COLD FLAT-ROLLING - LAB 1

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Objective Examine the cold rolling process of copper sheet and investigate the mechanical effects of each rolling step.

I. Basic Equations

Maximum Draft

$$h_o - h_f = \mu^2 R \qquad (1)$$

where h_o is initial strip thickness, h_f final strip thickness, μ is friction coefficient, and R is the roll radius. μ between copper and roll can be taken as 0.1.

Roll Force and Power Equations

Rolling force can be estimated as in the following

$$F = LwY_{avg} \qquad (2)$$

Here, L is the roll-strip contact length, w is the width of the strip, $Y_{avg}$is the average true stress.

The *torque* on the roll is the product of F and a. $a = L/2$. Thus, the power equation is

$$Power\ (kW) = \frac{2\,\pi FLN}{60{,}000} \qquad (3)$$

II. Equipment

Flat rolling machine powered manually can be seen in Figure 1. Flat rolling machine will be used to make thinner copper strip in this lab. Role diameter is measured as 60.8 mm.

Figure 1. Rolling equipment

Rockwell hardness tester TH500 as shown in Figure 2 will be used to measure the hardness of the strip after each step [1].

Figure 2. Rockwell hardness tester TH500

Copper sheet will be your sample to work on during this lab. It will be a rectangular strip with 100 mm x 20 mm x 3 mm dimensions.

III. Procedure

In this experiment, you will first cut your rectangular part out of a larger copper sheet. Then, measure your samples thickness and the width from three different locations. Before start rolling, measure the Rockwell Hardness (HRB). Make sure the setup is calibrated. Hardness measurements are taken to measure the material response to an indentation of a harder material. Details are given in the Appendix. After measuring the hardness, adjust the roll gap that matches with your sheet thickness first. Then, reduce the gap by 125 μm. Cold roll your sample multiple times at the same gap until rolling without too much resistance is felt. This concludes the rolling for this step. Take your sample and measure its thickness at least from three locations. Then measure its HRB. Repeat the rolling steps until the HRB values of you copper does not change anymore. At that point, you will reach the maximum hardness levels of copper that you can obtain.

After finishing the cold rolling operations. Put the part into furnace that was heated up to 800 °C. Note the duration of the time during the annealing. Then, measure the hardness of the part after cooling.

IV. Assignments

- Follow lab reporting steps while preparing your lab report.
- Calculate the roll force, power, and maximum draft for the first rolling step.
- Present your data and all the calculated values in the tables.
- Plot a figure as a function of the strain and hardness of your copper sample.
- Plot a figure of strip thickness vs HRB
- Plot a figure of strip thickness vs Yield Strength and Ultimate Strength. To be able to do this task, you need to read the article by Krisha et al.[2]. Use equations given in Table 1. You need to convert HRB to Vickers. Conversion chart is also supplied in the supplementary files folder.
- Explain why does your sample is wavy.
- Explain why does it become harder to manually roll as the strip gets thinner.
- What is the cast copper HRB value? Is your starting point same or different compared to that value? Why?
- What happened after annealing the part? Discuss the final HRB value variation. Is it the same with the initial HRB of copper? Why or why not?

References

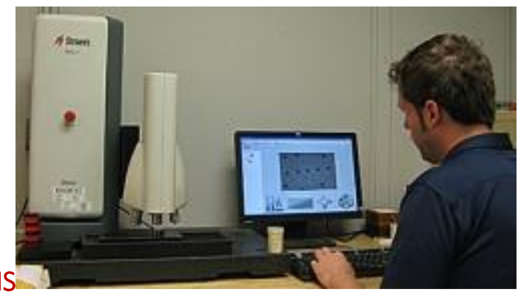
1. ASTM Committee E04 (2004) ASTM E18 - Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of. 01:1–11 . doi: 10.1520/E0018-14.2
2. Krishna SC, Gangwar NK, Jha AK, Pant B (2013) On the Prediction of Strength from Hardness for Copper Alloys. J Mater 2013:1–6 . doi: 10.1155/2013/352578

Appendix

Following information was taken from https://www.labtesting.com

ASSORTMENT OF METAL HARDNESS TEST METHODS

The **Rockwell Hardness Test and Superficial Rockwell** are performed on castings, forgings and other relatively large metal products and samples because the tests produce a large visible indentation.
The **Brinell Hardness Test** can be applied to almost any metallic material and is the method most commonly used to test castings and forgings that have a grain structure too coarse for other types of metal hardness testing.
Microhardness testing by **Knoop and Vickers Hardness Test** methods measure small samples or small regions in a sample. They are often used to measure surface or coating hardness on carburized or case-hardened parts, as well as surface conditions such as grinding burns or decarburization. (Vickers is also available on the macro scale to 50 kg.)
Conversion Charts comparing scales are available on LTI's website.



TEST METHODS/SPECIFICATIONS

- Rockwell – ASTM E18; NASM-1312-6
- Superficial Rockwell – ASTM E18; NASM-1312-6
- Brinell – ASTM E10
- Microhardness – ASTM E384; NASM-1312-6
- Vickers – ASTM E384, ASTM E92

Request a quote for testing to your hardness testing requirements.

THE TEST PROCESSES

Hardness Testing is generally performed using test machines equipped with an indenter that is forced into the test material over a certain amount of time. The shape of the indentor varies by type of hardness test and includes cone, ball and pyramid shapes. Each test machine also uses a different force or load application system and records an indentation hardness value in kilograms-force according to their individual hardness scales.

BRINELL HARDNESS TEST

During the Brinell Hardness Test, a carbide ball indenter is pressed into the sample with accurately controlled force for a specific amount of time. When removed, the material has a round indent that is measured to calculate material hardness according to a formula.

ROCKWELL HARDNESS TEST

In addition to a Rockwell Hardness Test, there is a Superficial Rockwell. For each test, a minor load is applied to either a diamond cone or a steel ball indenter positioned on the test material's surface to establish a zero reference position. Next, a major load is applied for a specified amount of time, leaving the minor load applied upon release. The Rockwell hardness number will be the difference in depth between the zero reference position and the indent due to the major load.
The choice of indenter is dependent upon the characteristics of the test material. The Rockwell Hardness Test applies larger minor and major load values than the Superficial Rockwell, yet both tests offer three

different major load options. More than thirty different scales are used between Rockwell and Superficial Rockwell hardness testing due to the various choices and combinations of tests, indenters and major loads.

KNOOP HARDNESS TEST

This Microhardness Test is used on very small parts and material features that are unable to be tested by the other methods and employs a test load of 1000 grams or less. The Knoop Test is performed like Brinell hardness by applying controlled force for a specific amount of time to an indenter in a rhombus-shape. The impression is measured microscopically and is used along with the test load to calculate the hardness value on the Knoop scale.

VICKERS HARDNESS TEST

The Vickers Hardness Test can be performed on both the micro and macro hardness scales with a maximum test load of 50 kilograms. This type of hardness test is also performed by applying controlled force for a specific amount of time to an indenter, which in this case is a square-based diamond pyramid. The impression measurement and test load are used in the appropriate formula to calculate the Vickers hardness value. Like Brinell and Knoop, this method has one scale that covers its entire hardness range.