Lab 3: Collecting Evidence for Metal Identification Using a Hardness Test

Jeffrey Harrick (pjh46), Nate Abrams (nla20), Jay Parmar (jp590)

Duke University: ME 221

Professor Xiaoyue Ni, Lab Manager: Patrick McGuire

Date of Experiment: 2/26/2025

Due Date: 3/7/2025

I: Procedure

a. General Procedure

The setup of this experiment involved the preparation of three unique metals and preforming a hardness test of the smooth surface of each. To start, the team was given three metal samples labeled A, B, and C (one cast iron, one annealed steel, and one quenched steel sample). In order gain evidence to determine the identity of each, a hardness test was performed, which will later be compared to a table with known harness values for these metals. To prepare the surface for the testing machine, the samples were first encapsulated in a rigid plastic. This was done using a mounting machine. Each sample was placed in the machine, Bakelite (thermosetting plastic) was poured on top, then the sample was heated and held at pressure. Once the plastic melted around the material, it was cooled and a hard puck with one face of the metal showing was produced. Next, this puck was sanded using 180, 320, and 600 grit sandpaper on a rotary grinding machine. The grits were used to eliminate any surface impurities/rough edges on the puck, as well as any sanding lines from the previous grit. This was done manually by applying pressure to the puck on the sanding wheel. Then the wheel was polished using a rotary polishing cloth machine and an alumina solution to provide the necessary grit. Once completed for all pucks, they were taken to the hardness testing machine. Using this machine, 5 indents were made on an assumed "inner" radius of the metal face, and 5 were made on the "outer" face. This was done via an indenter, which was pressed using a standard, predetermined load. The machine measured the distance traveled after the indentation, which provided the values needed for material identification.

b. Materials Used

- 3 unknown metal samples (cast iron, annealed steel, quenched steel)
- Bakelite – thermosetting plastic used to secure metal sample for further processing
- Molding machine – used to secure melted Bakelite around plastic
- Sandpaper – used to grind down metal/puck
- Rotary sanding machine – used to move sandpaper (coated in water from machine) to grind away surface impurities on metal surface
- Alumina solution – acted as very fine grit to take metal samples from 600 grit finished surface to near completely smooth
- Rotary polishing wheel – spun the built in polishing cloth to move the alumina solution across surface of metal and polish it completely
- Rockwell hardness testing machine indenter – tip used to press into metal surface using force from machine
- Rockwell hardness testing machine – used to press using a pre-determined load, creating an indentation into metal surface. Measures distance of indentation once load is released

c. Results (after each step)

i. Sample Mounting

3 hard, shiny, black pucks with one face of the metal showing. Imperfections were clearly seen on the metal's surface and some of the Bakelite had set in front of visible metal surface.

ii. Grinding

All of the visible imperfections were removed using the 180 grit. Sanding lines were still visible. The next grits were used until the sanding lines from the previous lines were no longer visible. After the 600 grit, sanding lines were still apparent, but the metal looked smooth and shiny.

iii. Polishing

After polishing, the metal had a mirrorlike, reflective surface. No lines or imperfections were visible. The black puck face surrounding the metal face did not experience any notable changes in grinding or polishing.

iv. Hardness Test

Each metal surface had 10 small indented bumps on the surface. 5 of these were radially "inward" while the other 5, radially "outward" (see Appendix 1 for diagram). Indentations were about 0.3mm across. Metal surface without indentations still appeared mirrorlike.

II: Statistical Analysis §

Table 1: Raw experimental hardness data

Sample	Inner Hardness Values Rockwell (Scale A)	Inner Hardness Average	Outer Hardness Values Rockwell (Scale A)	Outer Hardness Average
A	81.5, 82.0, 82.0, 82.0, 82.5	**82**	81, 81, 80.5, 80.5, 80.5, 80.5	**80.7**
B	60.5, 60.5, 61.0, 61.5, 61.5	**60.7**	62.0, 63.0, 63.0, 62.5, 62.5, 62.0	**62.5**
C	61.0, 61.0, 60.5, 59, 60.5	**60.4**	57.0, 56.5, 55.5, 57.5, 56.5, 58	**56.8**

The results above are from hardness tests conducted on three metal samples—quenched steel, cast iron, and annealed steel. Each sample was tested at five internal locations and six outer locations using the Rockwell Hardness Scale A, which measures hardness with a 60 kgf load and a diamond indenter.

Null hypothesis (H_o): There is no difference between the inner and outer hardness values. Meaning their means are equal ($\mu_{inside} = \mu_{outside}$).

Alternative hypothesis (H_A): There is a difference between the inner and outer hardness values. Meaning their means are not equal ($\mu_{inside} \neq \mu_{outside}$).

Method: A two-sample, two-tail t-test was performed on the internal and outer harness sets for each sample. A two-sample t-test is appropriate in this case as it compares the means of two independent groups to determine if significant difference exists. The test was conducted separately for each sample (A, B, and C) and the results are presented in Table 2.

Table 2: T-Test Values

Sample	P-Values	T-Values
A	$1.821 \cdot 10^{-4}$	7.016
B	$7.648 \cdot 10^{-4}$	-5.196
C	$7.287 \cdot 10^{-5}$	6.958

The p-values indicate the probability of observing a difference at least as extreme as the one measure, assuming that the null hypothesis H_o is true. With lower p-values suggest stringer evidence against H_o. The standard significance level for determining if the null hypothesis is rejected is p-value < $\alpha = 0.05$.

Discussion: All p-values are below the significance level $\alpha = 0.05$ therfore we reject the null hypothesis H_o and accept the alternative hypothesis H_A. There is statistical significance between the hardness of the inner and outer portion of all samples. These results are further supported by the large magnitudes of the t-values, which demonstrate that the differences (between inner and outer) observed were substantial.

III: Discussion

a. The Rockwell Hardness Test

The Rockwell Hardness test is a tool that is used to evaluate a material's resistance to plastic deformation. In this test, a standardized indenter is pressed into meticulously prepared specimens (polished to a flat mirror surface) under controlled loading conditions. Initially, a minor preload is applied to ensure that there is complete contact between the indenter and the specimen, establishing a reference point. A subsequent major load then causes a permanent indentation in the specimen, the depth of which is measured relative to the reference point and recorded. The resulting indentation depth is converted into a hardness value using a specific Rockwell scale, such as the A scale, which standardizes our findings. The fundamental principle is that a harder material will resist deformation, resulting in a shallower indentation and a higher hardness value, whereas a softer material will exhibit a deeper indentation and a lower hardness value.

This method is effective due to several factors. First, it is particularly cost effective and a relatively simple and replicable procedure to follow. Mounting the equipment using Bakelite and using grinding and polishing wheels are simple practices that come with little expense. Furthermore, the hardness test is minimally destructive, allowing for multiple measurements to be taken on a single sample, again helping with costs and simplicity of testing. Additionally, the results of the hardness test are useful indicators of other important mechanical properties, such as tensile strength, yield strength, and wear resistance. This correlation allows hardness measurements to serve as a rapid screening tool for assessing overall material performance. Moreover, the test is sensitive to microstructural variations, making it particularly useful for evaluating the effects of different heat treatments.

b. Identifying Samples

In the Rockwell A hardness test, the measured values offer clear insights into the microstructural differences induced by varied heat treatments. Sample A, which exhibits the highest hardness readings (82 and 80.7), is most consistent with cast iron. The high carbon content in cast iron creates numerous interstitial sites and contributes to a rigid, highly resistant microstructure. In contrast, Sample B shows intermediate hardness values (60.7 and 62.5) and can be attributed to quenched steel; rapid cooling traps a martensitic phase with its characteristic needle-like structure, which increases hardness relative to more slowly cooled steels, though not to the level observed in cast iron. Finally, Sample C, with the lowest values (60.4 and 56.8), is indicative of annealed steel. The annealing process allows the formation of pearlite and ferrite, phases that are comparatively soft and ductile, resulting in a reduced resistance to deformation. The subtle variation between inner and outer measurements in Sample C may reflect minor differences in cooling rates during annealing. Thus, based on the Rockwell A readings and the effects of carbon content and thermal processing on microstructure, it is reasonable to conclude that Sample A is cast iron, Sample B is quenched steel, and Sample C is annealed steel.

It is not universally true that cast iron has a greater hardness value than quenched steel. If gray cast iron is used, which carries a lower hardness value than quenched steel, it is more likely that Sample A is quenched steel and Sample B is cast iron. For the purpose of this discussion, we make the assumption that the form of cast iron used in this experiment carries hardness properties that exceed that of either of the steels in order to support our conclusions.

II. Appendix

Appendix 1: Plot showing what is meant by radially "inward"/"outward" on the metal surface