Module Title: Work Hardening and Annealing of Metals		
Lab compiled by: Tom Stoebe, MatEd Partner	Address:	Email: tgstoebe@earthlink.net

Time to complete module:

5 to 10 minutes for deformation and discussion
1 hour for annealing
5 to 10 minutes for deformation of the annealed specimen

Description of module, lab or demonstration:

Students will explore the process of work hardening or strain hardening of copper wire or tubing. Students should notice that as the copper specimen is plastically deformed (bent), it becomes harder and harder to further deform the material. "Work Hardening and Annealing of Metals," also introduces annealing, or the process of softening the copper sample.

Pre-requisite knowledge and skills:

A basic knowledge of metallic structures; however, it is not required.

Materials Category:	Structure of Materials	❒
	Metals	☑
	Ceramics	❒
	Polymers	❒
	Composites	❒
	Other	❒
Target Grade Level(s) (Check all that apply)	Middle School 6-8	❒
	High School 9-12	☑
	Two-year College 13-14	☑
	Four-year College 15-16	❒

MatEd core competencies that the training meets:

- 7.001 Describe the general nature of metals
- 9.101 Describe the primary constituents of steel
- 16.003 Describe how defects such as nicks and scratches affect properties of metals and alloys

List of equipment and supplies needed:

Supply of copper tubing (soft drawn ¼" or 5/16" tubing) 18" long (10 pieces)
If using tubing, use 1/4 " diameter (soft condition)
If completing the activity as an experiment, at least one specimen per group is necessary. (As a demonstration, only 1 to 2 samples is needed)

Supply of aluminum tubing (soft drawn ¼" or 5/16" tubing) 18" long (10 pieces)
If using tubing, use 1/4 " diameter (soft condition)
If completing the activity as an experiment, at least one specimen per group is

necessary. (As a demonstration, only 1 to 2 samples is needed) 10- Long nose pliers with insulated handle for handling tubing. Propane torch or annealing oven capable of 1000 degrees Fahrenheit 30- safety glasses (PPE)	
Curriculum overview and notes to instructor:	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 more difficult to bend. 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 it should be bent 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 (since the lattice will not be able to do so). Annealing the copper occurs at a high temperature (greater than half the melting point in degrees K- and even higher causes faster annealing, but not past the melting temperature. 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 deformation, thus leaving the material in its original soft condition. However, NOT its original shape- it will 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 at a high enough temperature. If not readily available, the copper can be taken elsewhere and annealed, the presented to the class at a later date in its annealed condition. A few notes: • Cooling rate after annealing does not matter (except at 10 million degrees per second the material could get harder again) • This is not "heat treating". Heat treating of steels actually causes a change in crystal structure, which is not possible here. • Aluminum, silver, and gold have the same crystal structure as copper and exhibit similar characteristics.

Mode of presentation: Laboratory or Demonstration	
Module	**Abstract:** This experiment demonstrates the process of work hardening in a metal; 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 the new, strain-free material to form and the copper will return to its original soft condition. **Experimental Process:** 1. Prepare lengths of copper wire, 6 to 8 inches long, or tubing , 1 to 1.5 ft. in length 2. Ask selected class members to slowly bend the tubing - 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 hardens the copper more by hammering the copper into a flat rod. 6. If available, anneal the tubing at a high temperature (400 degrees C or 700 degrees Fahrenheit is best) 7. After annealing, remove from the furnace and quench in water to cool 8. Re-bend and note the material is soft again. **Further Study:** 1. Do the same experiment with aluminum tubing (if tubing is not available, aluminum wire is usually available in the electrical wire section of a local hardware store). However, the experiment is more difference; please refer to the second reference. 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:	WebElements Ltd. (2007). *Copper*. Retrieved August 19, 2007, from http://www.webelments.com/webelments/elements/text/Cu/key.html

	Wieser, M. (2002). *Aluminum and copper wire*. Retrieved August 19, 2007 from http://www.evergreengardenworks.com/copperwi2.htm
Briefly describe how the effectiveness of the module was evaluated:	"10 Simple and Effective In-class Experiments and Demonstration for Materials Education" - Ryan A. Webster, Intern-Edmonds Community College
Author Bio:	Dr. Tom Stoebe works with the National Resource Center for Materials Technology Education (MatEd) housed at Edmonds Community College. Dr. Stoebe is a Professor Emeritus in Materials Science and Engineering at the University of Washington and has been at the forefront of materials education in the United States.