

8.4.2 Multiculti in Steel

The Melting Pot - What Goes in and What Comes Out

"Multikulti" was and is a big word in Germany, it stands for "multi-cultural society". Multiculti is achieved by mixing Germans, Turks, Africans and so on with their respective cultural traditions and habits, and it was supposed to bring out the best of all involved. [Ha!](#)

Multiculti, if you take it with a grain of salt, was and still is a good thing. It has substantially increased the quality of food in Germany, the singers in the opera are much better (and [far easier on the eyes](#)) - and just look at the national soccer team in 2010; not to mention 2014! However, there are also undeniable problems.

Nowadays the political viewpoint is a bit more differentiated. It became clear that if you just throw some minority culture into the German mainstream without any control of what is going on, the result might not be the perfect alloy you had in mind. What you will get depends on how you treat the various cultures that you try to alloy with German mainstream, and how they interact with each other.

Let's look at multiculti more scientifically and less sociologically. The result of what comes out of a "melting pot" as multiculti was called earlier, does not depend so much on what some anonymous "one" does with the mix but on how it [self-organizes](#) under the prevalent conditions. The Americans coined the term "[melting pot](#)" for people as an obvious analogy to the making of metal alloys. A sociological melting pot is supposed to make good Americans, a metal melting pot should produce good steel. Neither process is easy but all things considered, [steel making](#) is far more more complicated than the making of an American; the latter enterprise might be more fun, though.

We are alloying mainstream iron with minority carbon and several more minority elements in real steel. What you finally get will depend on the conditions for self-organizing. I have already shown you many different outcomes of a "melting pot" steel experiment. let's recall some:

What you could get for some simply low-alloy carbon steel is a wild mix of primary and secondary ferrite, retained austenite, primary and secondary cementite, more or less well-defined pearlite and to top it off, some martensite. This are the phases and pseudo-phases you might find.

In the phases we have interstitially dissolved carbon atoms, other dissolved elements, dislocations, grain boundaries, phase boundaries, and precipitates other than cementite of all kinds, sizes and shapes.

In addition there is stuff like "[bainite](#)" that I kept from you so far.

The self-organized mess you will eventually end up with at room temperature might be good or problematic for your applications. What it will be depends on the mix you started with and the conditions you provided.

So far we only scratched the surface of steel science and technology - and we didn't even make a deep impression! If you found this fascinating enough and really want to go a [lot](#) further, you should become a material scientist in general and a steel expert in particular. That means studying full time for 3 - 5 years plus spending some time in a smithy or steel mill. If you only want to go a [bit](#) further, read on.

Coming Out of the Closet

I will only look at a few more basic things in this backbone of the hyperscript:

**What happens for carbon steel [in between](#) the two extremes we glanced at:
Cooling v e r y s l o w l y - Cooling very fast**

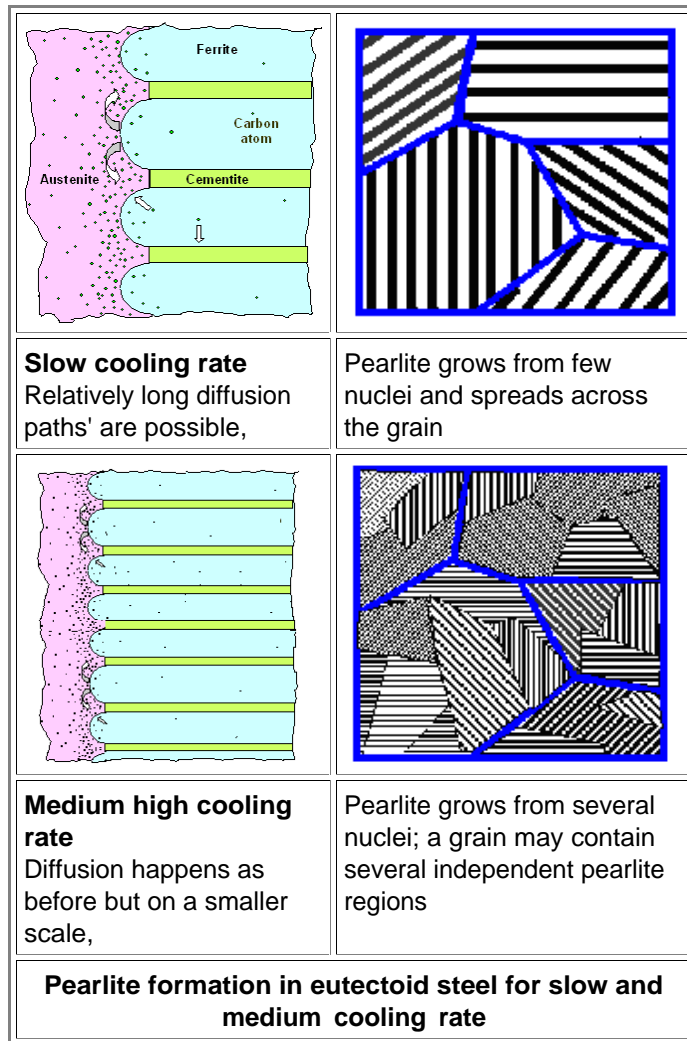
- Cooling very [slowly](#) yields well-developed pearlite + ferrite or pearlite + cementite by [civilian processes](#) (everything diffuses around at random).
- Cooling very [quickly](#) yields a lot of martensite by [military processes](#) (all atoms move simultaneously in lock-step) plus some other stuff.

What happens in between? Well, everything you can imagine—and more.

Increasing your cooling rate first forces the crystal to do the necessary transformation at a finer and finer scale, making the distances that atoms have to cover by [civilian](#) processes smaller and smaller. In other words: Cooling very slowly will eventually cause some pearlite to nucleate at some grain boundary corner. From this corner a pearlite-austenite front will develop that moves leisurely across the whole grain. If things now need to happen faster because you are cooling somewhat faster, the crystal starts pearlite in [more](#) places inside a grain and moves the pearlite-austenite phase boundary more quickly. The structure then becomes finer.

This is shown schematically below. If time is even [more](#) pressing, cementite starts to precipitate all over the place, and not in a nice orderly pearlite or zebra-pattern fashion (not shown here; you can imagine this. If not, look up the "[divorced eutectoid transformation](#)").

Cool real fast (or quench, in other words) and you have mostly martensite.



● If you look at the [old picture](#) of pearlite in eutectoid steel, you see that it is closer to the slow cooling case. You also see that even under ideal conditions, reality is far messier than can be shown in two-dimensional schematic drawings.

▣ In between cooling slow and cooling real fast is a region where things can get really messy. I need to trot out a few more chimeras (monstrous creatures composed of the parts of other animals) that so far I kept hidden in the closet:

In between halfway decent pearlite and fully developed martensite you find "bainite**".**

▣ The name "bainite" honors **E. C. Bain**, a well-known steel scientist. There are lots of people out there who will take offense at my grave oversimplification of Bain's work but trust me: you don't want to know much more than what I state here. Bainite is *not* a nice clean phase like ferrite, austenite, or cementite. It is neither a well-defined but *metastable* phase like martensite. It isn't even a **pseudo phase** like pearlite that at least can be represented in a phase diagram. It is a mix of all of the above and might at best be called a chimeraphase (Chimera= mythical creature composed of the parts of three animals: a lion, a serpent and a goat). However, a lot of people and books talk about "bainite" the same way they talk about martensite, pearlite or ferrite. That's not really correct but so what. Let's look at an analogy:

● Take a perfect male (like me) to symbolize a perfect single phase like hard cementite close to nirvana (and therefore single-crystalline). Take a bunch of male students to embody a less perfect polycrystalline phase of cementite, and a bunch of female students as (yielding and soft) ferrite. What you find in an old-fashioned class room (boys on the left, girls on the right) then would be pearlite. Not a real clean phase but a well-defined mix of two real phases. Martensite would correspond to teenagers, neither here nor there, just a transitory phase on the way to adulthood. Austenite corresponds to kids; capable to change into adults of either sex. Bainite then could be represented by people in a zoo. You get a mix of everything from above including, maybe, some apes (hard to tell from humans without a good

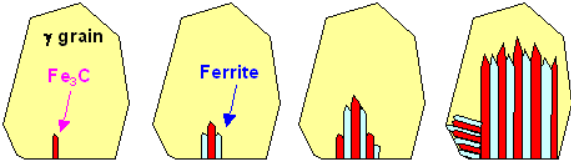
**Science
Module**

Bainite

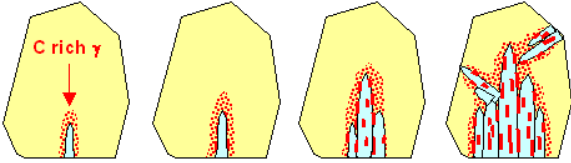
microscope).

- At best you could call this mess a chimeraphase - but nobody uses that word. You just call it bainite or, being a bit more discerning, "upper" or "lower" bainite, hoping that the other person knows what you mean even so you might not be too sure about that yourself. Use the science link if you want to know more.
It's simply that a lot of terms and names around iron and steel are from times when it was not quite clear what one was naming. A proper *scientific* name for bainite was "*dark etching acicular aggregates*" (=longish things appearing dark in a microscope)" since essentially you couldn't see all that much even at the highest available magnification. Naming this more or less invisible stuff "bainite" was not very scientific perhaps but made you feel much better psychologically. You might not have had the [true name](#) of the thing but at least you had some name. Often those names are still around and are used today, even so they are not completely correct anymore. Let's just resign ourselves to the fact that that all these names are used a bit indiscriminately. Some refer to *phases*, some to *structures*, and nobody cares.
- So what does bainite look like? I'll give you two pictures here. If you want to know more, you better consult the science link. It is simply not sensible to discuss bainite in simple terms only.

Pearlite Formation

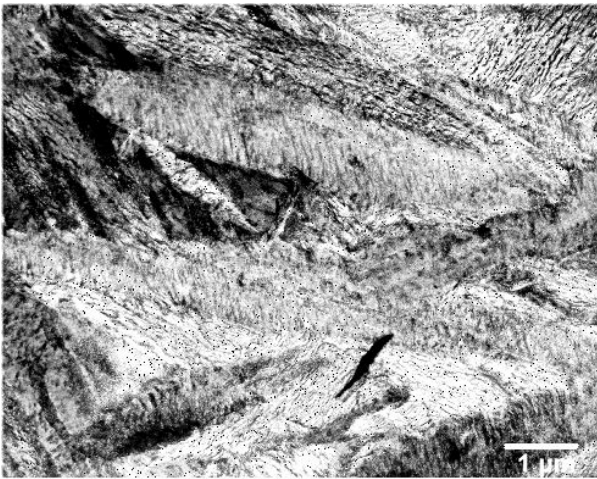


Bainite Formation



From (small distance) pearlite to bainite - schematically

Time progresses from left to right.
Yellow: austenite grain, blue: ferrite, red: cementite and "carbon cloud".



Bainite as seen in a [transmission electron microscope](#)

Source: Wikipedia; from J. Horton; Oak Ridge National Laboratory, Materials Joining and NDE Group

Now to the last last new *structure* I need to mention: **Widmannstätten ferrite**. The name tells it all: It's a phase (ferrite) with a special structure.

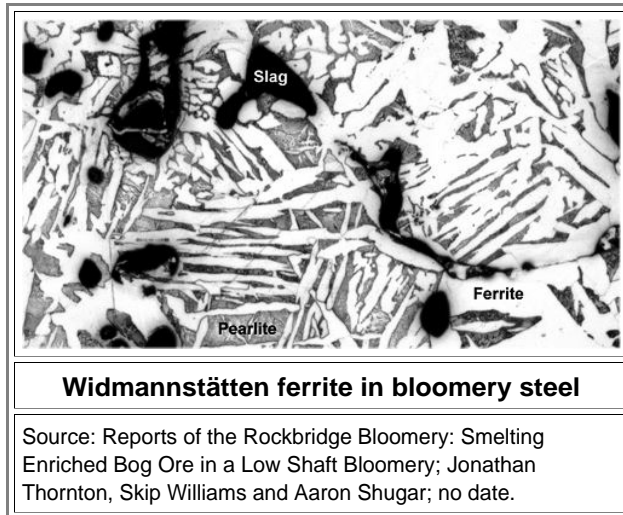
You get Widmannstätten structures, for example, if hypoeutectoid plain carbon steel is cooled down rapidly from a very high temperature well above the [A3 temperature](#). That is the temperatures where the pure γ -phase (austenite) starts to transform into primary ferrite and austenite. This is called "overheating" and makes sure that you have large austenite grains. If there is little time for the transformation because cooling is fast, ferrite crystals will nucleate all over the grain boundaries and, since the grains are so big, also in the grain. They quickly grow into some preferred crystal direction inside the grain and thus become

**Science
Module**

**Widmann-
stätten Ferrite**

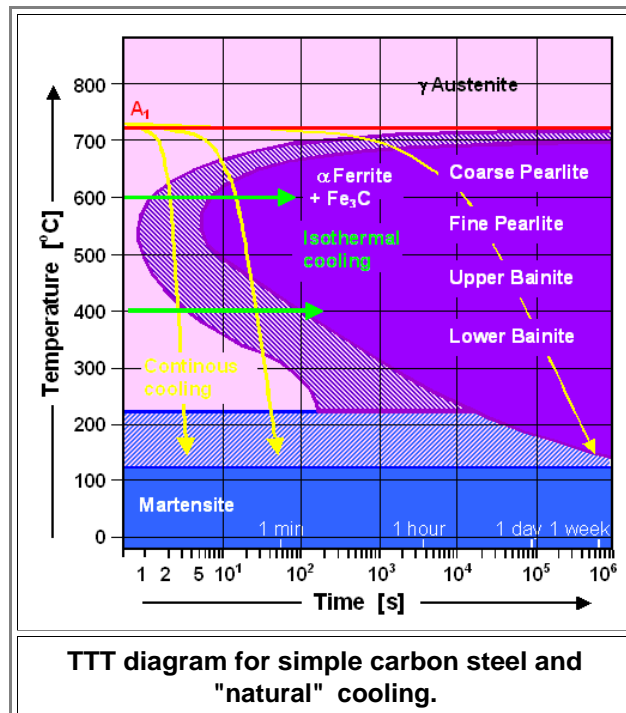
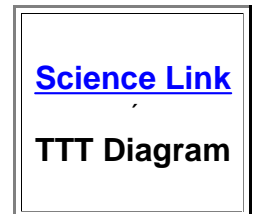
"longish". That simply means that you get ferrite needles ("acicular growth", lathes) or plates that tend to be aligned along the same direction within one grain.

- Do it with hypereutectoid steel and you get cementite needles; look up the science module for details. Here is a picture of Widmannstätten ferrite in hypoeutectoid steel as it comes out of a bloomery:



You should now slowly and reluctantly realize, I hope, that the iron-carbon phase diagram, our reliable guide or map through the labyrinth of iron-carbon alloys close to nirvana (now called "equilibrium"), is no longer of much use. The more interesting iron-carbon alloys known as "hard" steel, have microstructures that are far away from equilibrium. Of prime importance for what we will get in the end is not only the carbon concentration but also the "**thermal history**", the way the material was treated with "temperature". The "mechanical" history, the way the material was exposed to deformations by banging, rolling and so on, is also of some importance - but let's take one step at a time. What we would need now is a *new* kind of map that tells us where we will end up if we go down the fast, the slow, or the meandering road while cooling our steel.

- Such a map exists. It is called a "**Time - Temperature - Transformation diagram**" or **TTT** diagram for short. You draw in how you are going to move from high to low temperatures, and the TTT diagram tells you what you will end up with. Of course, exactly what you get does not only depend on the *temperature profile* as we call that road from now on, but also on the carbon concentration, not to mention the presence of other impurities. What I'm trying to tell you is that TTT diagrams just need to be a bit more complex than mere phase diagrams. Here is the probably most simple example of a TTT diagram for a medium carbon steel:



- The yellow curves show steady cooling at wildly different rates. It takes about 5 seconds, 5 minutes, or more than a week to get down to room temperature. In other words: the first curve embodies hard quenching by immersion in a cold liquid, the second one air cooling with maybe some blowing, the last one letting your steel cool down inside a large furnace that takes a week to get cold. The microstructure going with these curves are defined by the areas the curves run through.

I only show a TTT diagram here to make clear that you now must make a decision: Either you decide you want to know more, then you need to spend some time with the advanced module. Or you decide that this is all or possibly more than you ever wanted to know about the topic, then you can just read on. There is no middle road in this case. If you do a complicated thing like cooling your steel in a defined way to 800 °C, keeping it there for 30 min, quenching it to room temperature followed by tempering for 20 min at 300 °C, the TTT diagram will have to be complicated. I can't change that, sorry.

▸ I'm sure you can imagine a lot of cooling strategies or temperature profiles. And you can be sure that some smith somewhere and sometime has tried it already, provided it can be done without too much fancy equipment. Alas - it is very likely that mostly he produced junk or mediocre blades. But on occasion a **magical sword** might have come out by happenstance.

- Now you know why. There are just so many parameters that influence the final result. Deviating from some established standard process that you learned from your master will most likely not be good. The probability that you produce one of the many kinds of inferior steel is simply much larger than that you end up with something new and marvellous.