

We will wrap up this section with two microstructures that should help you reconnect with things seen before. The figure below shows on the left a 4140 low alloy steel (cf. Table 9.2) and on the right a white cast iron.

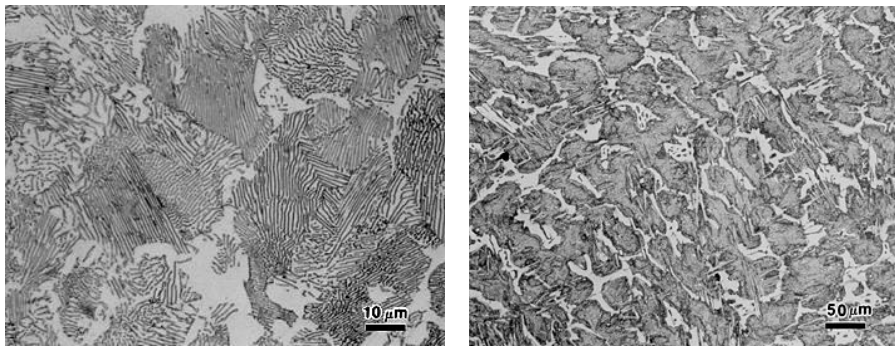


Figure 9.2: Electron micrographs of 4140 low alloy steel and white cast iron.

In the panel on the left, what you see is proeutectoid ferrite surrounded by pearlite, and in the panel on the right cementite (light) and pearlite (dark).

9.1.6 Alloying Elements and Microstructure

In Chapter 8 we examined the Fe-C phase diagram and its phase transformations. Strictly speaking, these arguments apply without modification only to plain carbon steels. Once we add another alloying element, the system becomes ternary. Moreover, many steels of practical interest contain more than one such element. Hence the question is what we can say about the microstructure in these more complex systems. We will not engage in a full discussion of this issue here, but we will examine some hints as to how what you know already can be adapted to more complex alloyed materials.

First, the main effects of some of the most common alloying elements can be summarized very briefly as follows:

Chromium

Chromium is the main element used for improving corrosion resistance.

Nickel

Nickel enlarges the temperature range in which austenite (γ -Fe) is stable.

Molybdenum

Molybdenum improves corrosion resistance; increases strength at high T.

Manganese

Manganese promotes the stability of austenite.

Silicon

Silicon improves strength and acts as deoxidizing agent binding oxygen.

In the simplest case, we need to consider two alloying elements at the same time. For example, if these were C and Cr, what we would have to do is fill in the three-dimensional phase diagram in Fig. 9.3 as follows:

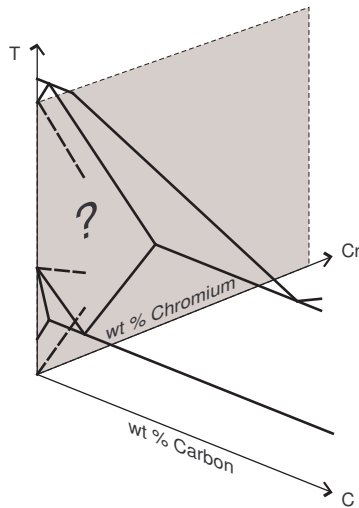


Figure 9.3:
Combined phase diagrams of Fe-C (in front) and Fe-Cr (in gray plane in back). The ternary system would include the entire region between the two two-component phase diagrams.

Think of Fig. 9.3 as combining the Fe-C and the yet unknown Fe-Cr phase diagrams with a common temperature axis. The ternary diagram would then include points in-between the two 2D coordinate systems $T(C)$ and $T(Cr)$. We will outline below how to fill in a few small parts of this puzzle.

The most critical feature of the Fe-C phase diagram is the eutectoid line. Thus, we will focus first on the effect of alloying on the eutectoid temperature. Fig. 9.4 shows that this effect depends on the alloying element. Cr and Si increase the eutectoid temperature, and Ni and Mn decrease it.

We can also ask what the effect of alloying will be on the carbon composition at the eutectoid point. You recall that in the Fe-C system the eutectoid point occurs at 0.76 wt % C. We do not need a quantitative answer here. Simply put: All alloying elements tend to reduce the carbon composition at the eutectoid point.

For our further discussion we will keep in mind primarily stainless steels, i.e. the alloying elements Cr and Ni, but we will also mention others. From the verbal descriptions above and the curves in Fig. 9.4, we may conclude that the alloying elements with a tendency to stabilize austenite are also the ones which lower the eutectoid temperature.

Partial binary phase diagrams for Fe-Cr and Fe-Ni are shown in Fig. 9.5. In comparison to the Fe-C diagram (Fig. 8.18), you realize that the T-axis (i.e. pure Fe) is identical in all three cases. In particular, on the T-axis the γ -phase exists between 912 and 1394 °C. But how the diagram extends to small amounts of the alloying element differs greatly between C, Cr, and Ni.

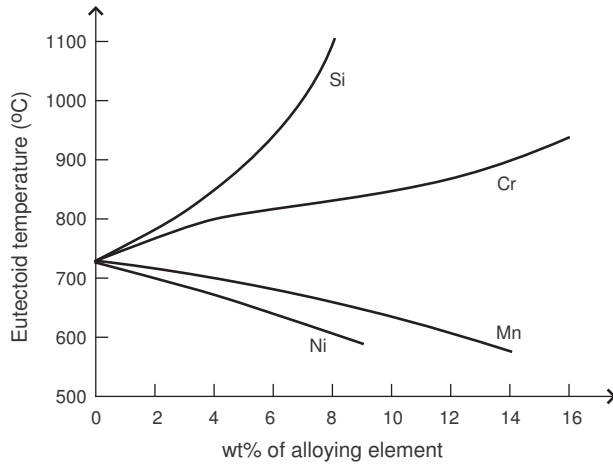


Figure 9.4: Effect of alloying on the eutectoid temperature in the Fe-C phase diagram

For small amounts of Ni, the Fe-Ni diagram looks similar to Fe-C: You can see a γ - and an α -region, depending on the temperature. At larger Ni content and low temperatures there is a region where α - and γ -phases can coexist, adjoining a γ -region at even larger Cr content. Of course, α - and γ -phases mean the same as for Fe-C, namely BCC and FCC structure. Most noteworthy is the fact that *for about 18 wt % of Ni or more, the γ -phase (austenite) is stable at room temperature!* So Ni greatly extends the phase region for austenite.

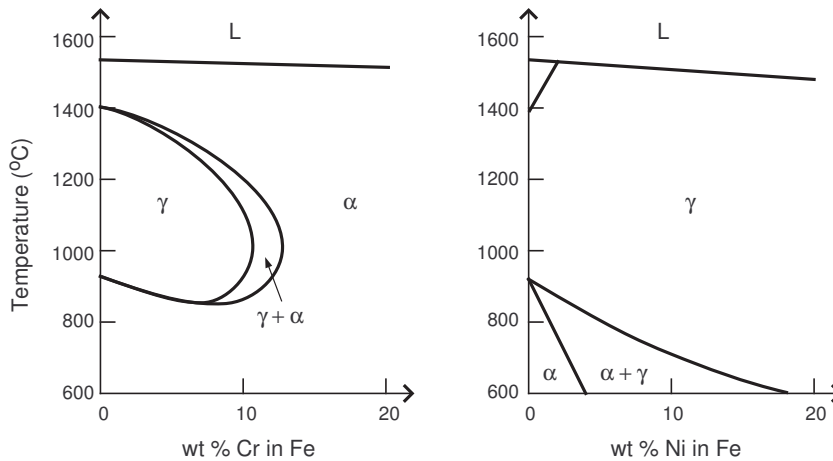


Figure 9.5: Binary Fe-Cr and Fe-Ni phase diagrams.

The Fe-Cr diagram also looks somewhat similar to Fe-C for small amounts of Cr. But the γ -region is now much more limited, and *for about 12 wt % of Cr or more, no γ -phase exists at any temperature!* In this case one say that Cr promotes the occurrence of ferrite.

But what about Cr and Ni together, and possibly combined with other alloying elements? It has been found that the effect of all these elements can be taken into account at least qualitatively based upon whether they tend to promote ferrite as does Cr, or austenite as does Ni. Two parameters named Cr_{eq} and Ni_{eq} have been defined as follows:

$$Cr_{eq} = Cr + Mo + 1.5 Si + 0.5 Nb \quad (9.1)$$

$$Ni_{eq} = Ni + 30 C + 0.5 Mn \quad (9.2)$$

In equations 9.1 and 9.2 the elements are understood to represent alloy content in wt %. With these two parameters in mind, it is possible to use a qualitative plot called Schaeffler diagram (Fig. 9.6) to determine what phases are present at room temperature depending on the composition of the steel.

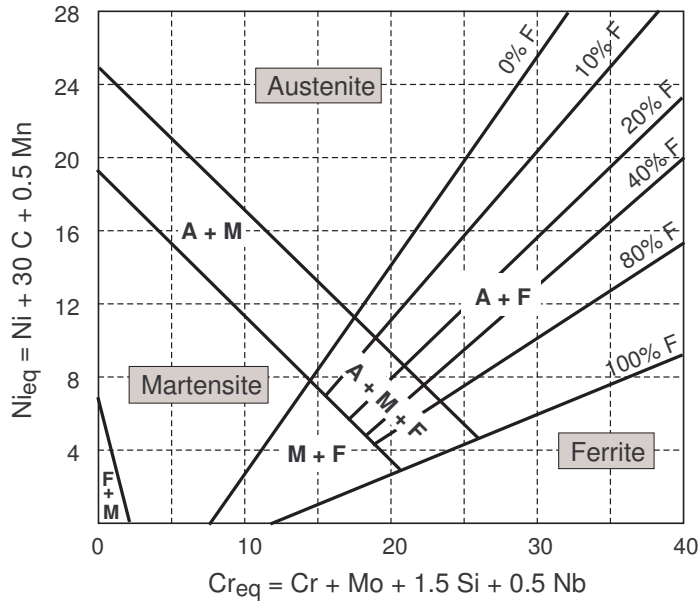


Figure 9.6: Schaeffler diagram indicating what phases are present in a multi-component Fe alloy.