C (660°F), hold for 100 s, then quench to room temperature.
- (h) Rapidly cool to 350°C (660°F), hold for 150 s, then quench to room temperature.



- a) The sample will be 100% bainite which is cementite fibrous crystals in a ferrite matrix. The cementite content is $(0.76)/(6.7-0.76) = 0.113$ or 11.3 wt. %.
- b) The sample will be about 60% pearlite which is $(0.76-0.02)/(6.7-0.02)=0.111$ or 11.1 percent cementite, and 40 wt. % austenite that is 0.76 wt. % carbon.
- c) The first step makes about 15% pearlite in austenite, the second step further separates the remaining austenite phase into 90% bainite. The final sample is 15% pearlite, 76% bainite and 9% austenite.
- d) The remaining austenite will convert to 70% pearlite.
- e) 300°C for 20 seconds is insufficient time for bainite to form. 103 seconds at 400 is sufficient to convert to 100% bainite. Slow cooling to room temperature does not change the morphology.
- f) At 665°C for 10^3 seconds the sample will be 100% pearlite.
- g) The first step produces 100% pearlite, the second step will have no effect.
- h) This will result in 50% bainite.

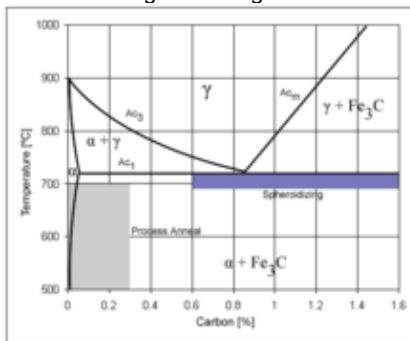
10.22 Make a copy of the isothermal transformation diagram for a 1.13 wt% C iron–carbon alloy (Figure 10.39), and then on this diagram sketch and label time–temperature paths to produce the following microstructures:

- (a) 6.2% proeutectoid cementite and 93.8% coarse pearlite
- (b) 50% fine pearlite and 50% bainite
- (c) 100% martensite
- (d) 100% tempered martensite



- 10.35** (a) Briefly describe the microstructural difference between spheroidite and tempered martensite.
 (b) Explain why tempered martensite is much harder and stronger.

Spheroidite forms when carbon steel is heated to approximately 700 °C for over 30 hours. Spheroidite can form at lower temperatures but the time needed drastically increases, as this is a diffusion-controlled process. The result is a structure of rods or spheres of cementite within primary structure (ferrite or pearlite, depending on which side of the eutectoid you are on). The purpose is to soften higher carbon steels and allow more formability. This is the softest and most ductile form of steel. The image to the right shows where spheroidizing usually occurs. (From Wikipedia)



From Wikipedia

Typically steel is heat treated in a multi-step process. First it is heated to create a [solid solution](#) of iron and carbon in a process called [austenizing](#). Austenizing is followed by [quenching](#) to produce a martensitic microstructure. The steel is then tempered by heating between the ranges of 150–260 °C (302–500 °F) and 370–650 °C (698–1202 °F). Tempering in the range of 260–370 °C (500–698 °F) is sometimes avoided to reduce temper brittling. The steel is held at that temperature until the carbon trapped in the martensite diffuses to produce a chemical composition with the potential to create either bainite or pearlite (a crystal structure formed from a mixture of ferrite and cementite). (From Wikipedia)

- 11.1** (a) List the four classifications of steels. (b) For each, briefly describe the properties and typical applications.

a) Low-carbon, medium-carbon, high-carbon and stainless

b) The majority of steel is low-carbon with less than 0.25 wt. % carbon. Martensite does not form in these steels. They are strengthened by cold working. These are the least expensive and most ductile and workable of steels. Low-carbon steels are used for I-beams, autobody panels, pipes, tin cans. Alloys of low-carbon steels can give higher strength.

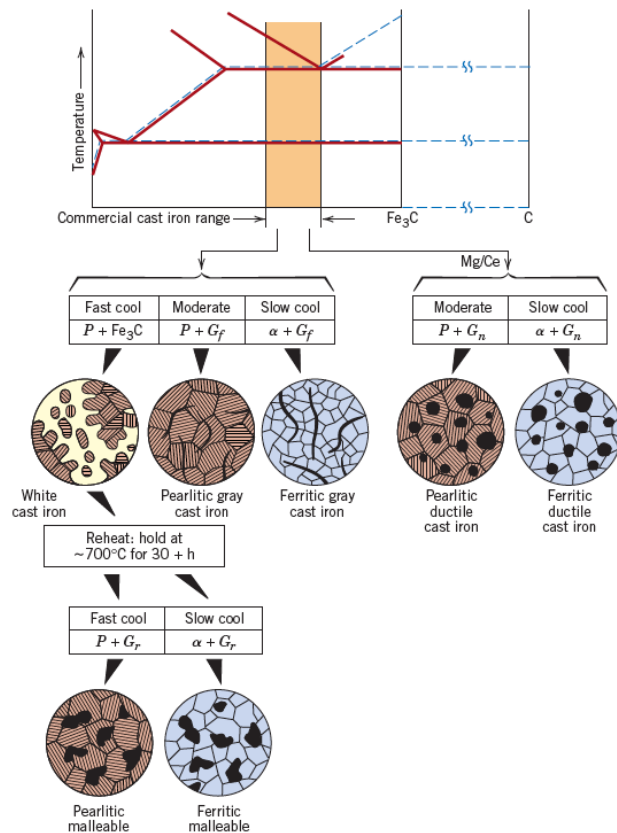
Medium-carbon steels are between 0.25 and 0.6 wt. % carbon. These steels are austenized, quenched to martensite and tempered. Generally used as tempered martensite. Alloys with chromium, molybdenum and nickel can make tempering easier. Less ductile but harder than low-carbon steels. Used for railroad wheels and tracks, gears, machine parts.

High-carbon steels between 0.60 and 1.4 wt. % carbon, are least ductile and hardest carbon steels. Tool and die steels, cutting tools, knives, razors, hacksaw blades, wire. Heat treated by tempering.

Stainless Steels having at least 11% chromium to provide corrosion resistance. Three kinds: Martensitic, Ferritic or Austenitic.

11.6 Compare gray and malleable cast irons with respect to (a) composition and heat treatment, (b) microstructure, and (c) mechanical characteristics.

Grey cast iron is 2.5 to 4 wt. % carbon and 1 to 3 % silicon. Microstructure includes flakes of graphite surrounded by ferrite or pearlite matrix. Grey cast iron is weak and brittle under tension but is strong under compression. Good damping for vibrations, easily cast, low cost.

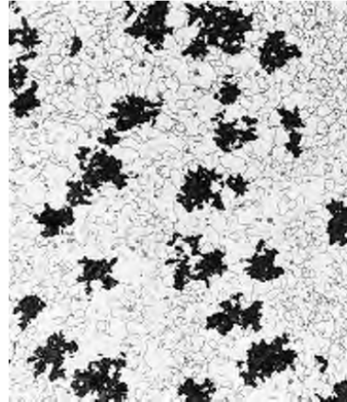


Malleable cast iron has low silicon content, less than 1 %. It is produced from rapidly cooled white cast iron with most of the carbon in a cementite phase. White cast iron is annealed at 800 to 900 °C under inert conditions causing decomposition of cementite to form graphite as rosettes

surrounded by a pearlite or ferrite matrix. It has high strength and ductility. It is used for gears, engine cases, pipe fittings.



Grey



Malleable

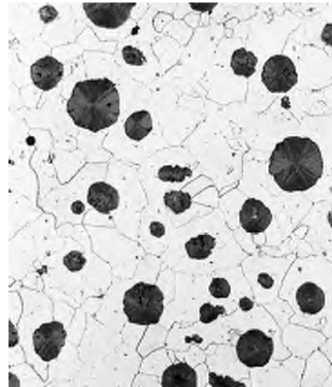
11.7 Compare white and nodular cast irons with respect to (a) composition and heat treatment, (b) microstructure, and (c) mechanical characteristics.

White cast iron is produced from low silicon iron with rapid cooling rates. The carbon exists as cementite. It is extremely hard and brittle. It is used as rollers in rolling mills because it is hard and wear resistant.

Nodular cast iron contains magnesium or cerium and the same composition as grey iron. Graphite forms as nodules rather than flakes. The matrix phase is pearlite or ferrite. Stronger and more ductile than grey iron. Used for valves, pump bodies, gears, automotive parts, machine parts.



White



Nodular

11.10 Why must rivets of a 2017 aluminum alloy be refrigerated before they are used?

This is an age hardening alloy that will harden at room temperature. It precipitation hardens since it contains 4% copper which precipitates out at room temperature. The copper grains serve to trap dislocations in this FCC Al matrix.