

BASIC HEAT TREATING FOR FASTENERS

by Guy Avellon

There are a variety of material compositions that are fed in wire form into a bolt making machine. The fastener materials may be either ferrous or nonferrous. All the bolt making machine does is to dimensionally shape and form the wire to look like a finished fastener; whether it is hex, square, flanged or stud.

Wire forms are drawn and / or extruded to smaller dimensions. Even though this aligns the grains somewhat, the grains are in a new position and need to be relieved of residual stresses. Prior to forming, steel wire coils are subjected to a form of annealing called spheroidizing. This process effectively aligns the grain structure to run in one direction, thereby increasing its pliability and making it easier to be cold formed.

After the bolt-maker completes the physical form of the cap screw or stud, steel and alloy steels may be further processed; such as SAE Grade 5 (ISO 8.8, 9.8) and Grade 8 (10.9) fasteners are heat treated at higher temperatures to increase their hardness and tensile strength. The SAE Grade 2 (5.8) fasteners are not heat treated because their carbon content is too low. The carbon content should be at least 0.20% and alloyed with boron to effectively increase the steel's hardness and tensile strength. However, some low carbon steel fasteners are required or recommended that they are stress relieved. The ASTM A307 mandates the stress relief of all cold headed fasteners with a head configuration other than hex.

Normalizing is different than stress relief annealing, though sometimes the two terms become confused. **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). Normalizing, when used, is performed at 100°F (38°C) above the upper critical temperature of the steel.**

Heat Treatment

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. Though complex, this article will try to bring understanding to this important process.

After the threads are roll formed, special care is exercised in handling, as the fastener is relatively soft and susceptible to thread nicking damage. Therefore, it is desirable to minimize the amount of handling and tumbling of large diameter fasteners. Contract heat treaters will use either batch loading, where the cap screws remain at rest in a basket which is slowly pushed through the ovens, or a continuous furnace belt loader on which the fasteners are free to move along the belt. Many in-house bolt manufacturers use the continuous furnace process.

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, while decarburization would rob the threads of their strength by removing carbon from the surface of the thread crests.

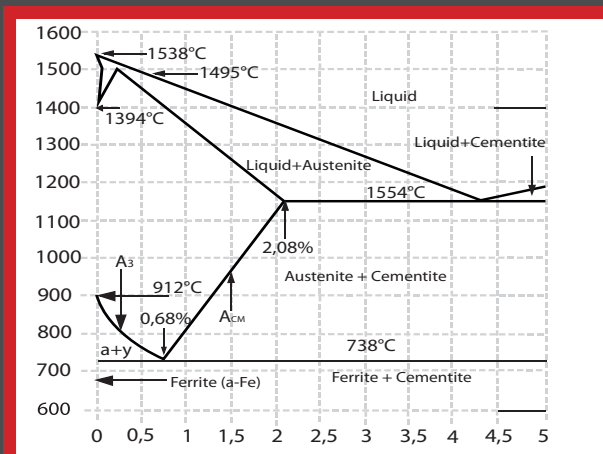
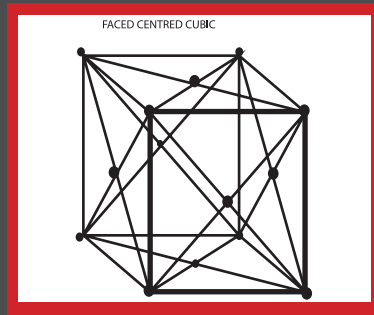
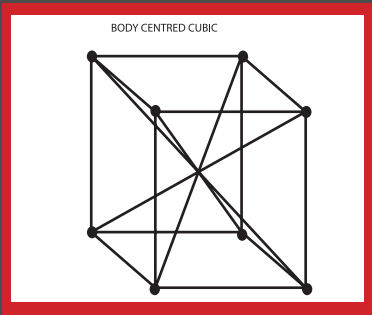
During the heat treatment process, cap screws are brought to a controlled red hot temperature of 1666°F (908°C) in gas fired ovens. This temperature is usually above the upper critical temperature in order to form austenite. Time and controlled temperatures will produce steel with very high hardness: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

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 crystallizes 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 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).

Medium carbon steels are hypoeutectic and contain less than 0.80% by weight of carbon. Hyper-eutectic steels contain between 0.8 and 2% carbon. Cast irons contain more than 2% carbon. An iron-iron carbide equilibrium diagram (shown below) 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.



Controlled Quenching

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 (°F or °C per second) that will avoid the formation of any softer products of transformation is known as the critical cooling rate.

Before heating and quenching any steel, a test must be performed to determine its hardenability. This

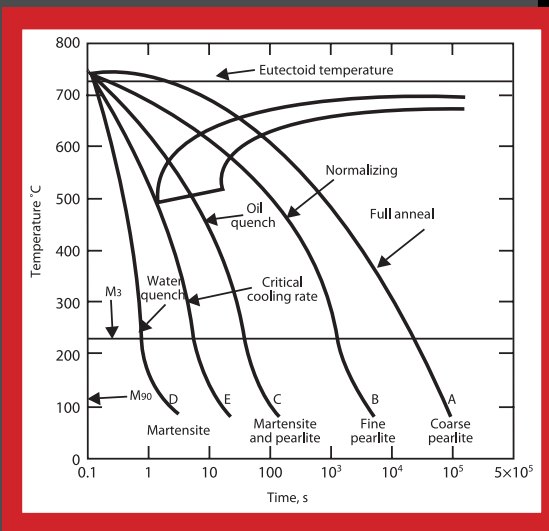
is called the end-quench hardenability test, or the Jominy test. After heat treating and quenching per standard methods, hardness readings are taken at 1/16" intervals from the quenched end at a depth of 0.015". Each location on the test piece represents a certain cooling rate.

The combination of heat treating and quenching refines the structure of the steel to enhance its physical characteristics. During the quench, the cap screw's temperature may be brought from above the upper transformation temperature to 600°F (316°C) in 2 seconds.

The critical cooling rate is determined by the chemical composition of the steel, the Jominy test and the austenitic grain size. These factors influence how fast steel must be cooled in order to form only martensite. **How the steel cools will determine its properties.**

For each steel and alloy, there is a cooling guide called a 'Time-Temperature-Transformation' graph, or TTT for short. It is also known as an Isothermal Transformation Diagram. This is illustrated below.

The bottom axis of the graph is the logarithmic time in seconds. It becomes apparent that the cooling rate must be very fast once the steel cools to 1333°F (723°C) to go from austenite to martensite. Misjudge the time and the structure becomes something else. The cooling path chosen determines the structure and properties of the steel.



The SAE J429 and certain ASTM product standards specify oil quenching on special alloys, such as; A354 BD and SAE Grade 8 cap screws, as well as 1/4" through 3/4" diameter A449 cap screws. The SAE J429 permits water quench on grades 5 and 5.2. Larger diameter A449 fasteners may be quenched in water. **The choice of the quenching liquid is determined by the amount of heat which must be dissipated, a function of the cap screw's cross-sectional area of diameter, and the steel to be quenched. Oil quenchants have been the preferred medium for controlled and rapid cooling rates.**

After quenching, the tensile strength and hardness of the cap screw exceed optimum levels. The SAE J429 specifies a microstructure of approximately 90% martensite prior to tempering. The 'as quenched' hardnesses are also taken to confirm core hardness. Since the hardnesses are high enough to produce a brittle material, the cap screws must be 'softened' from another heat treating process. This second heat treat is called tempering.

Tempering

Tempering is required to relieve the internal stresses that are built up during the initial heat treat hardening process. Tempering is similar to the annealing process carried out on the raw steel wire prior to bolt-making procedures. Tempering takes the super hardened martensitic structure and makes the cap screw less brittle and more ductile by relieving the internal residual stresses and improving its toughness. This treatment also increases the steel's shock resistance, and lowers the tensile strength to desirable levels.

It is this combination of heat treating, quenching and tempering that imparts a cap screw with its final physical specifications of hardness, proof load, yield strength and tensile strength. Steel that has a fully martensitic structure before tempering will produce the highest yield strength, the highest ductility, the highest fatigue strength and the greatest toughness.

Some high strength specialty bolts begin life with a steel differing in composition from standard ASTM or SAE recommended chemical compositions. The basic difference is during the tempering process. Unless enhanced alloys are used and special care is taken with the heat treating process, cap screws with higher than standard specification tensile strength and hardness are also more brittle. Regardless of the steel choice, it is the heat treatment that determines the fastener's final characteristics.