

Module 2.2.1

Effect of Rolling and Annealing on Hardness of Brass

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Abstract: The hardness of a material varies depending on the composition of material, and how it is treated when processed. In this module, students observe the changes in hardness of brass resulting from different percentages of rolling, along with the accompanying changes in microstructure. The brass samples are subsequently annealed, and changes in hardness and microstructure demonstrated. These are shown using a Power Point presentation, intended as an introduction the effects of rolling and annealing on material properties. No testing equipment is needed for this module. If required, a separate module on the process of hardness testing is also available.

Module Objective: This module provides a specific demonstration of the changes in properties of brass caused by rolling and annealing. Students observe hardness values and the accompanying changes in microstructure that provide an example of the effects of processing variables on properties of a material.

Student Learning Objectives: The student will be able to

- Differentiate between the hardness and strength of a material
- Describe methods of determining hardness of materials
- Describe property differences in brass after degrees of rolling
- Explain differences in microstructure caused by rolling
- Explain property and microstructural changes caused by annealing
- Extrapolate these results in brass to potential behavior of other materials under similar circumstances
- Generalize these results to the influence of changes in processing variables on material properties

MatEd Core Competencies Covered:

- 7.A Identify general nature of metals
- 7.I Explain causes for differing materials properties
- 9.D Discuss types and advantages of copper and its alloys
- 16.A Explain effects of processing variations in material properties
- 16.B Describe effects of defects on material properties

Module Data

1. Key Words: **Brass, Hardness, Microstructure, Annealing, Processing**
2. Type of Module: **Power Point Presentation with Discussion**
3. Time Requirements: **Up to one class period**
4. Pre-requisite Knowledge: **Intro to Hardness module recommended; basic understanding of yield stress and strength properties of materials**
5. Target Grade Level: **Technology and engineering classes at college and advanced high school levels**

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List of Equipment Required: Capability to show Power Point slides

Curriculum Overview and Notes for the Instructor:

This module specifically targets the effects of processing on properties of materials. Using brass as the example, changes in hardness and microstructure are shown as a function of rolling. In the process, the concept of hardness is introduced along with hardness testing methods and the relationship (indirect) between hardness and strength.

The module is designed such that no test equipment is needed. If test equipment is available, the module provides a good introduction to the subject. If equipment is available, some or all of these functions discussed can be performed by the students to help them get a better hands-on feel for processes such as rolling and annealing.

(As one example, if a rolling mill is available, a motivating example is to have the students roll pennies. It is important to choose high copper pennies, those minted prior to 1982 (after that, pennies are zinc with a copper plate). Severe rolling causes hardness and a strength increase that can be demonstrated by bending. In extreme cases of rolling, the copper becomes brittle and begins to break during the process.)

Brass is an alloy of copper and zinc, meaning that brass is made up of a chemical composition of copper and zinc. The samples used are alpha brass, containing about 30% zinc, producing a one phase face-centered-cubic structure. The brass alloy used in this teaching module is an easily available material that is ductile enough to be rolled easily.

Hardness tests can be done using a number of methods—this module uses Vickers Hardness ("HV"), but other tests would give similar results. All hardness testing methods are completed using the same general procedure: Using a known applied load and indenter shape/volume, a material sample is indented, resulting in a specific indentation (hole) size that is dependent on the material hardness. The measured size of the resulting indentation (hole) and the indenter shape is used to find the surface area of the indentation. The hardness value (for a specific method) is found by dividing the applied load by the calculated surface area of indentation. The differences in hardness measurement methods relate to the shape of the indenter—hardness numbers can be related to one another in many cases (see references). The relationship with strength is indirect and approximate—for Vickers hardness, yield stress is approximately $HV/3$. Geometry is important here (see slide 6), and the process is so different from a tensile test that variations between strength values based on hardness and those measured in a tensile test should not be surprising.

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Microstructure is generally observed under a metallographic microscope after polishing and etching of the sample. The captured photographs of the observed microstructure are called micrographs. Micrographs have a calibrated scale bar so the microstructure features can be measured, compared, and documented; in this case the bar shown is 0.01mm.

Rolling is a common method of working a material. The as-received brass was initially cold rolled from a casting into a sheet then annealed. This is why the initial microstructure shows metal grains that are somewhat elongated in one direction (slide 8). Each grain is a single crystal area differentiated from its neighbors by degrees of rotation and displacement. The grain boundary between grains is a narrow area with disturbed crystallography as it transitions from the orientation of one crystal grain to the next. The base line hardness of this annealed sheet is HV 91.

Rolling is measured by the percentage decrease in cross sectional area of the sample, termed percent cold work (slide 9). Thus, 20% CW in general refers to a sample reduced in thickness by 20%. This process is called “cold-rolling” because it is done at room temperature.

Rolling causes the grains to elongate and introduces defects in the grains called "dislocations" which make it more difficult for the atoms to slide over one another during deformation, thus increasing strength and hardness. Think about the work required to squeeze a piece of brass between a set of rollers reducing the original thickness of the brass piece (slide 9). Internal strain in the crystalline lattice is imparted through this work that squeezes the crystalline grains in the brass. Rolling also causes an increase in the number of grain boundaries, which also impedes atom sliding and increases strength. The “cold rolling” process is considered a strain-hardening process. This can be seen in the sequence of slides with increasing degrees of rolling, slides 11 – 13. In this case, the sample seems to have reached its maximum hardness at 40% rolling while the microstructure continues to be modified with increased rolling, as noted in slide 13.

Annealing is generally done at a temperature above half the melting temperature of the material. For these samples of alpha brass, the melting point is about 900C and annealing was done at 500C. The annealing process actually causes new, strain-free grains to form—these grains grow and when fully grown the defective material is consumed and hardness value will decrease to the original. In slide 14, we see that a 15 minute anneal reduces the hardness while modifying the microstructure, probably producing here a mixture of new strain free grains with remnants of the old, harder grains. The microstructure change from the annealing process is shown in slide 15 for the 60% CW condition. Full annealing provides a microstructure with more equiaxed grains (less elongation) and the expected reduced HV of 91, as seen in slide 17.

As noted under "student learning objectives," this module strives to teach the consequences of working brass and means to determine resulting changes in microstructure. As noted in the module procedure, discussions at each point in the Power Point should focus on these learning objectives. Discussion at the end of the Power Point and the module evaluation also focus on the potential influences of changes in processing procedures on material properties and thus on the performance of the resultant part. Deviations from recommended procedures are often the cause of materials failures of parts in service.

One optional module on the measurement of hardness can be used here if time permits:

Module 2.2.3 Hardness Testing Methods module, (one class period, PowerPoint with optional lab), available at www.materialseducation.org.

Module Procedure: Guide for the instructor

- 1) Before beginning the PowerPoint, perhaps on the day before presenting this module, develop a preliminary discussion with the class regarding their knowledge of brass, its properties and uses. If needed, refer the class to the Internet for this information.
- 2) Begin the module by discussing hardness and strength of materials and their relationship using slides 2, 3, and 4. If a hardness tester is available, then allow students to practice conducting tests. If a hardness tester is not available, there are a number of photos you can reference on the Internet.
- 3) Focus on Vickers hardness with slides 5 and 6.
- 4) Discuss expected property changes using slide 7.
- 5) Show the as-received microstructure in slide 8. On the microstructure point out the grain boundaries and trace out some individual grains to emphasize the point of grains and boundaries. If there is time conduct a rough measurement of the grain sizes using a ruler and the scale bar (in the bottom right corner of the image).
- 6) Discuss slide 9-10 then show the microstructure in slide 11 (20% reduction in area). Help the students to see that the grains are a bit elongated and that the grain boundaries appear to be modified. Note the increase in hardness. Have them estimate the increase in yield stress using the reported Vickers hardness.
- 7) Go on to slide 12, which clearly shows further elongation of the grains with an increase in hardness. Discuss the introduction of defects as the material is deformed.
- 8) Continue with slide 13. Have the students estimate the amount of grain elongation compared to the original. Note the increase in grain boundaries despite the lack of increase in hardness. There is always an associated hardness limit with any alloy resulting from its specific chemical composition (i.e. a limit at which hardness cannot increase unless chemical composition changes).
- 9) Go on to the effects of annealing, slide 14, 15 and 16. Note the effects of recrystallization and grain growth on grain structure and hardness. Note that slide 15 contains smaller grains than the original condition, and must also contain both new and old grains, since the hardness is not yet reduced to the original value. Note that some of the dislocation defects applied to crystalline structure have been removed when new grains formed during the annealing process. This thermal reduction of internal strain in the brass crystalline structure results in a decrease of hardness.
- 10) This effect continues in slide 17 where the fully annealed sample has larger grains and the hardness has gone back to the original value. Here all the defective (or dislocated grains) are removed due to recrystallization. Note that the shapes of the grains have changed and twining of the grains can be seen, when compared to the original in slide 8.
- 11) Conclude with a general discussion:
 - a) Discuss with the students the differences in microstructure caused by rolling and subsequent changes caused by annealing.
 - b) Have the students extrapolate these results in brass to potential behavior of other materials under similar circumstances.
 - c) Then ask the students to generalize these results to the influence of changes in processing variables on material properties.
- 12) This unit should sensitize students to the effects of changes in processing processes on materials properties and thus on the performance of the resultant part. The included evaluation questions should allow the instructor to determine the effectiveness of the module.

Supporting Materials: Please see accompanying Power Point presentation and refer to the additional references from the following Internet sites.

- Basic brass info - <http://en.wikipedia.org/wiki/Brass>
- Vickers hardness - http://en.wikipedia.org/wiki/Vickers_hardness_test
- Conversion tables between different hardness scales and more - <http://www.gordonengland.co.uk/hardness/vickers.htm>
- Cold rolling - http://en.wikipedia.org/wiki/Cold_rolling
- Annealing - [http://en.wikipedia.org/wiki/Annealing_\(metallurgy\)](http://en.wikipedia.org/wiki/Annealing_(metallurgy))

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Evaluation Packet:

Student Evaluation Questions (discussion or quiz):

- 1) Give an example of how rolling changes properties of a material.
- 2) Why is there a correlation between hardness and microstructure?
- 3) What does annealing do grain size and shape?
- 4) Would you expect similar behavior in other metals after rolling and annealing?
- 5) What would you do if a material you were working on accidentally deformed before you were to machine it?
- 6) Was the class discussion useful to your understanding of the effects of working and annealing of metals?
- 7) Was the PowerPoint presentation logical and easy to understand?

Course Evaluation Questions (for students):

- 1) Was the PowerPoint 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?

Instructor Evaluation Questions (for teachers):

- 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 PowerPoint and discussion work as presented? Did they add to student learning? Please note any problems or suggestions.
- 4) Was the background material on hardness, rolling and annealing sufficient for your background? Sufficient for your discussion with the students? Comments?
- 5) Did the PowerPoint and discussion 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.