Metallurgy Basics (for Non-Metallurgists): What's Happening to Metals During Heat Treat?

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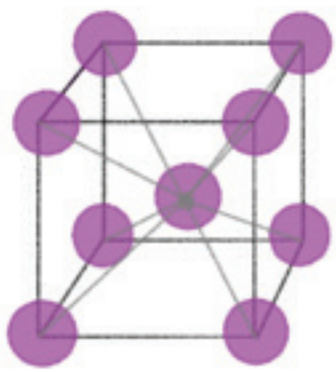

Figure 1: body-centered cubic crystal structure

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- *Improved wear resistance.*
- *Increased resistance to deformation and warpage.*
- *Increased strength or toughness.*

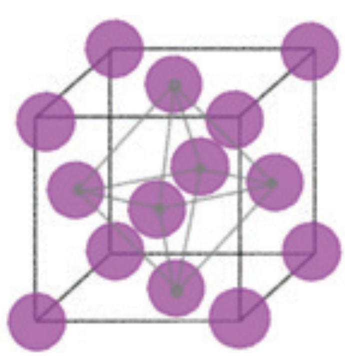

Figure 2: face-centered cubic crystal structure

For those who may have failed chemistry or perhaps didn't quite pay attention to their teachers, let's start with the basics. Steel has been around for ages--even the Romans used it back in 223 B.C.! Ancient people were able to find a way to make steel, as almost 5% of the earth's crust consists of iron, making it the 2nd most abundant metal in the earth.[1] Steel is made through the addition of carbon into iron (up to 2%) which happens with extremely high heat. One part of steel production that not too many people know about is heat treatment, the way to make metals stronger, harder, and more durable. This is a very important step for many steel and metallic parts.

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When common metals, such as steels, are heated to high temperatures, there is a significant change at the atomic level. Iron atoms are originally arranged into crystal structures that change shape when heated; of which there are two common structures. Depicted in Figure 1 is a body-centered cubic (BCC) crystal structure, which is common in steels at room temperature. Notice that nine total iron atoms make up the unit cell for this arrangement of atoms. Figure 2 depicts a face-centered cubic (FCC) crystal structure. There are 14 total atoms that make up the unit cell for this arrangement of atoms. The FCC transformation occurs when steel is heated above its critical temperature. The bonds between iron atoms are relaxed from their BCC state, and transformed into the FCC structure. The important thing to note is the effect of the increased atoms in the lattice. With more atoms, there are more interstitial sites that allow alloying elements to bond with iron and move into these lattices. One such element is carbon, a primary element for hardening steel. Because of the increased amount of interstitial sites that fit carbon, carbon atoms move more freely around iron at elevated temperatures. With a greater chance to interrupt geometry of the crystals, steel becomes less ductile, resulting in an increase in strength.

To increase the amount of carbon in iron (carburizing), the metal is typically placed in an atmosphere with an elevated carbon level to diffuse additional carbon into the surface.

Just heating these steels with an increased carbon atmosphere is not enough to keep it trapped in these lattices to increase hardness. Slow cooling will allow the carbon to diffuse back out, as the structure slowly changes back from FCC to BCC. To counteract this, several different quenchants can be used to cool the material quickly. The quenching allows a quick change of environment for a steel, from high to low temperatures, undergoing heat treatment. It acts to trap carbon and other elements in the middle as there is not enough time for diffusion out of the steel before a change in crystal structure. With these trapped carbon atoms in the crystal structure, we have an altered BCC structure known as martensite.

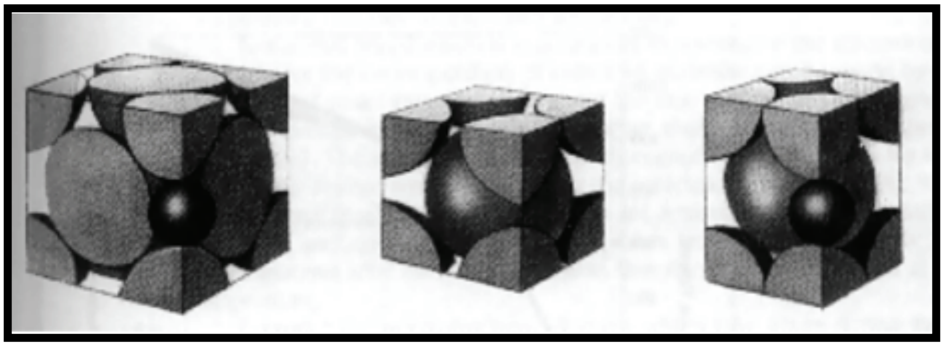

Figure 4: Carbon atom filling interstitial site in FCC crystal structure (left). BCC structure, before heating (middle). BCC after heat treat, with carbon trapped in interstitial site. Note the changed dimensions (right). [2]

Not every steel, however, reacts the same, as chemical composition can vary greatly between the different grades of steel. Certain alloying elements can greatly increase the hardenability of steels such as nickel (Ni), chromium (Cr), and molybdenum (Mo). Hardenability is NOT how hard a material is. Hardenability directly relates to the ability of a metal to form martensite and martensitic structure upon quenching, which points to how well hardness can be achieved. Ni, Cr, Mo additions, as well as higher carbon, allow more martensite to form, thus the metal is more "hardenable." High hardenability is the ability of a metal to transform into martensite throughout the whole part, not just high hardness at the surface.

Sources
[1] http://www.gsa.org.au/resources/factites/factitesIron.pdf
[2] http://www.ce.berkeley.edu/~paulmont/CE60New/review1.pdf

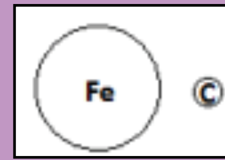

Figure 3: Relative size comparison of a carbon atom (C) vs. iron atom (Fe)

Glossary of terms:

Crystal Structure – a classification of the way atoms are arranged in a metal. Typical for carbon steels and when comparing only iron and carbon.

Critical Temperatures – Temperature to which steels are heated above to change the crystal structure. Typically between 1400°F and 1800 °F.

Interstitial sites – the space between atoms in a crystal structure, that can fit atoms of other elements within.

Quenchant – Liquid used, typically oil or water, to cool heated steel at a much faster rate than air.

Hardenability – Ability of a metal to form martensite upon quenching. Martensite provides a metal's hardness.

About The Author

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Clayton Short has been a Process Metallurgist at Advanced Heat Treat Corp. since June of 2015. He graduated from Iowa State University with a B.S. in Materials Science and Engineering, and a specialty in Metallurgy. Clayton enjoys getting involved in the community and taking leadership positions. He is a chairman of Phi Kappa Theta's Alumni Corporation Board, and also a member of the Young Professionals of the Cedar Valley. You can reach him at shortc@ion-nitriding.com or call 319.232.0745.