Steel: The Toolmaker's Metal

Steel is the one absolutely essential metal to toolmakers, for the simple reason that unlike most other metals it can be hardened. Most of the jewelry metals will "work-harden" from mechanical stress, but while this characteristic is useful for the metalsmith, it doesn't help the toolmaker. Imagine trying to create a file or saw where you had to cut the teeth, then crush them to make them hard, or alternatively, smash the blank, then try to cut teeth on it, with tools that were the same hardness. Clearly, this way lies madness. What is needed is a metal that can be hardened without mechanical deformation. None of the non-ferris (non-iron based) metals have this property to any great degree. Neither does pure iron. Fortunately, steel does.

Steel is an alloy, not a pure metal. In the generic sense, the term steel refers to any iron alloy containing between .4% and 1.2% carbon. These alloys can be hardened with heat. Below .4% carbon, they don't really harden, and this group of alloys are generically called "mild steels". (Mild because they don't harden.) Above 1.2% carbon, they become brittle, and are generally called cast iron. Between these two numbers, magic can happen. As a general rule, the higher the carbon content in a steel, the harder it can get. Since nothing comes for free, the trade off is that they become progressively more brittle as hardness increases. The lower carbon steels are very tough, and make great hammers and anvils, but would make lousy knives. In the same light, the high-carbon blade steels would make lousy hammers: they'd shatter under the impact. Most steels have other elements mixed in to them to change their characteristics in some fashion. Add a pinch of vanadium, and the steel becomes even harder, a dash of lead, and it machines better, while chromium and molybdenum make it very tough indeed. I've got a book 2 inches thick with various steel recipes in it, and that was just the stuff that one of the suppliers in Detroit stocked on hand. For basic toolmaking however, we can concentrate on just a few alloys. One of the ways to define a steel is by a numeric code system. (Called the SAE system.) In its full glory, this system is mind-boggling. The good news is that mostly we don't need to worry about it. Basic steels are defined by a 4 digit number. In the case of simple steels, this number begins with 10, and the second two numbers are the carbon content in percent. For example, a basic steel with .45% carbon, good for hammers, is called "1045", while the high-carbon music wire sold in the hardware stores is "1095", and it contains...you guessed it, .95% carbon. There are steels where the first two digits are not '10", they have other alloys rather than just plain iron and carbon, and typically are not something a beginner would want to mess with. However, there are a few of these alloys that are useful. Fortunately, they have names as well as numbers. They are "A-1", "W-1"&W-2", and "O-1" (and very rarely, "M-2"). These metals combined with the carbon series steels comprise the bulk of the "tool steels". (The "carbon series" steels are the "10XX" steels. The tool steels in that series are between 1050 and 1095. For reference, basic mild steel is "1018" in the SAE system.) This being America, there is, of course, ***another*** system. This one is a little easier to use, and is called AISI. (American Iron and Steel Institute.) The names may seem a bit cryptic at first, but generally they have something to do with a property of the steel. In the case of O-1, W-1 and A-1, they relate to the medium the steels are designed to quench in. O-1 is an oil quenching steel, W-1 is designed for water, and A-1 is designed for air.

The AISI letter codes are as follows:

- A-Air hardening steels.
- D-Die steels
- F-Carbon/Tungsten alloys (Very hard)
- H-Hot working steels
- L-Low alloy. (All of the SAE 10XX steels would be in the "L" series.)
- M-Molybdenum alloys. (Very hard, but brittle)
- O-Oil hardening
- P-Mold steels. ("P"???)
- S-Shock resistant alloys
- T-Tungsten alloys
- W-Water hardening alloys.

After all this talk of hardening and quenching, perhaps I should explain what I'm talking about. The process of making steel hard is, oddly, called "hardening". What you do is form the annealed steel into whatever shape you need, and then heat it up red hot and then plunge it into a bucket of water or oil. Steel is a very odd metal compared to most others. If you heat silver or gold to red heat, and then plunge them into water, they get soft. Steel on the other hand, gets ***hard.***

The way to anneal steel, to the extent that you can, is to heat it up red hot, and then let it cool ***slowly***—many minutes—back to room temp.

What's going on is that the carbon in the steel starts out in little tiny crystals called carbides. These carbides live between the much larger balls of the iron crystals. This form of steel is sometimes called cementite. As you heat the metal, there will eventually come a point where the carbides melt into the alloy. This is called either the "critical point" or the "Curie point". It's usually somewhere around 1200°F, or red hot. The best indicator is that the steel will suddenly become non-magnetic. In this phase, the carbons are called "austenite". The steel is now ready to quench. Quenching is simply the process of cooling the steel quickly back below the critical point in some fashion. If you cool the steel quickly below the critical point, the carbon crystals don't have time to re-form themselves into the little balls of cementite carbides, instead they stay stuck as little needles of "martensite". These martensite needles "get in the way" of the iron crystals moving around, and act sort of like reinforcing bars in concrete, preventing the steel from bending, and thus making it hard. Unfortunately, they also make it brittle, so the next step in hardening steel is to controllably soften it. This is called "tempering".

Before we move on to tempering, I need to mention yet another of steel's quirks: it cares what you quench it in. The jewelry metals are all quenched in water, and this is just fine, but some steels won't work right if quenched in water. Some steels are designed to quench in oil, some in water, and some in air. When steel is red-hot and you start to rapidly cool it, the dissolved carbon austenites change into martensite needles. This causes tremendous internal stress in the metal, because for one thing, martensite crystals are ***bigger*** than either austenite or cementite. So the exact nature of how fast the transition occurs, and thus how much of the austenite gets changed into martensite has some pretty serious consequences. The reason why some steels care about what they're quenching in has to do with how quickly the various quenching media can carry the heat away from the steel part. Most simple carbon steels will quench well in water, which is a medium-fast quench. If you want to make these same steels even harder, you quench them in brine. (sea water) Brine can transmit heat even faster than simple water, so it quenches harder. (Ask me about the red-headed boy.) Oil doesn't transmit heat as well, and is considered a slower quench than water. Air is slower yet. (Air quenching steels have some pretty annoying quirks, and are best avoided by beginners.) The reason this matters is that if you quench O-1 in water, it will cool faster than it was intended to, and probably crack from the stress. If you quench A-1 in ***anything***, it'll crack. O-1 is probably the cheapest and most common tool steel. The advantage of quenching it in oil is that the slower heat transfer allows some of the austenite to revert all the way back to cementite, which helps relieve the internal stress on the steel, and makes it tougher without sacrificing hardness. It'll still need to be tempered, but it will come out tougher at the same hardness.

Tempering is really just a very controlled annealing process. By a fortunate quirk of fate, the oxide rainbow you see when clean steel is heated just happens to occur at just exactly the right range of temperatures to enable us to judge how much the steel has been annealed. The rainbow forms certain colors at certain temperatures, and these colors can be used as a judge of how hot the steel is, and thus how soft it has become.

Color	Temp °F	
Pale yellow	300°F	
Bright yellow	350°F	Gravers/°Files
Straw yellow	400°F	Sawblades
Dark straw	425°F	
Brown	450°F	
Purple	475°F	Chasing punches
Violet	500°F	
Dark blue	525°F	
Bright blue	550°F	Hammers
Blue grey	575°F	

The higher the temperature, the softer the steel becomes. The trade-off is that it also becomes tougher. Engraving tools, drills and files are typically tempered (or "drawn") to bright yellow (350°F), since they have to hold an edge well enough to cut through other metals, while hammers are typically drawn to bright blue (550°F) since they just have to be harder and tougher than what they're hitting. Chasing punches are typically in the purple/violet range.

Finishing a tempered item is relatively simple, as long as you remember that if you do something to it that causes it to heat up, you can anneal it accidentally, just the same as if you'd been trying to do it deliberately.