

Work Hardening and Annealing of Copper

Thomas Stoebe
University of Washington
Seattle, WA
stoebe@u.washington.edu

Copyright Edmonds Community College 2007; Permission granted for use and reproduction for educational purposes only.

Abstract:

This experiment demonstrates the process of work hardening in a copper, that is, hardening the metal by deformation. If an appropriate furnace is available, it also demonstrates the softening process of annealing. Copper wire or tubing is quite soft in its initial state, allowing for a variety of uses where the tubing needs to be bent to a desired shape. Upon bending, the copper hardens due to work hardening (also called strain hardening). Enough bending will make it impossible to return it to its original shape. However, annealing at a high enough temperature causes new, strain-free material to form and the copper will return to its original soft condition.

Objectives: Students will be able to
Experience the process of work hardening
Explain the effects of work hardening in metals
Experience property changes affected by annealing

MatEd core competencies addressed (most important in bold):

- 4A Demonstrate effective work with teams
- 7A Illustrate the general nature of metals
- 8B Apply mechanical testing processes to solid materials
- 16A Distinguish effects of processing on materials properties**

Key words: copper, work hardening, annealing, properties

Type of Module: Demonstration with class participation or lab experiment

Time required:

5 to 10 minutes for deformation and discussion
30 min. for annealing, 10 min for cooling
5 to 10 minutes for deformation of the annealed specimens

Target Grade Levels:

Grades 4 and up will appreciate the experiment as a demonstration.
High School and College level students will be able to do the experiment in detail and follow up with detailed conclusions

Equipment and supplies needed

Supply of copper wire or tubing.

If tubing, use ¼ or 3/8 inch diameter copper tubing, soft condition (often comes in a roll—if so, do not straighten it too much as that could harden it)

If wire, use 8 or 10 gage solid core wire; if electrical wire, strip the insulation.

Propane torch or annealing oven capable of 1000 degrees F (500 degrees C) or more (perhaps available in a ceramics lab)

Instructor information and notes

Copper has a cubic crystal structure (Face Centered Cubic) that gives it high ductility. Bending the copper causes work hardening (or strain hardening) because working or straining the copper introduces defects, known as dislocations, into the structure. These defects interfere with further deformation, making the copper harder and stronger, thus making it more difficult to bend further. Copper tubing is used here because it is readily available in hardware stores. Caution must be taken on bending, however, as it can crimp if bent too far too fast. Thus the instruction to bend it slowly. After bending, the material is harder and thus more difficult to re-bend it to its original condition. The best effect is to have a person of average physical condition do the bending, then ask an obviously strong person to un-bend the copper (this person will typically not be able to get the copper back to its original shape).

Annealing the copper requires a high temperature. Copper melts at 1357 Kelvin and annealing generally occurs at greater than half the melting point in degrees K; even higher temperature causes faster annealing (but not past the melting temperature, of course). Typical temperature to use is 400C or 700F. Annealing causes the structure to create and grow new grains that are free of strain. The new grains remove all dislocations and other defects caused by the deformation, thus leaving the material in its original soft condition, although NOT in its original shape—it will still be the same shape as after deformation, but can be easily bent again. Annealing takes time and temperature, so that this part of the experiment can only be done with a high enough temperature annealing furnace or in a propane torch. If not readily available, the copper can be taken elsewhere and annealed, then presented to the class at a later date in its annealed condition.

A more advanced module that looks at changes in microstructure during deformation and annealing in brass is available as the MatEd module "Hardness of Brass: Effect of Rolling and Annealing."

A few notes:

- Cooling rate after annealing does not matter (except at 10 million degrees per second the material would get harder again)
- This is not 'heat treating.' Heat treating of actually causes a change in crystal structure, typically used in steel. There is no change in crystal structure in this experiment.
- Some types of copper wire come in a hardened condition, in which case the wire should be annealed prior to the experiment.

- Aluminum, silver and gold have the same crystal structure as copper and exhibit the same characteristics. Melting temperatures are different so that annealing is at different temperatures for different materials. Aluminum melts at 933K, 660C and annealing is done at about 200C.

Experimental process

1. Prepare lengths of copper wire, 6 to 10 inches long, or tubing, 1 to 1.5 ft in length.
2. Ask selected class members to slowly bend the copper—careful not to cause crimping.
3. Once bent, ask another class member to unbend the copper.
4. Discuss why the copper cannot be fully unbent due to work hardening.
5. Now work harden the copper more by hammering the copper into a flat rod.
6. If available, anneal the tubing at a high temperature (400C or 700F or higher)
7. After annealing, remove from the furnace and quench in water to cool
8. Re-bend and note that the material is soft again.

Further study for students

1. Do the same experiment with aluminum (aluminum wire is usually available for electrical wiring at a hardware store—but the experiment is more difficult (see reference 2)). Be sure to look up the melting temperature of pure Al then calculate the best annealing temperature.
2. Research the process of work hardening—what are the defects and how are they formed?
3. Research the annealing process. How does the structure change during annealing?

References

1. <http://www.webelements.com/webelements/elements/text/Cu/key.html>
2. On copper and aluminum wire
<http://www.evergreengardenworks.com/copperwi2.htm>
3. An extension of this activity is available in the MAST modules at
<http://matse1.matse.illinois.edu/metals/c.html>

Evaluation:

Student evaluation questions (discussion or quiz):

1. Why is it easy to bend the copper at the beginning? Explain.
2. Why is it difficult to unbend it? Explain.
3. What does annealing do to make the material easier to bend?
4. Why does temperature of annealing matter?
5. Machinists who machine metal often stop during the process of machining and anneal the metals they are working on. Explain why they do this.

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?

3. Did the activity work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the activity generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the activity clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?