

Heat Treatment of Metals

Annealing, Hardening, and Tempering



Introduction

Heat treatment of metals is used to increase their hardness and their “workability”—their ability to be bent and shaped. Annealing, hardening, and tempering are examples of changes that occur in the physical properties of metals as they are heated and cooled. The changes are related to the crystal structure of the metal.

Concepts

- Properties of metals
- Crystal structure
- Body-centered cubic
- Face-centered cubic

Materials

Bobby pins, 16
Bunsen burner
Beaker, 250-mL

Crucible tongs
Heat-resistant pad or wire gauze
Water, tap

Safety Precautions

Exercise care when working with hot metals. Wear chemical splash goggles and heat-resistant gloves whenever working with heat, chemicals or glassware in the lab.

Procedure

1. Ask students to describe the properties of the metal in a bobby pin. Determine the average number of times a bobby pin can be bent back and forth before it will break. (*On average, a bobby pin will break after it has been straightened out and rebent seven times.*)
2. Hold the ends of a bobby pin with crucible tongs. Heat the bend of the pin in a burner flame until the metal is red hot. Place the pin on a heat-resistant surface and allow it to cool to room temperature. Repeat if desired to obtain several samples for testing.
3. Test the properties of the metal: Count the number of times the treated pins can be bent back and forth before breaking. (*The treated pins are easier to bend but more difficult to break—the treated pins can be bent back and forth about 12 times before breaking.*)
4. Steps 2 and 3 represent the *annealing* process. Define annealing. (*Annealing is the process of strong heating followed by slow cooling. Annealing softens a metal and makes it less brittle.*)
5. Hold the ends of a bobby pin with crucible tongs and heat the pin in a burner flame until it is red hot. Immediately drop the pin into a beaker filled with cold water. Repeat if desired.
6. Remove the pins from the water and dry them. Test the properties of the metal: Count the number of times the treated pins can be bent back and forth before breaking. (*The pins are extremely hard to bend but break easily—on average, the pins break on the first try!*)
7. Steps 5 and 6 represent the *hardening* process. Define hardening. (*Hardening is the process of strong heating followed by “quenching” or rapid cooling. Hardening makes a metal very rigid and brittle.*)
8. Heat a bobby pin until it is red hot, then drop it into cold water to cool it quickly. Dry the pin and *gently* reheat the pin by holding it above a burner flame until it acquires a blue oxide coating. Place the pin on a heat-resistant surface and allow to cool to room temperature. Repeat if desired.
9. Test the properties of the metal: Count the number of times the treated pins can be bent back and forth before breaking. (*The pins are hard but “springy”—they do not break.*)

10. Steps 8 and 9 represent the *tempering* process. Define tempering. (*Tempering is the process of strong heating and rapid cooling followed by gentle reheating and slow cooling. Tempering reduces the extreme hardness of the metal but increases its “toughness.” The tempered metal is nonbrittle.*)

Disposal

Consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Used metal pins may be disposed of in the trash according to Flinn Suggested Disposal Method #26a.

Tips

- Refer to the discussion of metal crystal structure to explain the properties of metals. Models of face-centered cubic (FCC) and body-centered cubic (BCC) crystal structures will help students visualize the changes that are observed. The “Cubic Unit Cell Model” available from Flinn Scientific (Catalog No. AP7037) is a versatile super-size model and a valuable teaching aid for demonstrating crystal lattice structure.
- Metals that crystallize in the BCC crystal structure include vanadium, chromium, manganese, iron, and all of the alkali metals. Metals that crystallize in the FCC crystal structure include aluminum, lead, copper, silver, and gold.
- The FCC structure is an example of “closest packing” of solids—identical atoms are packed as closely as possible into a given space. If one assumes that the atoms behave as small spheres, the atoms occupy 74% of the volume of the FCC crystal structure and have a coordination number of 12. This is the maximum coordination number and maximum density possible for atoms in a solid lattice composed of small “spheres.”

Discussion

Bobby pins are made of steel—iron that has been alloyed with about 1% carbon to improve its hardness and toughness. Heat treatment affects the crystal structure of the metal. At room temperature, steel crystallizes in a body-centered cubic (BCC) structure called *alpha*-ferrite. This BCC structure does not dissolve carbon and is soft and ductile. Heating the BCC form transforms it into a face-centered cubic (FCC) crystal structure that dissolves carbon and is very hard. Sudden cooling of the high-temperature FCC structure by quenching it in water (hardening) causes the dissolved carbon atoms to become trapped in the BCC lattice. The resulting stress and distortions in the crystal structure make the metal extremely hard but also very brittle. This form of iron is called martensite. Slow cooling of the high-temperature FCC structure (annealing) allows the iron to crystallize in the stable BCC form and the carbon to precipitate out in the form of large particles that cause minimal disruption or dislocation of the crystal structure. The result is a soft, nonbrittle, very workable form of the metal. Gentle reheating of the hardened form followed by slow cooling (tempering) allows the trapped carbon to precipitate and removes many of the internal stresses in the distorted martensite crystal structure. This reduces the extreme hardness of the metal but also eliminates the brittleness. The tempered metal is very strong yet still “workable.”

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12

- Evidence, models, and explanation
- Constancy, change, and measurement

Content Standards: Grades 9–12

- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science, structure and properties of matter, conservation of energy and increase in disorder, interactions of energy and matter
- Content Standard F: Science in Personal and Social Perspectives, science and technology in local, national, and global challenges
- Content Standard G: History and Nature of Science, science as a human endeavor

Acknowledgments

We are grateful to Penney Sconzo, Westminster Academy, Atlanta, GA, for sharing the idea and instructions for this activity.

References

This activity was adapted from *Chemical Bonding*, Volume 5 in the *Flinn ChemTopic™ Labs* series; Cesa, I., Editor; Flinn Scientific, Inc., Batavia, IL (2004).

Materials for *Heat Treatment of Metals* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP5344	Bunsen Burner, Adjustable, Natural Gas
AP7037	Cubic Unit Cells Model
AP7098	Models of Ionic and Metallic Crystals

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.