The Processing of Steel for Fasteners

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In the August issue (Hardware & Fastener Components Magazine, No.48) we discussed the steel composition and alloys used in steel fasteners and how the addition of certain alloying elements will enhance the performance characteristics of the finished product. This article will discuss how we arrive at the finished product.

When the raw coils of steel arrive at the fastener manufacturer on a flat bed truck, the coils are generally stored outside, exposed to varying weather conditions. However, their surface heat-treat scale will prevent the buildup of heavy rust. The coils are each tagged with their heat lot number for traceability.

When ready for use, the first step is a cleaning operation called "pickling". The steel is cleaned in a solution of sulfuric acid, which removes superficial rust and other surface contaminants. The time in the acid solution is controlled to avoid hydrogen absorption in the steel, which would cause embrittlement in high strength fasteners. Pickling is followed by neutralizing and cleaning, where the wire is rinsed to remove any remaining acid, and subsequently coated with a lubricant, such as a lime or phosphate solution. This coating acts to neutralize any residual acid. It also helps prevent corrosion if the steel is not used immediately, and it increases the ability of the steel to pick up the lubricant used in the bolt-making machinery.

Spheroidizing

Spheroidizing is a form of annealing and is the first heat treating process to which the cap screw material is subjected. This operation 'globularizes' the carbide microstructure of the steel and is modified into an elongated pattern when the steel is upset during the deformation of the bolt in the forming operation.

Spheroidizing increases the pliability of the steel and makes it easier to be cold formed to produce a consistent and reliable product. This annealing process is carried out in a hermetically sealed oven that is purged with nitrogen gas to prevent scaling and also eliminates the possibility of carburization or decarburization during this annealing phase. However, the steel is still very susceptible to decarburization during the final heat treatment. Carburization or decarburization is the gain or loss of surface carbon, which would adversely harden the threaded surface by increasing brittleness or soften the surface, respectively, thereby decreasing its ultimate load capability and functionability, especially during assembly, with some structural products.

In the sealed oven, the iron-based alloy is heated near the critical temperature to approximately 1600°F (870° C) for 24 to 48 hours, during which time it slowly cools so that the iron carbide forms a pearlitic structure of ferrite and carbide, Fe_3C, and assumes a microscopic spheroid form. Some grades of fasteners may use a process anneal. After annealing, the wire is tested for proper microstructure, re-cleaned, and re-limed. It is now ready for the bolt-maker.

Many times, 'stress relief annealing' is confused with 'normalizing'; however, both are quite different. Stress relief annealing, or subcritical annealing, is changing the distorted cold-worked crystal lattice structure back to one which is strain free by heating the material to below the lower critical line; 1,000 to 1,200° F (538 to 650° C) and can be air cooled. Normalizing, when used, is performed at 100º F (38° C) above the upper critical temperature of the steel and provides grain refinement and uniformity of the steel.

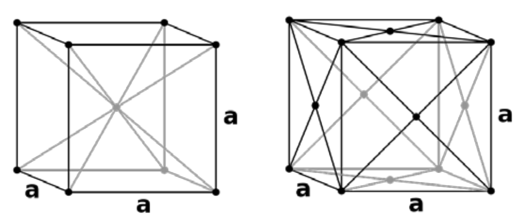
Heat Treating

After the threads are roll formed, special care is exercised in handling, as the fasteners are relatively soft and susceptible to thread nicking damage. Therefore, it is desirable to minimize the amount of handling and tumbling contact of large diameter fasteners. Contract heat treaters will use either batch loading, or a continuous furnace belt loader. Many in-house bolt manufacturers use the continuous furnace process.

There are two basic methods of batch heat treating; basket, or 'pusher' and belt loading. The basket method employs placing the fasteners into a large titanium or stainless-steel basket. Here, the fasteners remain at rest in the basket which is then slowly pushed through the multiple oven zones. Multiple zones are used to accommodate other following baskets for a continuous flow of products. The fasteners remain stationary in the basket during the full heat-treating process.

The other method is a continuous furnace belt loader. Here, the fasteners are dumped from a tote into a hopper, where they tumble onto a moving belt. The belt and fasteners journey through several heat zones and will then dip into a quenching media, followed by the tempering ovens.

Special care is exercised in the handling of the fasteners when they arrive from the bolt makers because they are called 'green' fasteners; they are relatively soft and very susceptible to thread nicking damage. Therefore, handling and movement must be minimized to avoid thread nicking. In many cases with larger fasteners, the batch heat treatment method minimizes movement.

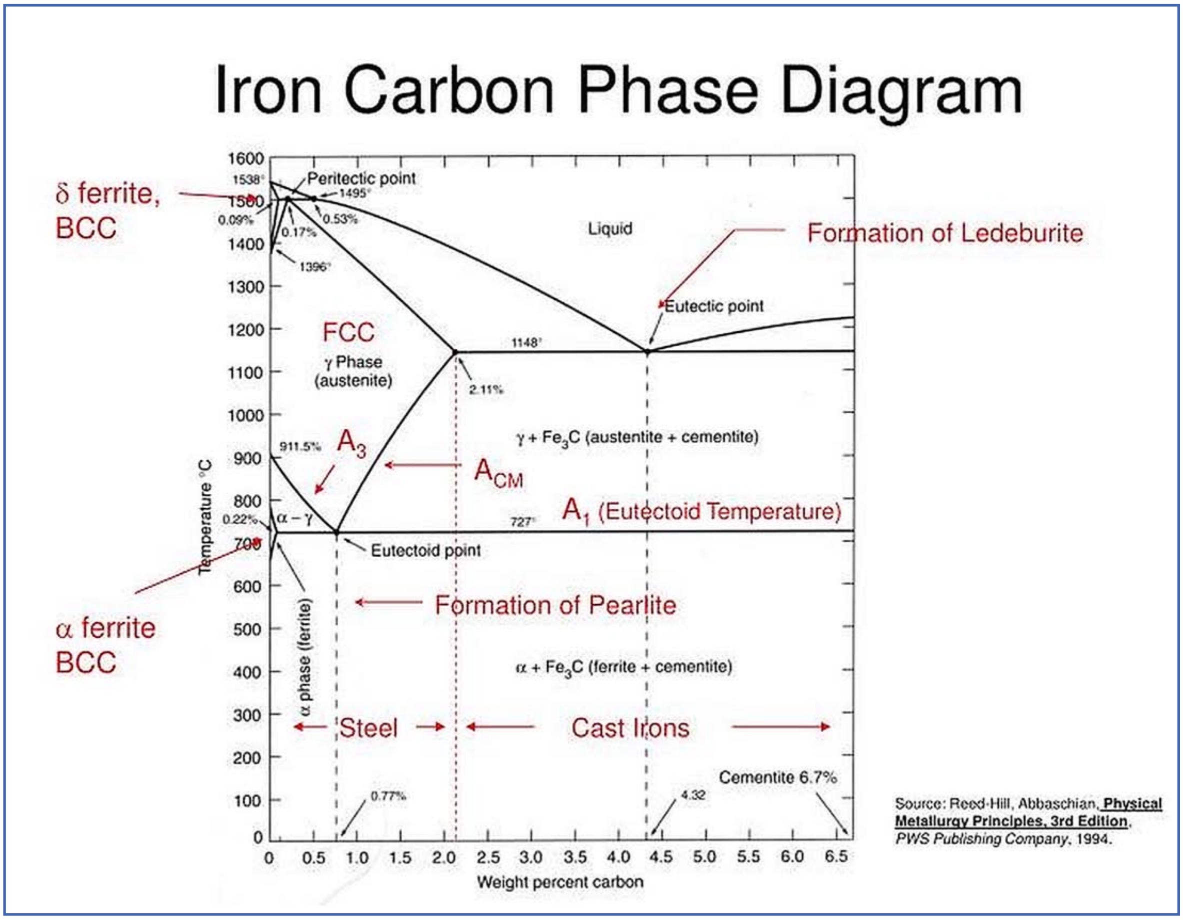


Body-Centered-Cubic   Face-Centered-Cubic

The heat treatment of steel is an art and an exact science. It is a delicate process that can in an instant, change the performance of the product without any external indications. That is, it may pass hardness and tensile strength but fail proof load testing or fail in service.

Steel is one of the few elements that can exist in more than one type of crystalline lattice structure, which is known as polymorphism. If the change in structure is reversible, then it is known as an allotropic change.

When iron crystalizes at 2800° F (1538° C) its lattice structure is a body-centered-cubic (b.c.c. for short). It is also known as a δ-Fe (delta iron). When the iron cools to 2554° F (1401° C) the structure changes


Iron Carbon Phase Diagram
δ ferrite,
BCC
Peritectic point
1495°
1538°
1500
0.09%
0.17%
0.53%
1400
1396°
Liquid
Formation of Ledeburite
Eutectic point
FCC
γ Phase
(austenite)
1148°
2.11%
911.5%
A3
ACM
γ + Fe3C (austenite + cementite)
A1 (Eutectoid Temperature)
727°
0.22%
α − γ
Eutectoid point
Temperature °C
Formation of Pearlite
α ferrite
BCC
α phase (ferrite)
α + Fe3C (ferrite + cementite)
Steel
Cast Irons
Cementite 6.7%
0.77%
4.32
Source: Reed-Hill, Abbaschian, Physical Metallurgy Principles, 3rd Edition, PWS Publishing Company, 1994.
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5
Weight percent carbon
1600 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0

to a face-centered-cubic lattice (f.c.c.), which is known as γ-Fe (gamma iron) and at 1670° F (912° C) the structure reverts back to a b.c.c. as an α-Fe (alpha iron).

The following are illustrations of a b.c.c and f.c.c. lattice structure.

Medium carbon steels are hypoeutectic. An iron-iron carbide equilibrium diagram will indicate the relationships of temperature and carbon to the solubility of iron in different stages: ferrite and pearlite to ferrite and austenite to a full austenitic structure. Also, as temperatures increase, the iron's lattice structure changes from a face centered cubic (f.c.c.) to a body centered cubic (b.c.c.). Cold worked materials should be heat treated more slowly than stress-free materials to avoid distortion.

The following Iron Carbon Phase Diagram illustrates the areas where the different structural formations occur.

During the heat treatment process, cap screws are brought to a controlled red-hot temperature of approximately 1666ºF (908ºC) in the gas fired ovens. This temperature is usually above the upper critical temperature in order to form austenite. Time and controlled temperatures will produce steel with very high hardness: some steels will achieve a hardness up to 55 HRC (Hardness, Rockwell C scale). As a finished product, this is not desirable as the steel is brittle and further processing is necessary.

Special monitors in the gas fired ovens control the natural gas and oxygen mixture to control the free carbon atmosphere to avoid unintentional carburization or decarburization. Carburization would produce excessive surface hardness from the addition of carbon from the natural gas, while decarburization would rob the threads of their strength by removing carbon from the surface of the thread crests.

The importance of exact temperatures, times and cooling rates are extremely critical, which is why these "thresholds" are called upper and lower critical temperatures. When steel is heated above its critical temperature, its crystalline structure changes to austenite. Austenite can hold more carbon in its structure than other forms of iron. As the steel parts are withdrawn from the furnace, the parts begin to cool very rapidly. It is when the steel reaches a temperature of 1333ºF (732ºC) that it becomes necessary to control the cooling rate. This temperature is the 'lower transformation line', also known as the Eutectoid Temperature. It is the same for all iron and steels. If the austenite was allowed to cool naturally, it will turn into α-ferrite (b.c.c.) and cementite (iron carbide).

The goal of hardening the steel is to produce a fine grain, fully martensitic microstructure, as it is much harder than austenite. Martensite is formed upon cooling. The minimum cooling rate (ºF or ºC per second) that will avoid the formation of any softer products of transformation is known as the critical cooling rate. ■