Overview of Major Steels

1. Classifying Steels

Advanced

The logical way in **categorizing** major steels would be to follow some system. Of course there are steel-categorizing systems and as it turns out, there are at least *two* basic ways to do this:

1. By **composition** (and microstructure).
2. By **properties**.

In either case you want to come up with a short string of symbols, e.g. S355J2+N or St 52-3 N (same thing, by the way) that, if you are familiar with the code, gives you the major parameters of the steel in question. The American SAE standard goes mostly for the first option, the European Norm for the second. There is a lot of compromising though, because rigidly sticking to one basic system just will not get you there.

It comes as a a great relief that you, like me, do not care for strict and highly formalized codes. I'm sure about this because sticklers to formalized details would never have made it that deeply into this Hyperscript. Or else they would still be pondering this link. Thus I will not categorize steel in some *formal* way but go through some major points my way. Since I'm not a steel expert, I must rely on what's around in the literature. I will also emphasize on steels that illustrate some point I find interesting, and not so much on actually making and using steels.

Classification according to time	
Name	**Description / Properties**
Old Steels	The trial-and-error-type. Nobody had the faintest halfway correct idea of what makes a steel in terms of composition, microstructure, and so on. This includes all steels from the very first ones around 1500 BC to - roughly - 1775 AD. I picked 1775 because it was around then that it finally became clear that carbon was an element and that a small amount of the stuff mixed with iron produced steel. We can take that as the beginning of:
Engineering steel	Steel making still involved following working recipes but reasoning about cause and effect was there now, triggering experiments based on some (often wrong) forethought. This culminated in the various methods (Bessemer, Siemens-Martin, ...) for mass-producing steel. This period lasted until about 1900, when we move into:
Proto-science steel	As a starting date we can take the year 1897 when **Roberts-Austen** published the first iron-carbon phase diagram in preliminary form. The next decisive period in time centers around 1930 (metals = crystal; plastic deformation by dislocations) and 1960 (Electron microscope and advanced analytics). A lot of steel related things were understood in principle but steel making still relied on science-based general rules, experience plus trial and error
Science steel	This period started around 1980, when computing power became large enough for *calculating* some properties of newly conceived alloys and using the results for optimizing a steel *before* first samples were made and tested. The impact of this period is becoming noticeable since about 2000.

Now let's look at the three major alloy groups of the backbone again. The emphasize now is on the concentration of major **alloying elements**, *not counting the carbon and the ubiquitous manganese, silicon, aluminum etc.*, needed for the usual reasons (taking care of sulfur, "killing" the steel, ..). This allows a general and often used classification:

Classification according to alloying element concentration	
Name	**Description / Properties**
"Micro" Alloy steels	Always with a *very low carbon* content. That ensures formability and weldability. Strength comes from small concentrations (usually less than 0.10 %) of *carbide-forming* alloying elements like niobium (Nb). titanium (Ti) or vanadium (V) with a total alloy element concentration that is less than **0.15 %**. I put the "micro" in quotation marks because it doesn't mean 10^{-6} but just "little". Major commercial steels of this group go under the generic name: *High-strength low-alloy steel* (***HSLA***).
Low Alloy Steels	The "normal" everyday steels, covered to some extent in the backbone. We only add less than about **3.5 %** of the major alloying element(s) and keep the carbon concentration mostly (but not always) in the hypoeutectoid range.
High Alloy Steels	We add a lot more than **3.5 %**, possibly as much as **20** weight **%**, of alloying elements like nickel (Ni) and chromium (Cr). The (low) carbon concentration then may not be important.

If we only look at ("low alloy") **carbon steels** , the sub-groups to distinguish are:

Classification according to carbon concentration	
Name	**Description / Properties**
Mild and low carbon steel	0.05 % - 0.25% carbon content Simple, easy-to-work with everyday steels. "**Mild steel**" at the upper end of the concentration range is the most common form of steel. It is rather cheap and good enough for many applications.
Medium carbon steel	0.25 % - 0.6% carbon content. The typical "**tempered steels**" of the 19th century. The best steels up to beginning of the 20th century are found in this group. Good hardenability; extensively used for machinery parts that need to be mass produced and "strong", as well as for 19th century swords.
High carbon steel	0.6 % –1 % carbon content. Hard and brittle steels, difficult to work with, decreased machinability, poor formability and poor weldability. Good for springs or when abrasion is of concern, e.g. plough shares, scythes, wrenches, hammers, mauls, pliers, screw drivers and cutting tools. They also make high-strength wires for your piano or wire saw.
Ultra-high carbon steel	1 % - 2 % carbon content. These steels can be tempered to great hardness. They are used for special purposes like axles or punches. **Wootz steel** also falls into this category.

Most of the Hyperscript up to chapter 8 was about plain carbon steel, including various hardening mechanisms. *Knowing* about things like phase diagrams, ferrite, austenite, pearlite, martensite, driving forces, transformation temperatures and so on, allowed to produce amazingly good "plain carbon" steel in modern times.
Not knowing about all of that nevertheless allowed some artists to produce amazingly good and beautiful steel swords in ancient times. So why would we want to alloy steel with *other* elements if carbon already does the trick?

- Because hardness is not everything. And because we want to be in control. In more ancient times you, the black smith, didn't like it all that much that you weren't in control but rather some typically irresponsible and finicky God. You had to make expensive sacrifices to keep your iron / steel in good order. You might have hated doing that (the oxen, lambs, goats, chicken and so on also hated this) because it often didn't work, but it was your only option.
  Your boss wasn't in control either. He was dependent on you, his master smith, for forging that special sword. He also needed you to pass on your craft to apprentices in good time since he himself didn't have the faintest idea about how it was done, and it wasn't written down somewhere either. His only degree of freedom concerning sacrifices to proper Gods was that he could sacrifice you if he wasn't too happy with your work.

Being in control means knowing why and how - that's what we call *science*. It works completely without Gods and sacrifices, and it works much better, too. Making it better or cheaper comes after that and is called *engineering*. Since we are human, there is a lot of overlap and confusion between the two. That makes life richer and more fun.

Let's look at some reasons for making "**alloy steel**", as we call all steels with intentionally added elements not being carbon (and here I include manganese, silicon aluminum, ...). More reasons in this link.

- **Neutralize** unwanted but unavoidable **impurity elements** that are impossible or too expensive to keep out. Manganese (Mn), counteracting the detrimental effects of sulfur (S), is the typical example. If you like, you can also file the "killing" of modern steel (i.e. the removal of the oxygen used to purify the pig iron) with silicon (Si), aluminum (Al) or calcium (Ca) under this heading.
- **Improved strength** not based on carbon. Cementite, pearlite, and martensite, the stuff you get with carbon steels, do increase strength or hardness but are not so good for "workability", i.e. properties like ductility or weldability, not to mention corrosion. The key words in this context are: **solution hardening**, **precipitation hardening**, and **grain size hardening**. The first two mechanisms are clear in principle, the third one relies on alloy elements to keep grain boundaries from moving, disallowing grain growth. Two kinds of (always small) precipitates are used: hard metal carbides or nitrides like niobium carbide, and hard intermetallic compounds like nickel-titanium Ni_3Ti.
- **Improving hardenability** by quenching. The key is to enable martensite formation even at relatively low cooling rates. It then can occur in the interior of massive steel pieces and is not limited to a thin surface-near layer..
- **Improved corrosion resistance**. The key word is "**stainless steel**", resulting from rather large additions of Chromium (**Cr**). But between "no corrosion at all" and "rusting like crazy" is much room for improvement.
- **Stabilizing austenite** at low temperatures. Reduce the transition temperature and you may get (nonmagnetic) **austenitic steel** (with an fcc lattice) at room temperature and below. That's a *rather* different material from bcc steel.
- **Lower costs**. It's rewarding if you you can make some new cheap steel by alloying cheap stuff that has about the same properties as some presently used expensive steel containing expensive alloying elements like nickel. Boron (B) is he champion in this field.

It goes without saying that alloying does not just mean to pitch some alloy elements in your heat of steel but to follow precise and complex processing routines; cf. this module for an example.

The following links give plenty of information about alloying elements, what you use them for, and the science behind it. But beware!

Some of the desirable features from above can be achieved by adding a suitable amount of the *right* elements. But most elements do several things from the list above, and a combination of two elements usually does *not* just produce the sum of the individual properties, but something new. In addition, improving *one* property by adding a certain element might easily produce problems with some *other* properties. You will have to compromise.
Never forget: Very different properties can result from alloying just *one* element in a given concentration by different kinds of processing. We have seen that by alloying iron with *only* carbon.
In other words: processing matters *very much*—for plain carbon steels *and* for alloy steels!

Alloy Links
1. Overview
2. List
3. Science

In the linked modules I will give very short essentials of some interesting steels. It will *not* be an exhaustive overview . If you want that, you must consider buying a good-sized library.

Some steels have already been treated elsewhere in the Hyperscript. Here are the links:

- Tempered Steel (including austempering and martempering).
- Low alloy steels.
- High-strength steel.
- Stainless steel.
- Maraging steel.
- Phosphoric steel.

- Back to **Overview of Major Steels**
- On to
  - **2. Some Common Steels**
  - **3. Some Special Steels**
  - **4. Scientific Steels**