Phase Diagrams and Solidification: A Brief Primer

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1 Introduction

Understanding phase diagrams is of critical importance when studying steel specifically, largely due to the vastly different mechanical properties of the different compositions of steel. In this primer, we will cover: what phase diagrams show, some key points on a binary phase diagram and the solidification process.

2 A refresher on single phase diagrams

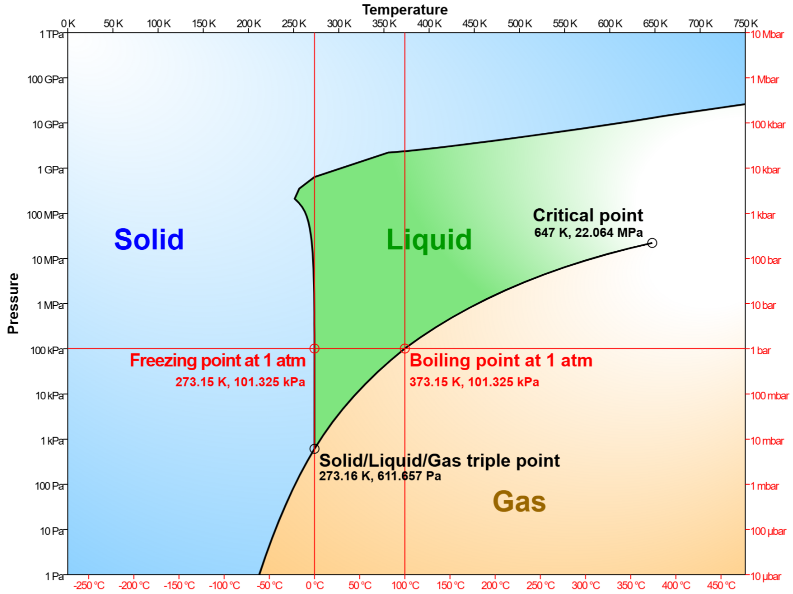

Figure 1: An example single phase diagram (water)

A single phase diagram simply shows what phase of matter a given compound will be in at a given temperature and pressure. The red horizontal line in this case shows atmospheric pressure, and gives the boiling and melting points of 373.15 and 273.15 Kelvin respectively. This is extremely simple, but of course, only covers one compound - mixtures of compounds complicate the problem, as if they have different melting temperatures and pressures, one can exist as a liquid and one can be a metal.

3 Binary Phase Diagrams

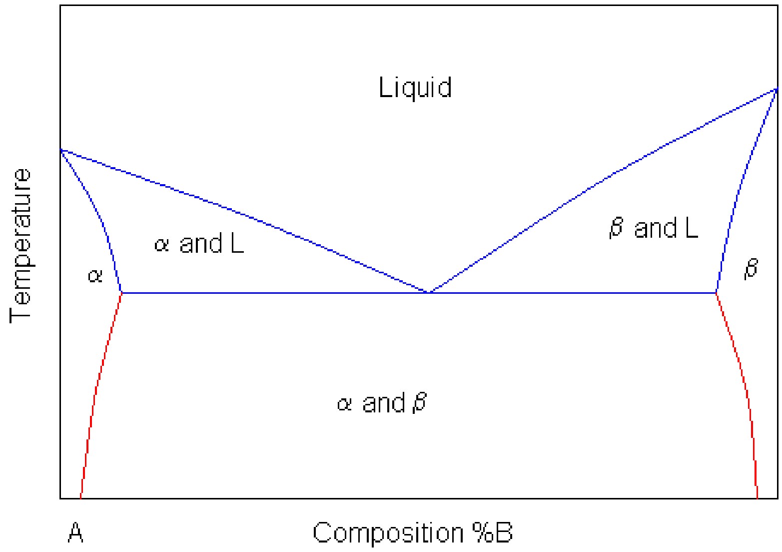

Figure 2: An example binary phase diagram

This example shows a typical phase diagram - with α representing the first compound and β representing the second. L represents a liquid in this case - so the L region is a liquid mixture of both compounds. $\alpha + L$ and $\beta + L$ represent a solution. $\alpha + \beta$ is a solid region, and they will both organise into some microstructure (layers or regions of a particular compound). The α and β regions represent solid regions of that compound - this is intuitive if there is no other compound present, but in the case that there is some other compound, the predominant compound can achieve a lower energy by 'forcing out' the second compound, hence the solid regions of one compound.

This plot is also an example of a eutectic system:

Definition 1. *A eutectic system is a mixture of substances (in fixed proportions) that melts and freezes at a single temperature that is lower than the melting points of the separate constituents or of any other mixture of them.*

In short, a eutectic system is one in which there exists a composition where the whole mixture transforms from liquid to solid at the same time, rather than one part solidifying first. This composition and temperature are called the eutectic composition and temperature respectively, with the point that they intersect being the eutectic point.

Now certain mixes of compounds may in fact have multiple forms, depending on the temperature - with the important one in this case being steel.

4 Steel

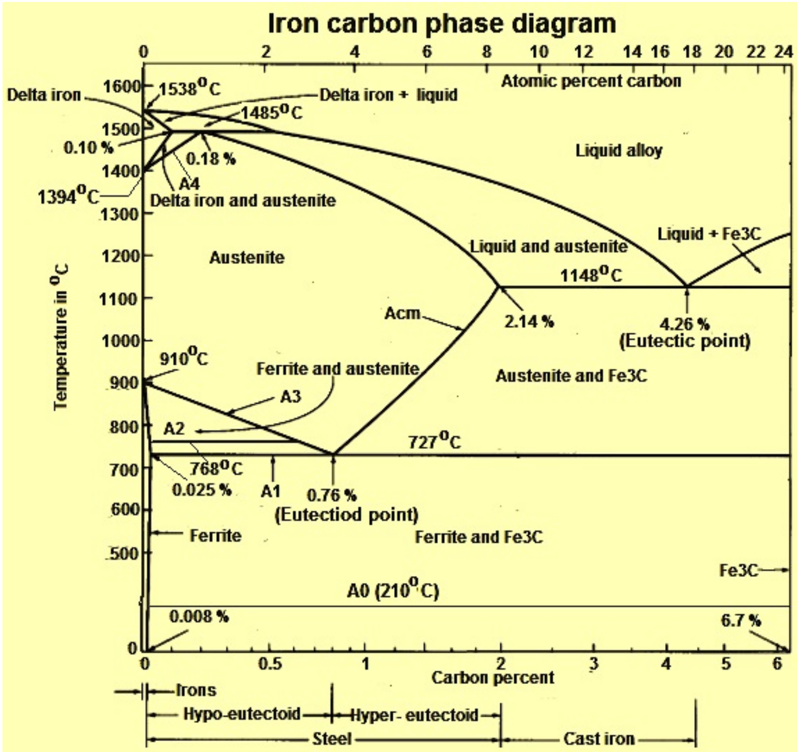

Figure 3: An steel phase diagram (a mix of Fe and C)

This diagram looks a bit more complicated, but this is due to steel having a few possible structures, which form depending on as it is cooled - however the basic format is the same. In Figure 3, we can see the eutectic point on the right hand side, but we can also see another point - the **eutectoid point**[1]. While this has a similar name, it represents a different process. If you look at the region directly above the eutectoid point, it is labelled as **austenite**, which is solid. Thus, by cooling through the eutectoid point, we generate a combination of ferrite and Fe_3C - two solids. This is the definition of a eutectoid reaction:

Definition 2. *The eutectoid reaction is a solid-state transformation where a high-temperature γ phase decomposes into two distinct phases, α and β, typically exhibiting a lamellar morphology, as part of the microstructural evolution in engineering steels.*

[1]this diagram has a typo - the correct spelling is eutectoid.

5 Solidification

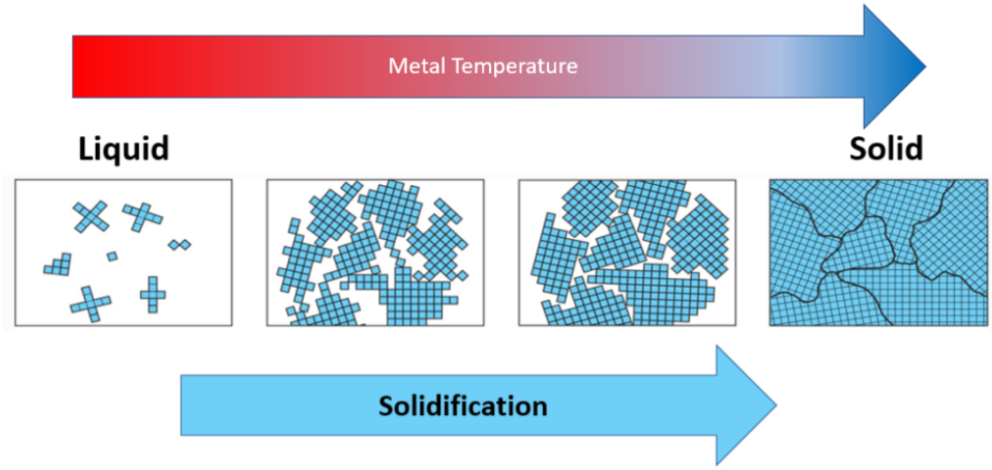

Figure 4: A diagram showing the solidification process in metals

Solid metals contain grains of atoms which are oriented together, which is as a result of the cooling process. Essentially, at the start of cooling, nucleation occurs at random (the formation of tiny solid grains), which then grow as the cooling progresses. As these grains all formed separately, the lattices are oriented in random directions, and as such, once they grow to a point where the grains are interacting, it is not energetically favourable for them to 'snap together', meaning they stay as individual grains. This is fundamentally why different forms of steel can form - depending on how the liquid steel is cooled, the grains can form a variety of structures. We will discuss more on this point in the lectures and practicals.

6 Key Points

- **Eutectic point** - if liquid steel is cooled through this point, it transforms directly into a solid *without* forming a solution first.
- **Eutectoid point** - if a solid metal is called through this point, it forms two distinct solids.
- Metals can form different structures as a result of **grain formation** during the solidification process.