Heat Treatment of Iron

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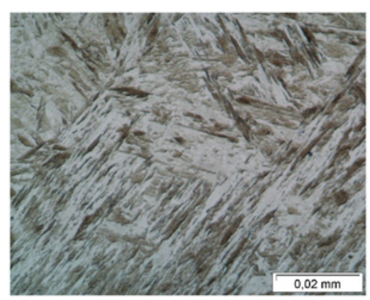
The purpose of this experiment is to investigate the effects of heat-treating on the properties of iron.

Background

Iron (element 26, atomic weight 55.845) is one of the most common metals encountered in everyday life. It has been used for over 2000 years to make tools, cooking utensils, weapons, and machinery. Although iron has a bright silvery surface when polished, it is quickly oxidized in moist air to form rust, a red-brown mixture of FeO and Fe_2O_3 usually written as Fe_3O_4. Iron, itself, has a hardness of 4 on the Mohs hardness scale (talc has a hardness of 1, copper has a hardness of 3, and diamond has a hardness of 10), but is made harder by alloying it with carbon, silicon or other metals to form carbon steel, nickel stainless steel, or other specialty steels. (Steels have a hardness of about 7). Iron is attracted to a magnet and also has the property of being ferromagnetic, a result of its crystal structure being aligned in one direction.

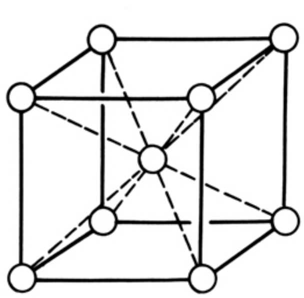
Depending on how the iron is processed, it can take various forms. Pig iron, with about 4-5% carbon and some other metallic impurities is usually used for cast articles such as stoves, cookware, pipes, lampposts and rails. Iron can be made hard and brittle by heating to a high temperature and then quenching it quickly in water. In this form, the iron is more amorphous than crystalline. Hardened iron is useful for making knives and swords. If the iron is heated and allowed to cool slowly, a process called **annealing**, then the crystal structure is organized and the iron is softer and easier to bend as atoms can slide over one another. **Tempering** is the process of heating the hardened iron enough to allow some crystals to reform, but still retains some of the amorphous structure. Tempered iron has more spring than the hardened iron.

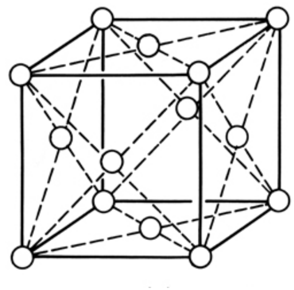
Hardened steel has a structure called the Martensite phase. This phase is named after the German metallurgist Adolf Martens (1850–1914), who, in the 1890s, studied samples of different steels under a microscope, and found that the hardest steels had a regular crystalline structure of plate shaped crystal grains. The Martensite is formed by rapid cooling (quenching) of Austenite iron which traps carbon atoms (in carbon steel) that do not have time to diffuse out of the crystal structure.

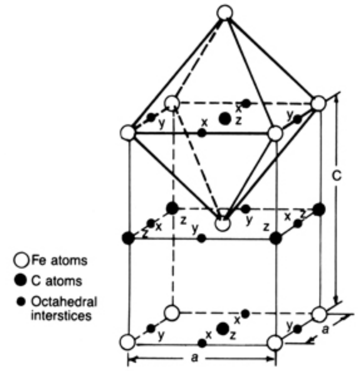


The Austenite phase is named named after Sir William Chandler Roberts-Austen (1843-1902). In this high temperature phase, iron changes it crystal structure from body-centered cubic to face-centered centered resulting in a softer and ductile form of iron which is non-ferromagnetic. The temperature at which a metal alloy changes from a magnetic to a non-magnetic state is known as the Curie point and is usually very close to the austenite transformation temperature.

The martensite and austenite phases occur in other metals in addition to iron.







The body-centered cubic structure of iron crystals (left, above) allow for the easy bending of iron while the face-centered crystal structure (center, above) of the austenite phase allows space for carbon atoms to “dissolve” into the crystal lattice. When quenched, the martensite phase contains a body-centred tetragonal lattice structure (right, above). This crystal lattice is like a vertically elongated body-centred cubic crystal lattice with the carbon atoms trapped in the crystal lattice during transformation. This results in high internal stresses, making martensite hard, but also brittle.

Materials Needed

four bobby pins
300 mL of cold water in a 400 mL beaker
magnet
Bunsen burner
Matches or striker
Crucible tongs
Forceps

Procedure

Examine one of the bobby pins. Try bending it. How easily does it bend? Is it springy (does it return to its original shape after bending)? Is the bobby pin attracted to a magnet? Write your observations on the data page and tape this bobby pin to your data page in the designated area.

Light the Bunsen burner.

Grasp one side of the open end of the bobby pin with tongs. Hold the bent end in the hottest part of the Bunsen burner flame. As the pin heats up and glows red, use the forceps to bend it straight and remove it from the flame. Repeat this with the other two bobby pins.

Holding a straightened pin in the middle with tongs, heat the entire wire to a glowing red-hot temperature. Let it cool slowly. This process is called **annealing**. Repeat this with the other two bobby pins. When one of the two bobby pins is red hot, hold the magnet near it. Is it attracted to the magnet?

When the annealed wires have cooled, bend them into hooks. Do the wires bend more easily now after they have been heated? Are they as springy as they were before? Are they attracted to a magnet? Write your observations on the data page.

Tape one of your annealed hooks to the data page.

Place the beaker of water next to the Bunsen burner. Holding one of the hooks with tongs, heat it to a glowing red-hot temperature in the flame of the Bunsen burner. **Quickly** cool by dropping the red hot hook into the beaker of cold water. Repeat this with the other hook. This will form hardened iron.

Remove one of the hardened iron hooks from the water. Try bending it. Does it bend as easily as before? Are the hardened hooks attracted to a magnet? Write your observations on the data page. Tape the pieces of this hardened iron to the data page.

Remove the other hook from the water. Grasp it with the tongs and hold it way above the Bunsen burner flame. **Slowly** lower it toward the top part of the flame until an iridescent blue coating forms on the hook. It must NOT be heated to a glowing red heat, so keep it out of the hottest region of the flame. Allow the hook to cool slowly. This forms tempered iron.

Try bending this hook. It is brittle or springy? Is it attracted to a magnet? Write your observations on the data page. Tape it to your worksheet.

Reference

Chemistry Can Be Fun, Summer 1993 (Day 3 Metals & Alloys booklet), Institute for Chemical Education (ICE), Department of Chemistry, University of Northern Colorado, Greeley, CO

Heat Treatment of Iron
Data and Results

Name ____ Date _________________

Partner(s) _______________________________________ Course ___________________

1. Observations of a normal bobby pin.

2. Observations of an annealed bobby pin.

3. Observations of a hardened bobby pin.

4. Observations of a tempered bobby pin.

Tape your samples here.

ORIGINAL BOBBY PIN (NOW BENT)	ANNEALED HOOK	HARDENED HOOK	TEMPERED HOOK