


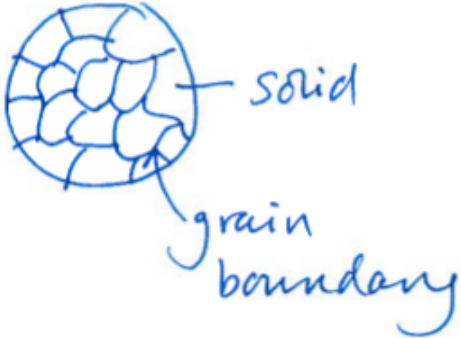
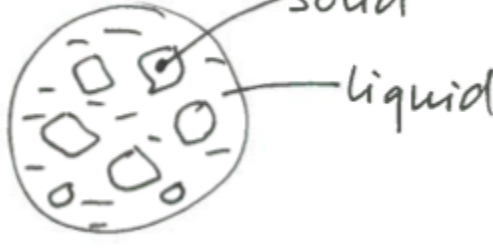
Materials 2 Questions set 5, Comments and answers

Phase diagrams and applications

NB Some of these questions are in the Phase Diagrams interactive activity.

1. Consider the Cu-Ni phase diagram (see appendix)

Make representative annotated sketches of the microstructure of

(i) pure nickel at 1500 °C	
(ii) pure nickel at 1100 °C	
(iii) Cu50-Ni50 at 1300 °C	

2. (a) State the meaning of (i) eutectic and (ii) eutectoid, and label them on an Fe-C phase diagram (see appendix).

(i) eutectic (composition is at 1147 °C and 4.3 wt% C on the Fe-C phase diagram)

The point at which a eutectic reaction occurs, which is: a reaction where upon cooling a liquid phase transforms isothermally and reversibly into two intimately mixed solid phases

(ii) eutectoid, (composition is at 727 °C and 0.76 wt% C on the Fe-C phase diagram)

The point at which a eutectoid reaction occurs, which is: a reaction where upon cooling one solid phase transforms isothermally and reversibly into two intimately mixed solid phases

(b) What are austenite, ferrite, pearlite and cementite?

Austenite is an allotrope of iron, with a face-centre cubic packing structure. It is not thermodynamically stable at room temperature (see section on phase diagrams for more details)

Ferrite (α) is an allotrope of iron, with a body-centre cubic packing structure. It has a low solubility of carbon in solid solution. Carbon is present as random interstitial atoms.

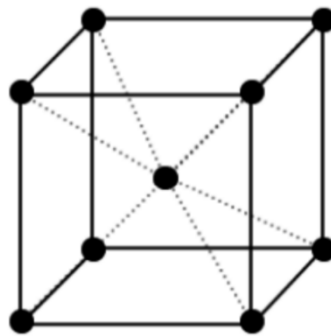


Figure 1 – Body-centre cubic structure

Cementite (Fe_3C) is a compound of iron and carbon. It contains 6.7 wt% carbon and has a complex packing structure.

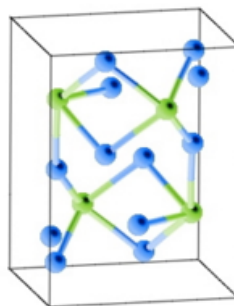


Figure 2 – Cementite structure showing iron atoms in blue and carbon atoms in green [1]

Pearlite is 'the composite eutectoid structure of alternating plates of α and Fe_3C ' [Ref: Ashby, M.F. and D.R.H. Jones, Chapter 12 - Steels 1—Carbon Steels, in Engineering Materials 2 (Fourth Edition), M.F. Ashby and D.R.H. Jones, Editors. 2013, Butterworth-Heinemann: Boston. p. 205-220.]. It is not a phase itself, but a combination of two phases: ferrite and cementite. The pearlite forms in a lamellar (layered) structure of alternating ferrite and cementite. You can see the lamellar structure of the pearlite in this image of the 0.4% C steel micrograph:

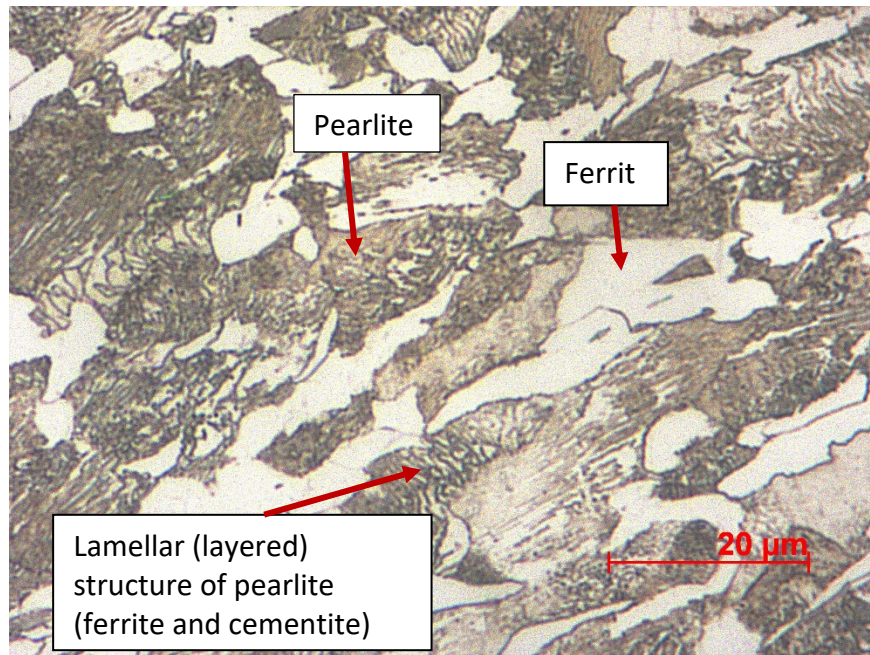


Figure 3 - 0.4% C Annealed steel cross-section showing lamellar structure of pearlite: alternating plates of ferrite and cementite.

3. What is the maximum solubility of carbon in (i) ferrite; (ii) austenite?

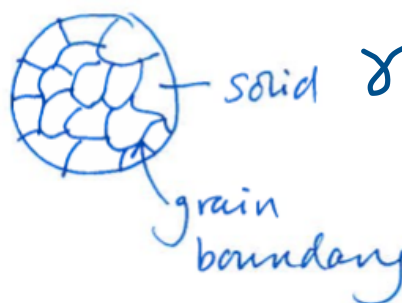
(i) 0.035 wt% C, (ii) 1.7 wt% C

These values are taken from table 11.1 in Engineering Materials 2. However the key concepts within the question are

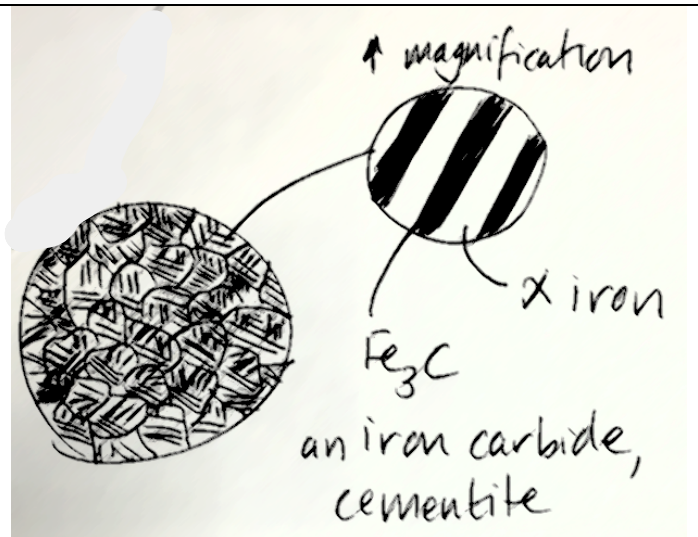
- that the max solubility of C in Fe is MUCH higher in austenite (this behaviour underlies why heat treatment of steels can give such a large variation in mechanical properties)
- that you can read these values off the phase diagram (NB not to such precision with the phase diagram given in EM2, chapt 11; I do not expect you to memorise the precise values; you should know there is a very large variation in max solubility)

4. Consider the Fe-C phase diagram make representative annotated sketches of the microstructure of eutectoid composition steel (i.e. at approximately 0.8wt%C)

(i) above the eutectoid temperature



(ii) below the eutectoid temperature, after slow cooling



5. (i) cast iron composition is typically Fe-2-4 wt% C, and

(ii) steel composition is typically Fe <2 wt% C (some reference sources, state <1.7 wt% C)

(iii) At what temperature and composition is the eutectic in the Fe-C system?

read from phase diagram: 1147 °C and 4.3 wt% C

(iv) Cast irons have higher carbon content than most steels. Why is cast iron easier to cast than low carbon steel?

Because it

- it freezes at a lower temperature

This is extra detail beyond the core content of the course: so less energy is needed to heat the material, and it tends to solidify more controllably because of the lower temperature

- it has a smaller semi-solid range (the semi-solid range is the temperature range between the liquidus and solidus)

extra information similarly, this generally means the solidification process happens in a more controllable and better way – *sometimes alloys can literally tear themselves apart* because a fraction of the material solidifies (but is very weak because there is not much solid material) while the remainder is still liquid – a major factor that contributes to this behaviour is a large semi-solid range.

6. From interactive guide to phase diagrams: “Phase diagrams are useful in understanding why materials, particularly metallic alloys, behave as they do. They are used in processing for example in casting metal alloys, and in heat treatments.”

Discuss instances where phase diagrams have limited applicability.

Phase diagrams apply in equilibrium, that is slow cooling, conditions. If alloys, or parts of alloys (e.g. the surface) are cooled rapidly a transition across a phase boundary in solid state may not occur. The more rapid the cooling the less likely the alloy is to reach equilibrium.

The phase diagrams we have considered are for binary alloys – that is just two components, or two elements. In practice many commercial alloys have more than two components.

- See additional note on Chemical Composition of Structural Steels [reference: MIT Department of Civil and Environmental Engineering, 1999]. [Note: the element they refer to as columbium \(Cb\) is now called niobium \(Nb\).](#)
- The intention of sharing this is to give you an awareness of the complexity of designing the chemistry and physical metallurgy of many engineering alloys; and an indication of what particular elements do in an alloy. In the context of Materials 2, it is useful for you to be aware that this knowledge and understanding exists (but this is **not** shared so that you learn what each element does), and that resources are available for you to find out more.

In both these cases (rapid cooling and more than two elements) phase diagrams can still be useful when used with care, and experience that is developed over time. The details of this are beyond Materials 2 but conceptually having some knowledge and understanding of these limitations is beneficial.

7. Briefly discuss how the mechanical properties, and microstructure, of steel to change with: (i) carbon content, (ii) work hardening of annealed material and (iii) rapid cooling, rather than slow cooling.

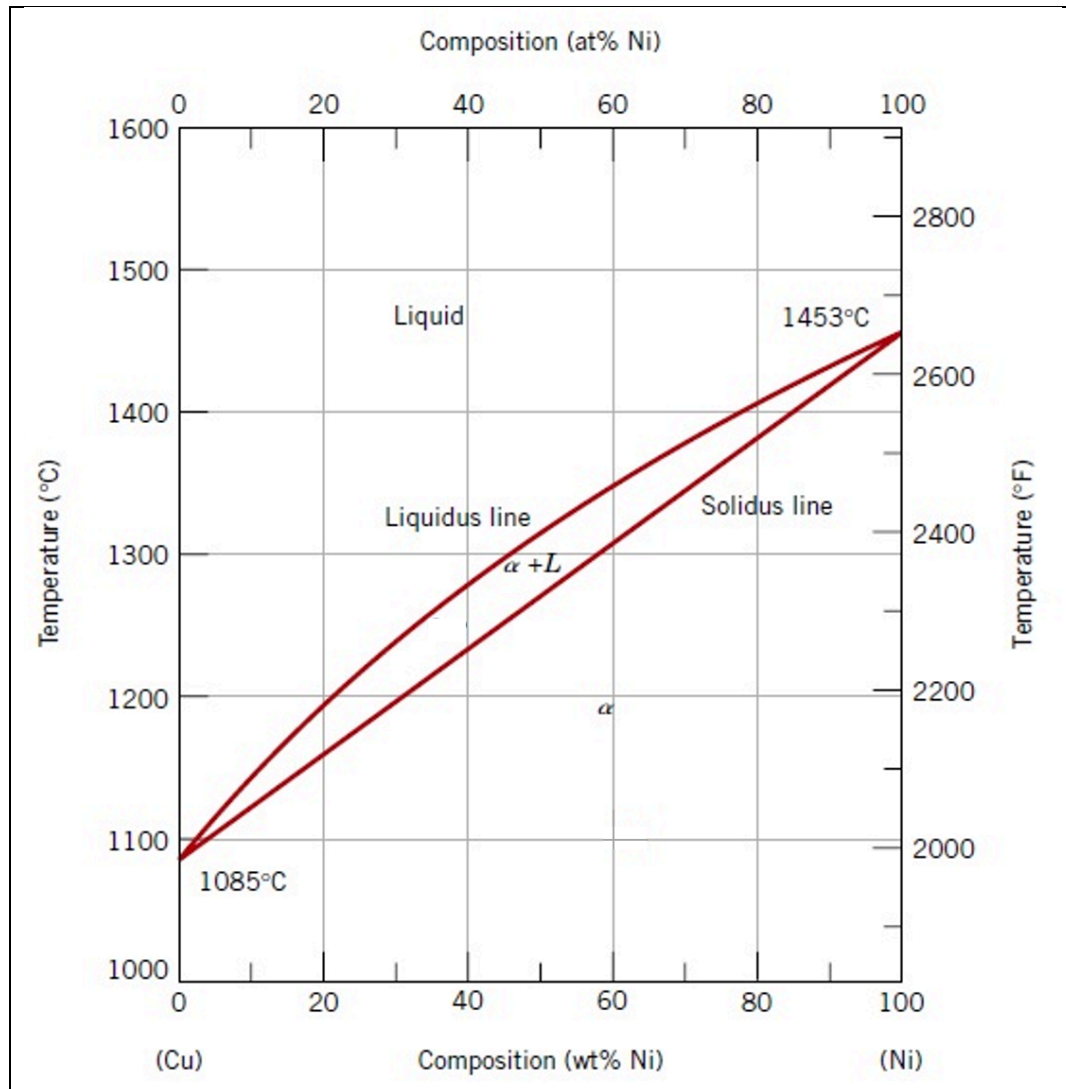
For this question you need to make links between properties and microstructure.

In general, for metallic alloys when we increase strength (yield strength and UTS), and increase hardness, we decrease elongation to failure (a measure of ductility).

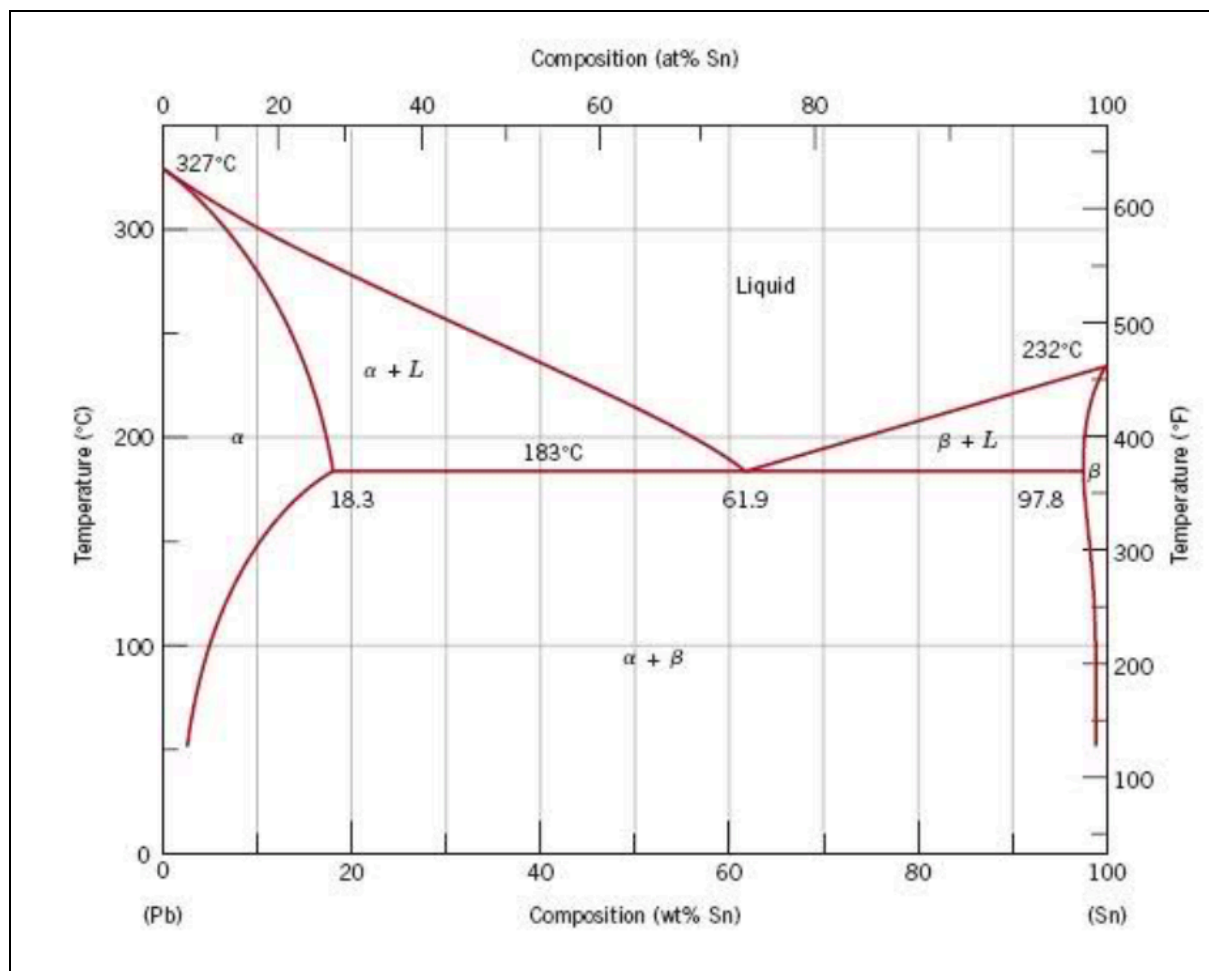
In all three cases above for steels if we increase carbon content, work harden the steel, or cool it rapidly we increase the strength and hardness and decrease the ductility. With a more in depth discussion we can explain these phenomena by relating the changes in microstructure to the changes in properties.

Appendix of phase diagrams: Copper-nickel, lead-tin, iron-carbon

Copper-nickel phase diagram



Lead (Pb) – tin (Sn) phase diagram



Iron-carbon phase diagram

