Cold Work

Lab 4 :: Monday 10/12/2009 9:30am

TAs: Uttarwar & Yang

Lab Report

Chad Huard

Matt Hartley

Sean Lechkun

Mike Menking

Introduction

The purpose of this experiment is to determine the increase in hardness of an annealed (heat treated) copper sheet after it is passed through a rolling mill. The rolling mill reduces the thickness of the copper sheet by exerting compressive stress. This is an example of cold working, as the deformation of the copper sheet is performed at a temperature below that at which recrystallization occurs.

The density of dislocations in a metal such as copper increases as a result of cold work due to the multiplication of dislocations or the formation of new dislocations. As dislocation density increases, dislocation motion becomes increasingly difficult [1]. Therefore, the copper sheet becomes harder as cold work is performed upon it. The percentage of cold work performed on the metal sheet is calculated as a function of the change of thickness in the sheet as a result of the rolling process. The corresponding change in hardness values for the sheet are then used to show the proportional relationship between cold work and an increase in hardness.

Hardness can be measured in many different scales. For this experiment we will be using the Rockwell Hardness B scale. This system measures the depth of penetration of an indenter resulting from the application of two different loads, minor and major. The difference in depth between these two indentations is used to calculate the hardness [1]. The Rockwell process can be used with a variety of indenters and loads in order to accurately test a broad range of materials.

Procedure

The objective of this lab was to obtain experimental data from the Rockwell Hardness Tester in order to determine the hardness of the material at varying levels of cold work. The copper sample was fed through a rolling mill in order to make the sample thinner. Each time the copper sample is made thinner the thickness was measured and then the hardness is measured using the Rockwell Hardness Tester.

Setting up the experiment:

This lab requires the use of the Rockwell Hardness Tester, a rolling mill, an annealed copper sheet and calipers (for measuring the thickness of the copper).

Measuring the Hardness using the Rockwell Hardness Tester:

1. The annealed copper sheet is placed in the Rockwell Hardness Tester where the hardness was measured in three different spots.

Reducing the thickness of the annealed copper sheet:

1. After the hardness was measured, the annealed copper sheet was placed into the rolling mill where the thickness was reduced to 95% of the initial thickness.

2. The thickness was measured with calipers in three different spots

Subsequent Steps:

1. The hardness was measured in three different spots for 95% thickness.

2. These steps were repeated for 80%, 65% and 50% thickness.

Determining the amount of Cold Work:

1. The cold work was determined based on how much the thickness changed.

$$\frac{d_0 - d_1}{d_0} \times 100\% = \text{\% Cold Work} \qquad (1)$$

Graphing the results:

1. The hardness values obtained from the Rockwell Hardness Tester are plotted against the percent cold work calculated.

2. The data points were then fit to a polynomial.

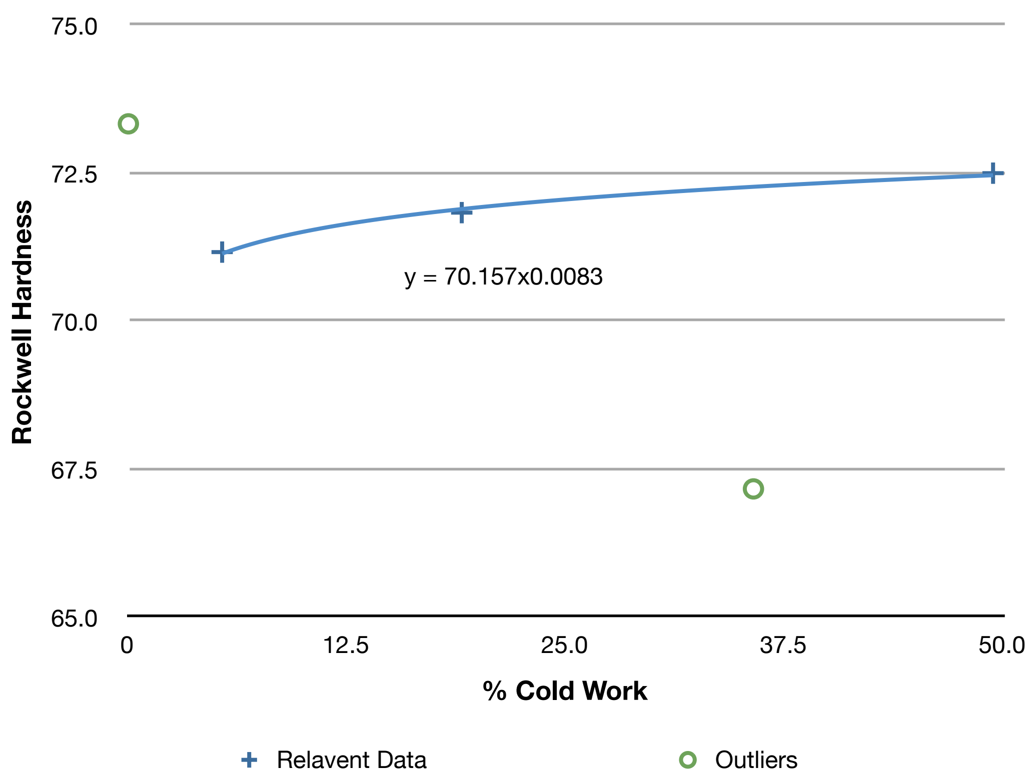
Results

Table 1 - *Data*

	Thickness					Hardness			
	Trial 1	Trial 2	Trial 3	Average	% Cold Work	Trial 1	Trial 2	Trial 3	Average
d_0	0.056	0.056	0.056	0.056	0.00	73.000	74.500	72.500	73.333
$.95d_0$	0.053	0.053	0.053	0.053	5.36	69.500	73.000	71.000	71.167
$.8d_0$	0.045	0.046	0.045	0.045	19.05	71.500	70.500	73.500	71.833
$.65d_0$	0.036	0.036	0.036	0.036	35.71	67.000	67.000	67.500	67.167
$.5d_0$	0.029	0.028	0.028	0.028	49.40	75.000	72.500	70.000	72.500

Our raw data includes hardness measurements for each thickness. Two of the five (**d_0** & **$.8d_0$**) measurements did not match the theoretical trend of cold work versus hardness and were labeled as outliers. These measurements do not influence the trend line in figure 1.

Figure 1 - *Hardness vs. % Cold Work*



Discussion

Our experiment did not conform well to the expected theoretical values. By allowing two measurements to be considered outliers we were able to find a trend-line that resembles the theoretical shape of a cold work vs. hardness trend. Still, the results only show a 2% increase in hardness with a 50% increase in cold work. This is inconsistent with the hypothesized results and other experimental determinations which would suggest the hardness should increase dramatically more than this. In a similar test performed by Dr. Dana Medlin, the increase in hardness for 50% cold work was 35% [2]. There are several factors that could have lead to the deviation in our results:

1. Inaccurate cold work calculations. Our calculations for cold work (equation 1) assume that the rolling press only elongates the sample without widening it at all. The more general formula for cold work is:

$$\frac{d_0 w_0 - d_1 w_1}{d_0 w_0} \times 100\% = \%\ \text{Cold Work} \qquad (2)$$

   So, if the width was increased when rolling, it would have decreased the total cold work. We did not make any width measurements, but we feel that any change in width would have been small since it was not visually noticed. This could have contributed slightly to the lack of hardening, but not accounted for the entire effect.

2. After each flattening there was a significant bend in the sample. This may have yielded false calibration when the minor load was applied, but we could not determine what effect this would have. Since this bend was always present to some degree the results may be affected in an absolute way, but should still have good relative precision. We do not believe that this could totally explain the measurements.

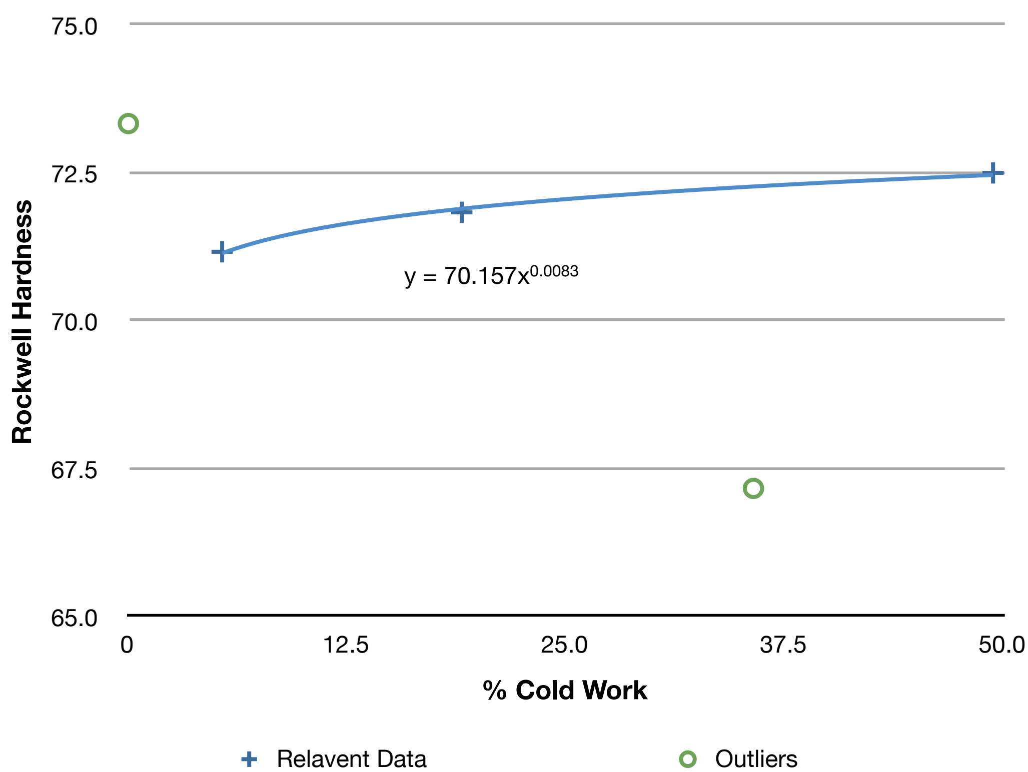
3. The most probable source of error comes from the Rockwell Hardness tester itself. Many of the measurements had to be repeated multiple times due to erratic readings. Furthermore, the tester was sent in for repairs before the experiment was performed and may still have some unresolved issues.

Conclusion

From our data we conclude that copper hardens with cold work at a rate of approximately:

$$70.2 \times (\%CW)^{0.0083} \tag{3}$$

Figure 1 *(reprint) - Hardness vs. % Cold Work*



Appendix

Sample Calculations:

1. Average Thickness:

$$\frac{0.053+0.053+0.053}{3}=0.053$$

2. Average Hardness:

$$\frac{69.5+73.0+71.0}{3}=71.2$$

3. Calculate % Cold Work:

$$\%CW=\frac{d_0-d_1}{d_0}=\frac{0.056-0.053}{0.056}\times 100=5.36\%$$

Bibliography

1. Callister, W.D. and D.G. Rethwisch, *Fundamentals of materials science and engineering : an integrated approach*. 3rd ed. 2008, Hoboken, NJ: John Wiley & Sons. xxv, 882 p.

2. Medlin, D. *Rockwell Hardness Testing*. [cited 2009 10-16]; Available from: http://glenstone.sdsmt.edu/My-files/Labs/RollingStoryBoard.html.