Widmanstätten Structures

What are Widmannstätten Structures?

The expressions "Widmannstätten ferrite", "Widmannstätten structure", Widmannstätten pattern" and so on refer to two or rather three *completely different* things:

1. A very special structure found in nickel-rich meteorites.
2. A not-so-special but recognizable structure in hypoeutectoid carbon steel concerning the shape of the ferrite grains .
3. A not-so-special but recognizable structure in any steel concerning the shape of something.

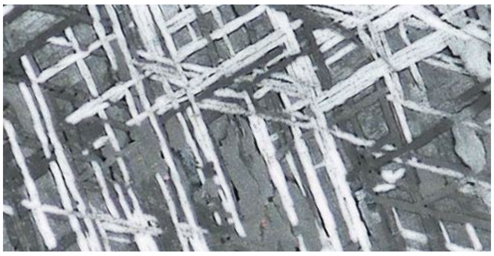
In all three cases something appears to be "longish" and that is the *only* common denominator.
Let's look at the three cases in turn.

- The "Bible" (1985 ASM Metals Handbook) has the following to say:
  "***Widmanstätten structure****. A structure characterized by a geometrical pattern resulting from the formation of a new phase along certain crystallographic planes of the parent solid solution. The orientation of the lattice in the new phase is related crystallographically to the orientation of the lattice in the parent phase. This structure was originally observed in meteorites, but is readily produced in many other alloys, such as titanium by appropriate heat treatment."* Aha!

Science

Widmannstätten Pattern in Iron Meteorites

Count Alois von Beckh Widmanstätten (1753 - 1849), the director of the Imperial Porcelain works in Vienna, is usually credited with discovering the well-know pattern of interlocking longish to rectangular structures on etched iron-nickel meteorites. The following picture gives an example of what that looks like:



Typical Widmanstätten pattern on an etched iron-nickel meteorite

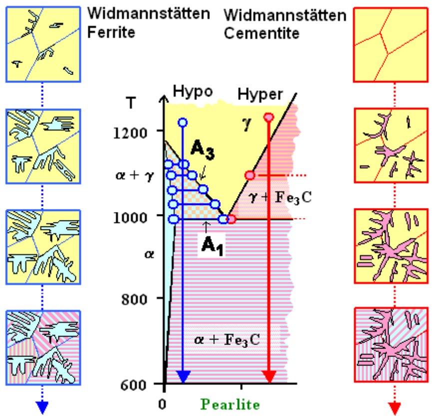
- Widmanstätten only talked about his observations and never published anything. The term "Widmanstätten pattern" was coined by others in 1808. It is now believed that the credit for the discovery should actually go to one **G. Thomson** (1760 – 1806), an English geologist, who published the same findings four years earlier. That's why we also refer to these structures as **Thomson structures** on occasion.

The structure consists of a fcc γ-phase and a bcc α-phase that develops in nickel (Ni) rich iron if the cooling rate is r e a l l y s l o w. And with "really slow" I mean something like a temperature decrease of a few centigrades in a *million* years! That's what happens inside planets or other big objects but never inside a laboratory run by mortals.

- What happens on this kind of time scale, and why it results in the typical pattern, is quite well understood and documented in many papers. However, some details have been recently challenged (look for one Phyllis Budka in this context).
  Since it is impossible to produce a Thomson structure in the laboratory, its presence in some specimen proves the extra-terrestrial origin of the specimen.

Widmannstätten Ferrite

In German, Widmanstätten ferrite is also known as "Überhitzungsgefüge" or over-heated structure. You get that particularly well expressed in hypoeutectoid plain carbon steel that is cooled down rapidly from a temperature well above ("over-heated") the A_3 temperature, where the pure γ-phase (austenite) starts to transform into primary ferrite and austenite. Here is the relevant part of the phase diagram once again but with a schematic view of structure development for fast cooling



Formation of Widmanstätten structure in hypoeutectic or hypereutectic steel during fast cooling down.

- If one starts in the pure austenite region at rather high temperatures, the austenite grains will be large. When the α + γ region is hit, ferrite needs to develop. If there is little time 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 "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 .
  When the A_1 transformation temperature is reached, the remaining austenite turns into fine and possible messy pearlite that may not even show a clear "zebra" pattern.
- In other words: We have a bainitic structure! In the bainite module I have looked mostly at the eutectoid compositions because that is most easily understood, but whatever is described there would read pretty much like what you read above if it would have been written for hypoeutectoid steel.
  The left-hand picture below shows some typical Widmannstätten ferrite.

Widmannstätten ferrite (white)	Widmannstätten cementite (white)

Widmannstätten structures of hypo and hyper eutectoid steel

Widmannstätten Structure in Hypereutectoid Steel and Generalization

- Well - see above. Just replace the words "primary ferrite" with "primary cementite". No more needs to be said. The right hand picture above shows "Widmanstätten cementite".
  - Once more, it's just some special form of bainite. Since it started from large grained (overheated) austenite, the structure is coarser then in "regular" bainite.
- It is clear (I hope) that you *cannot* get Widmanstätten stuff for mixtures around the eutectoid composition. The formation of the characteristic longish structures happens when primary ferrite or primary cementite are formed, and you just don't get this around eutectoid compositions.
  - It is thus small wonder, that "good" Widmanstätten *ferrite* is only observed in steels on the low carbon side, say less than about 0,4 % carbon.
- Widmannstätten ferrite structures do not only occur when you cool your steel under certain conditions but also in those parts of a weld seams or in of cast pieces that cool down fast enough. They are not particularly welcome because they tend to be more harder and in particular more brittle than the normal ferrite / pearlite structure. If you picked a 0.3 % carbon steel, you probably went for ductility and not for hardness, and the properties of the "bainitic" Widmanstätten structure is not what you had in mind.
  - Of course, being more brittle makes Widmanstätten low-carbon steel easier to machine (it flakes off more easily). So you may go for these structures if you need to do a lot of machining on a lathe or drill press, and then restore your finished piece to high ductility by normalizing it, i.e. heating to just beyond the $\mathbf{A_1}$ temperature for a while and cooling it down not too fast.