9.2 Low Alloy Steels

9.2.1 A Closer Look at Low Alloy Steels

How to Make Low Alloy Steel

"**Low Alloy" Steels** are all iron alloys where the concentration of each alloying element is low, say below 1 % or on occasion 2 %. Some formal definitions demand less that 3.5 % of alloying elements *in total* but that is an arbitrary number.
This means that all **ancient steels** where low alloy steels - as long as you don't count the elements contained in the slag inclusions.

- Don't let yourself get confused by names like "micro-alloyed steel". This kind of steel and just about everything else are just a subgroups of low or high alloy steel. At this point it is sufficient to distinguish between

  - *Low alloy steel* - see above
  - *High alloy steel*. Obviously steel with alloy element concentrations far larger than 1 % (above 3.5 % in total if you are a formalist).
  - *Wrought iron*. The special "low-alloy steel" case of having rather pure iron with just a little bit of carbon and possibly phosphorous right from the smelting process.
  - *Cast-iron*. The special "high alloy" case of iron with about 4 % carbon (and all kinds of other stuff).

- The next distinction I like to make for low alloy steels is:

  - The major alloying element is *carbon*. It "works" well if the goal is to increasing hardness cheaply, because it enables the formation of cementite, pearlite, martensite and bainite.
  - The major alloying element is *phosphorous* (P). That is *only* valid for ancient steels but then it is important. I will deal with "**phosphorous steel**" in more detail shortly.
  - The major alloying element is neither carbon nor phosphorous but *other stuff*. Whatever carbon is still in there might not be used for producing cementite and so on but for making carbides with the alloying elements. That essentially covers modern "high-performance" steels.

Since this chapter is about *real* steel and not "paper" or laboratory steel, we need to look into how steel making techniques relate to alloying. It is clear by now that our forebears could neither produce *extremely* pure iron as starting material (wrought iron is not *extremely* pure) nor could they do conscious alloying. But how about modern steelmakers? Real steel is mostly modern steel, and the first question to address is how *modern* steel making interfaces with alloying. I'm going into steel making in the next chapter but a few things in the context of alloying are important now .

- As stated before, the advent of the blast furnace, very roughly around 1500, completely changed the process of steel making. Before that your iron / steel was never liquid (except high-carbon crucible steel) and you either lived with whatever elements happened to be in your steel naturally, or you put the alloying element (pretty much always carbon) *into* your (wrought) iron after you made it. After - roughly - 1500, steel making consisted of making **pig iron**", the dirty high-carbon stuff we would classify as cast-iron, and now you needed to take unwanted elements (including too much carbon) *out* of the stuff.
  Nowadays, as for the last 150 years, pig iron is cleaned by blasting air (or oxygen) through it while it is still liquid. That works quite well but has the drawback that your clean liquid iron now contains substantial amounts of dissolved oxygen. That is not so good for further processing because the oxygen wants out, and the whole thing fizzles. Imagine casting a sword blade with champagne (or beer if costs matter) after you shook it vigorously, then pouring it into a very cold mold. If you rather drink the stuff, just look at water ice that formed out there in the winter: it's full of pores or bubbles containing the air dissolved in the liquid that can't stay dissolved in the solid. Now imagine casting at 1500 ^oC (2732 ^oF) from a huge barrel full of the fizzy stuff. You don't want to do that. You want someone else to do that while you are far away.
- It just won't work. You need to "**kill**" your iron or steel first. That unfriendly action simply means to take out the oxygen by reacting it with strong oxide formers or oxidizers like silicon (Si), aluminum (Al) or even calcium (Ca). The silicon oxide (SiO_2, also known as quartz) or aluminum oxide (Al_2O_3 , also known as sapphire or ruby if it contains the right dirt) that is formed in this process floats on top of the liquid iron and can be ladled off.
  By the way, in Germany we do not kill our steel, we do a "Beruhigung" (calming down, pacification). I resist the temptation to veer off into a little essay about language and culture at this point.
  The problem, of course, is that after you produce your "silicon-killed steel" or "aluminum-killed steel", you now have some left-over silicon or aluminum in your killed steel. You have also some left-over dirt in small but possibly noticeable concentrations and, of course, plenty of (hopefully) harmless trace elements.
  You do not, however, have a lot of solid stuff swimming in the liquid that later would form major inclusions. Whatever is still solid will typically swim as "dross" on the surface or rests on the bottom if it is really "heavy", and can be taken out. That is a huge advantage!

After you have killed your steel, serious alloying can commence. Knowing the weight of your **heat of steel**, as we call a (huge!) bucket full of the liquid stuff, you now throw in the proper amount of your alloying elements. For example, if you go for 0.001 % of boron (B) in your 5 tons of steel, you need to pitch in 50 g of elemental boron, some metal-grey substance that is easy to get. If you want 0.5 % of carbon, you add 25 kg of coke, and so on.

- That seems to be an easy process. It isn't. All kinds of things can happen if you just pitch in your alloying elements indiscriminately. For the case of boron, you probably buy some stuff from some supplier that contains boron, of course, but also all kinds of secret ("proprietary") ingredients. This link gives an impression about this.
  For all the other stuff that goes into the brew, you better make sure how it is best done, too.
  If you enjoyed (or suffered) a decent education, something from Shakespeare might now come to mind.

When you're finally done with concocting the brew, solidification and thus processing starts. Temperature profiling is the thing to do in order to get the microstructure you want. Easy in principle, not so easy if you make steel by the ton on an hourly base. Nevertheless:

In essence, we understand how modern steel alloying is done.

Basic Carbon Steels

It's time to ask a simple question (again): Considering that I can make rather clean (killed) iron, why should I now add carbon? I can get all kinds of hardening mechanisms from other elements. Maybe it is better to use something else and to make what I will call a "**designer steel**"?

- Good thinking. That is actually the trend for modern steels. Nevertheless I'll stick with carbon steels for a little longer. For less demanding applications relatively simple carbon steels might just be more economical than fancy alloy steels without carbon. Not better, mind you, but cheaper.

So even today a lot of carbon steel is made. In fact, most of the steel made today, around 90 % or so (or roughly more than a billion tons a year), is carbon steel despite all the fancy "High-Tech" kinds of steel you find in the link. Their strength and **hardenability**, though less than that of many alloy steels, is still adequate for many applications. Process refinements made it possible to improve properties of carbon steels other than hardness, too. Fine tuning by adding a little of this and that allows to make many different kinds of carbon steels, matched to some particular needs. It goes without saying that all of this is still rather cheap. I also goes without saying that all these steels are either silicon (Si) or aluminum (Al) killed. So they always contain a little of the killing element. Of course some intentional manganese (Mn; around 1 %) as standard alloying element is always in there too, to keep the remaining sulfur (S) in check (and for other friendly objectives).

- We might distinguish four major groups:

  1. **Mild and low carbon steel** with 0.05 % - 0.25% carbon content
  2. **Medium carbon steel** with 0.25 % - 0.6% carbon content.
  3. **High carbon steel** with 0.6 % –1 % carbon content.
  4. **Ultra-high carbon steel** (UHCS) with 1 % - 2 % carbon content.

The first group, *low carbon steels*, are the simple and easy-to-work with everyday steels. They are not very hard and thus easily "drawn", e.g. into wires from which nails are made. A bit of hardening is possible but martensite formation usually does not take place.

- What is often called "**mild steel**" is found at the upper end of the concentration range, i.e. around 0,15 % - 0.25 % carbon. It is the most common form of steel, rather cheap, and provides for material properties that are acceptable for many applications. If needed, the surface region can be hardened somewhat by carburizing.

The second group, *medium carbon steel*, includes the typical "**tempered steels**" of the 19th century. From it the best sword blades were made for some time, superior to everything from the past, including wootz swords, Japanese katanas, or pattern-welded composite blades.

- Medium carbon steel is still used for products like crankshafts, couplings, tie rods or generally machinery parts that need to be mass produced and "strong".

The third group, *high carbon steels*, provides for rather hard and brittle steels, difficult to work with. They are also more costly to fabricate, because of decreased machinability, poor formability and poor weldability. **Machinability** is a measure for how easy it is to drill a hole into it or, more to the point, to work the material on a ***lathe***.

- These steels are good for springs where fatigue resistance is important (if you have a spring in your machine something is meant to vibrate) or parts where abrasion is of concern, e.g. plough shares and scythes or the modern equivalent thereof, not to mention wrenches, hammers, mauls, pliers, screw drivers and cutting tools, such as hatchets, and axes. They also make high-strength wires for you piano or wire saw.
  A modern spring steel might give you a sword blade far superior to anything made in the old times and in the 19th century.

- The fourth group, *ultra-high carbon steel* is of interest to us because ancient **wootz steel** belongs into that category.
  - These steels are difficult to work with but can be tempered to great hardness. They are used for special purposes like axles or punches. Most steels with more than 1.2% carbon content are made by using powder metallurgy. Above 2.0 %C the world of cast-iron begin.
  - Here are some major modules concerning steels and alloying:

Illustr. Module **Properties**	Science Module **Alloying science**	Illustr. Module **Alloy elem. Overview**	Advanced Module **Alloying elements**	Module Hub **Major Steels**