MAY 2002 / VOLUME 54 / NUMBER 5

BY STEVEN A. BATZER, PH.D.

Blowing Hot & Cold

To fully appreciate the value of cryogenic treatment, an understanding of conventional heat treatment is necessary.

Conventional, nonexotic steels are normally heat-treated by a three-step process:

1. Austenitizing. Heating the annealed steel to form carbon-soluble austenite.

2. Quenching. Rapidly cooling the steel to form martensite.

3. Tempering. Reheating the steel to a temperature below the austenitic range to reorganize the microstructure, forming ferrite plus finely dispersed Fe_3C carbides. Highly alloyed steels may be tempered multiple times to precipitate carbides completely.

The austenizing and quenching steps are called hardening. Carbon is insoluble in room-temperature, body-centered-cubic (BCC) iron, as there is insufficient void space for carbon atoms. Therefore, at room temperature, carbon steels show microsegregation into two regions. One is virtually pure iron (ferrite), and the other is made of carbon-rich carbides called cementite.

For the carbides to disperse more efficiently, allowing the steel to harden, the carbon must become soluble in the iron. By elevating the temperature of the alloy above the upper critical temperature, ferrite changes to austenite and the carbon becomes fully soluble. The hard carbides dissolve and, therefore, by diffusion, the carbon becomes fully dispersed through the austenite.

After austenizing, the alloy transforms back into relatively soft pearlite, if cooled in a slow, near-equilibrium fashion. Therefore, it is necessary to quench the alloy to prevent diffusion-based reorganization and lock in the dispersed carbon. Upon quenching, the face-centered-cubic austenite attempts to revert back to BCC. One of the atoms at the face moves back into the center and displaces the carbon atom, which migrates to a position between two corner atoms, distorting the normal BCC structure into a body-centered-tetragonal structure.

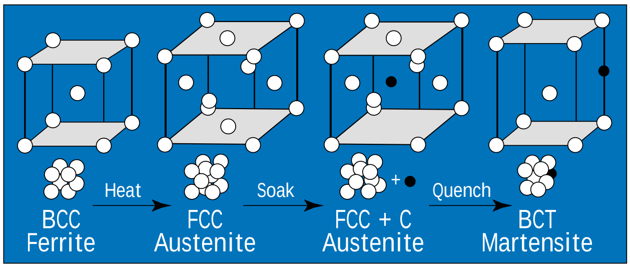
Martensite formation is a shear-based process—not diffusion-based. There is no migration of carbon atoms. At the proper temperature, the lattice stresses become sufficient to force the change.

It is convenient to think of martensite as a supersaturated solution of carbon in alpha iron. It forms either a needle-shaped structure or plates at higher concentrations of carbon. The martensite spears reside in a region of soft, untransformed austenite known as retained austenite.

When there is enough energy added during the tempering process to drive diffusion, the carbon agglomerates and forms small, blocky particles of cementite. Then the martensite transforms into tempered martensite. The greater the added energy, the greater the agglomeration of carbides. This means that the carbides are less finely dispersed and the steel becomes softer.

If, during tempering, the temperature of the martensite is raised above the lower critical temperature, the carbon will go back into solution over time, and the process will not work. This is because pearlite will be formed upon cooling.

The difference between annealed-and-quenched steel and



This illustration shows an iron grain structure as it changes from ferrite to martensite with the heat-induced migration of carbide. Body-centered-cubic (BCC) ferrite describes a crystal having an iron atom at each corner of a cube and a single iron atom in the center of the cube. An austenitic face-centered-cubic (FCC) structure has iron atoms at each of the eight corners of the cube and an additional iron atom centered in each of the cube's six faces. A martensitic body-centered-tetragonal (BCT) structure is basically a cube with one elongated leg to accommodate the carbon atom that was pushed out of the center by an iron atom. BCT has an iron atom at each corner and in the center.

tempered steel is not the volume of carbides, but their effective dispersal. It is more efficient to have millions of small carbides than an equal volume consisting of thousands of larger carbides.

Cryogenic Treatment

Cryogenic treatment is a straightforward process. During the treatment, the steel cools after quenching to cause microstructural changes. The steel does not freeze, since it's already solid.

Due to the alloying strategies of many steels, the martensite finish (M_f) temperature is often well below room temperature. After a conventional quench, significant amounts of retained austenite remain. This retained austenite is unstable and generally undesirable.

By itself, cryogenic treatment is incomplete. Retained austenite does not transform to tempered martensite, but rather to simple body-centered-tetragonal, untempered martensite. Untempered martensite is relatively unstable, brittle and may quickly lead to surface cracking of the part. Therefore, tempering is the critical post-cryogenic procedure because it ensures both part stability and surface integrity.

Cryogenic treatment is an indirect stress-relieving process. Some processors indicate that they cryogenically stress-relieve steel parts, but that is not entirely true. Stress relieving is accomplished by adding heat to facilitate diffusion and move crystallographic dislocations.

Other processors offer multiple cryogenic treatments, which may be unnecessary due to the law of diminishing returns. Also, secondary tempers made after cryogenic treatment can cause softening of the alloy due to coarsening of the primary carbides.

About the Author

Stephen A. Batzer, Ph.D., P.E., is an associate professor in the Mechanical Engineering Department at the University of Arkansas, Fayetteville. E-mail: batzer@engr.uark.edu.