Heat Treating

Training Objective

After watching this video and reviewing the printed material, the student/trainee will learn the basic concepts of the heat treating processes as they pertain to carbon and alloy steels.

- Metallic crystal and grain structure are defined.
- The heat treating phase diagram is introduced.
- The concept of “alloying” to enhance mechanical properties is explained.
- The methods for hardening, tempering, and softening are detailed.

Heat treating processes are used to alter the metallurgical structure of metals and in doing so impart specific mechanical properties. While all metals and alloys will respond to heat treatment in some way, understanding the thermal effects on the carbon and alloy steels is particularly important. These steels are ferrous alloys, meaning they contain more than 50 percent iron. Other ferrous types are the tool steel, cast irons, and the stainless steels.

The mechanical properties of metal affected by heat treatment are:

- **Tensile strength** that is a measure of the force required to permanently deform the metal by stretching. This point is termed “yield strength.” Ultimate tensile strength is the force required to fracture the metal.
- **Ductility** is the ability of the metal to bend or stretch before fracture. Aluminum is a metal of high ductility, while cast iron has very low ductility.
- **Impact strength** (toughness) is the metal’s ability to absorb mechanical shock (impact) without fracturing.
- **Hardness** is the ability of the metal to resist penetration, wear, and surface scratching. Hardness testing results are expressed as hardness number.

When molten metal solidifies, atoms become arranged in recognizable patterns called crystal structures and may be found as either body-centered cubic or face-centered cubic. Crystals will grow uniformly in all directions and as the metal continues to cool, each crystal is confined by adjacent crystals forming grains. Points of intersection between grains are called “grain boundaries.”

The atoms in the crystalline structures are bound in place by electromagnetic force. Under a load these magnetic bonds stretch. As the load or stress ceases, the atoms return to their normal position. When an excessive force is applied, the bonds sever causing permanent deformation in the metal.

To make metals stronger and more resistant to deformation, the crystalline structure is improved by adding alloying elements. Typical alloying elements added to metals include:

- carbon
- manganese
- chromium
- molybdenum
- silicon
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Beyond the simple addition of these and other elements, heat treatment is used to gain maximum strengths afforded by the alloying. There are three main heat treating processes. They are:

- **Through hardening** - affecting the metal throughout its cross section
- **Surface hardening** - forming a shell of metal with particular qualities different from those at the center
- **Softening processes** - used to decrease hardness and brittleness

Hardening or strengthening is the most used heat treating processes. They include:

- harden and temper
- quench and temper
- harden and draw
- austenitize, quench, and temper

These processes occur in three stages:

- heat to a point where the basic metallurgical structure changes
- quench to obtain an even harder state
- temper or re-heat to obtain a specific level of hardness

A “phase diagram” can graphically show temperature and cooling duration’s which depict actual instances of metallurgical changes. Hardening processes begin with a breaking down of an alloy’s ferrite and cementite by heating to a specific level at which more carbon can be absorbed. Quenching at the proper time prevents reforming of the ferrite and cementite. The common microstructures produced by austenitizing and quenching are bainite and martensite with the latter requiring tempering. Quenching speed, time, and the quenching medium is dependent upon the metallurgical structure required in the steel. Generally steels should not be quenched any faster than necessary. Quench mediums can include brine, water, synthetic polymers, oil, and air. The temperature of the quench medium is an important factor for consistent results.

The quenched parts, though stronger and harder, are also very brittle and prone to cracking and shattering. This brittleness is removed by tempering and drawing. In the hardening process, two significant factors affect the properties of the quenched metal. First is the austenite grain size and the second is the size or mass of the workpiece.

The longer the work is held above the critical transformation temperature, the larger the grain size growth, further increasing the hardness. In respect to the size of the workpiece, the heavier the cross-section, the slower the cooling and the less quench effect at the center.

Marten tempering and austen tempering are two modified hardening methods that produce good strength characteristics without creating excess internal stresses. Both processes use salt baths and critical timing down to room temperature and subsequent tempering.

Case hardening is used to produce a hard, wear resistant surface over a tough and shock resistant center. The two methods of case hardening are
Differential Heat Treating and Differential Metal Structure. Differential heat treating, using either flame or induction heating, heats up the surface of the work very quickly while the center remains relatively cooler. When the surface reaches austenitizing temperature, the part is quickly quenched.

The differential metal structure method actually alters the chemical composition of the surface of the work only. The entire workpiece can then be subjected to the same heat treating cycle with the surface becoming harder than the interior. The chemical alteration is accomplished by “carburizing” and “nitriding.” Both of these processes infuse either carbon or nitrogen to the surface layers, and at specific temperatures, alloy the surface only. Beyond hardening the workpiece, heat treating can also be used to soften metals that through cold working, machining, and welding, have acquired residual stresses and have hardened, increasing the chance of fracture.

The three principle softening methods are:

- **Annealing** - heating to a point where deformed grain structure recrystallizes and the metal softens
- **Normalizing** - heat to a point above the metal’s upper transformation point, then air cooled to room temperature
- **Stress relieving** - heating a workpiece to a low or moderate temperature and holding it for a specific time period at that temperature, then air cooled to room temperature
Review Questions

1. A ferrous metal is one whose iron content is more than:
   a. 10%
   b. 25%
   c. 30%
   d. 50%

2. Impact strength refers to a metal’s:
   a. ductility
   b. toughness
   c. elasticity
   d. hardness

3. Grain boundaries occur:
   a. just below the metal’s surface
   b. at the core of the workpiece
   c. where even grains intersect
   d. between atoms

4. The force holding atoms in place and in alignment is called:
   a. molecular force
   b. magnetic force
   c. electromagnetic force
   d. bonding force

5. Tempering requires the workpiece to be:
   a. quenched
   b. heated and quenched
   c. reheated and quenched
   d. held in an oven

6. A pictorial representation of critical heat treating temperatures is called a:
   a. cycle diagram
   b. alloy absorption diagram
   c. phase diagram
   d. interface diagram

7. Marten and austen tempering use:
   a. salt baths
   b. oil baths
   c. water baths
   d. air cooling only

8. Differential heat treating and differential metal structure refer to:
   a. stress relieving
   b. case hardening
   c. tempering
   d. normalizing

9. Carburizing and nitriding affect the metal’s surface by adding:
   a. ductility
   b. toughness
   c. hardness
   d. temper
10. Stress relieving temperatures are usually:
   a. low to moderate
   b. high
   c. 1/2 the metal’s melting temperature
   d. at room temperature
Answer Key
1. d
2. b
3. d
4. c
5. c
6. c
7. a
8. b
9. c
10. a
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Heat Treating Glossary

**Austempering** - A special tempering technique in which dwell temperature is maintained slightly above the martensitic transformation temperature for a long period of time.

**Austenite** - One of the basic steel structures wherein carbon is dissolved in iron. Austenite occurs at elevated temperatures.

**Austenitic** - Steel that has the structural form of austenite.

**Bainite** - A steel structure that is harder than pearlite, cementite, or ferrite and more ductile than martensite.

**Body-centered cubic** - One of the common types of unit cells. This arrangement is typical of the ferritic form of iron.

**Cementite** - A very hard structural form of low-temperature steel that contains more than 0.8% carbon. Cementite occurs in steel that has not been previously heat treated or in steel that has been cooled slowly after being transformed into austenite.

**Crystal** - A lattice structure of atoms in solidified metal.

**Crystallization** - Formation of crystals as a metal solidifies. The atoms assume definite positions in the crystal lattice.

**Face-centered cubic** - One of the common types of unit cells in which atoms are located on each corner and the center of each face of a cube. This arrangement is typical of the austenitic form of iron.

**Ferrite** - A structural form of low-temperature steel that contains a very small percentage of carbon. Ferrite occurs in steel that has not been previously heat treated or in steel that has been cooled slowly after being transformed into austenite.

**Ferritic** - Steel containing ferrite.

**Lower transformation temperature** - The temperature at which the transformation of iron to austenite begins and the body-centered cubic structure starts to change to face-centered cubic.

**Martempering** - A special tempering process in which steel is held at a specific temperature during quenching, cooled to room temperature, and then re-heated to a tempering temperature to produce tempered martensite.

**Martensite** - A very hard, brittle structure of steel produced when steel is rapidly quenched after being transformed into austenite.

**Pearlite** - A mixture of ferrite and cementite that contains approximately 0.8% carbon. Pearlite occurs in low-temperature steel that has not been previously heat treated or in steel that has been cooled slowly after being transformed into austenite.
Upper transformation temperature - The temperature at which the transformation of iron to austenite is complete and the body-centered cubic structure has completely changed to face-centered cubic.