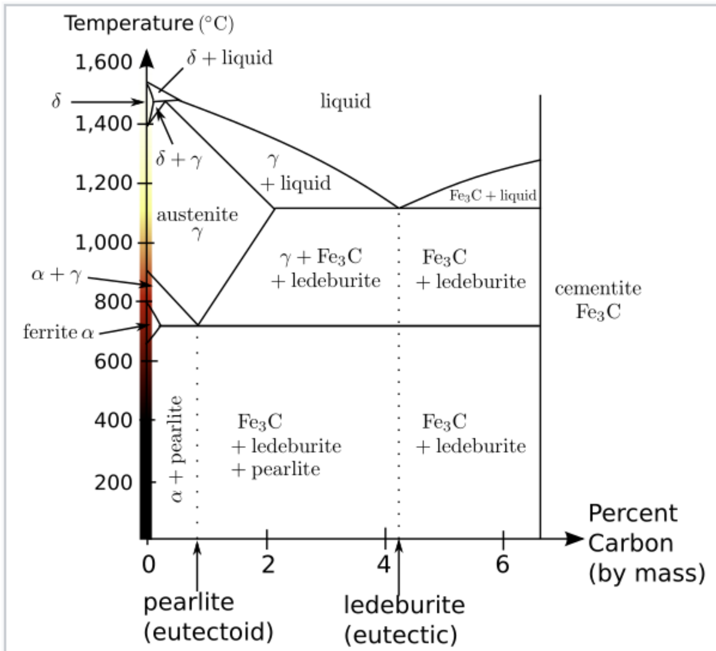
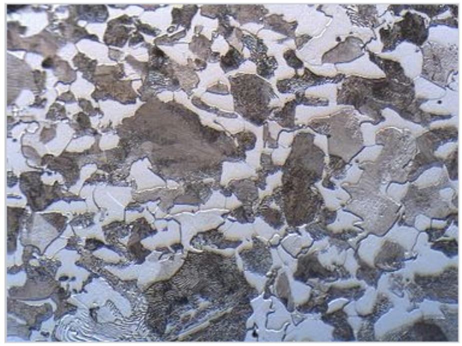
# 7.4: Iron and Steel

One other very important place where the difference between the hardness of a BCC and a close-packed metal is important is in steelmaking. Between room temperature and 912$^oC$, iron has the BCC structure, and is a tough, hard metal ("tough as nails"). Above 912$^oC$, pure iron switches over to the FCC (austenite) structure, which is much more ductile. So hot iron can be bent and worked into a variety of shapes when it is very hot but still solid (it melts at 1535$^oC$). Rapid quenching of hot iron - e.g., when the blacksmith plunges a red hot piece directly into cold water - cools it to room temperature, but doesn't allow time for the FCC --> BCC phase transition to occur; therefore, such pieces are still relatively malleable and can be shaped.




The iron–iron carbide (Fe–$Fe_3C$) phase diagram. Below 912 °C, pure iron exists as the alpha phase, ferrite, which has the BCC structure. Between 912 and 1,394 °C, pure iron exists as the gamma phase, austenite, which has the FCC structure. Carbon is more soluble in the FCC phase, which occupies area "γ" on the phase diagram, than it is in the BCC phase. The percent carbon determines the type of iron alloy that is formed upon cooling from the FCC phase, or from liquid iron: alpha iron, carbon steel (pearlite), or cast iron.

Carbon is added (about 1% by weight) to iron to make "carbon steel", which is a very hard material. Carbon is rather soluble in the FCC phase of iron, but not in the BCC phase. Therefore, when the ductile FCC phase cools and turns into BCC ("tempering" the steel, which means cooling it slowly enough so the FCC to BCC transformation can occur), the iron can no longer dissolve the excess carbon. The carbon forms layers or grains of an extra phase, $Fe_3C$ ("cementite" - a very hard material) which are layered or dotted throughout the matrix of BCC iron grains. The effect of all these little grains of $Fe_3C$ is to stop the motion of dislocations, making for a harder but (with higher carbon content) increasingly brittle material. This is why knives and swords are quenched from the FCC phase, cold worked into the appropriate shapes, and then heated up again and tempered (before they are sharpened) when they are made. Cast iron objects (frying pans, radiators, etc) have a higher carbon content and are therefore very strong, but tend to fracture rather than bend because of the larger fraction of the brittle $Fe_3C$ phase in the alloy.



Upon cooling, high carbon steels phase segregate into a mixture of bcc iron (light gray) and Fe3C (dark gray) microscopic grains.