Lab Experiment # 4

Hardness Testing:
Rockwell B and C & Vicker Microhardness Testing

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Objective

The goal of hardness testing lab is to understand the hardness of metal specimens (Aluminum, Steel and Cast Iron) utilizing the Rockwell and Viker Hardness machine. The lab seeks to show the relationship between hardness and tensile and yield strength.

Material/ Equipment

- Rockwell Machine
- Vicker Machine
- Aluminum 2024 Specimen
- Steel 1018 Specimen
- Cast Iron (Gray 20)
- DiaMet Software
- 1/16" steel ball indenter
- Diamond Cone indenter
- 100 kg load
- 150 kg load

Procedure

1. To test the two softer materials, Steel 108 and Aluminum 2024, set up the 1/16" steel ball indenter in the Rockwell machine.
2. Place one of the materials on the plate below the indenter. Apply a minor load to the machine until the Rockwell machine reads at the 2 dots intersecting
3. Reset the scale to read 0 and apply the major load (100 kg load) and wait until the machine reaches an equilibrium. Once it does, pull back the lever and obtain the final B scale reading.
4. Repeat steps 2 and 3 four times for the first material then do the same procedure for the other soft material
5. For the Cast Iron using the Rockwell Machine, first unload the indenter and place in the Diamond cone indenter and put in the 150 kg load.
6. Repeat the same procedures as with the other two material
7. Using the Vicker machine, first connect the DiaMet Software with your machine.
8. Apply the appropriate loading and set the reading of the microscope to appropriately read within the bounds of your specimen.
9. Read off the measurement of your Cast Iron. Repeat this test 2 other times.

The average each test data used in the Rockwell test can be summed to be used to find the Brinell number with the following equations:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

The calculations to obtain the standard deviation (S) is found with the following formula:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Where x_i represents the specific test value and n = the number of trials. The $\bar{x}$, the average value.

The formula for σ_y (yield strength) is:

$$\sigma_y = 470 * HB$$

The tensile strength (σ_t):

$$\sigma_t = 500 * HB$$

$$\% \, error = abs\left(\frac{true - calculated}{true}\right) * 100\ \%$$

Results

In this experiment a 1/16’’ steel ball indenter was used for the hardness test of Aluminum 2024 and Steel 1018 with a 100 kg load. A diamond cone indenter of load 150 kg is used for the Rockwell hardness test of the Cast iron. A diamond cone is used for the Vickers test of the Cast Iron.

Test method	Material	Scale	Test number			
			1	2	3	4
Rockwell	Aluminum 2024	B	77	78	80	80
	Steel 1018	B	70	71	71	72
	Cast Iron (Gray 20)	C	15	15	16	16
Vicker	Cast Iron (Gray 20)	HV10	228	221	198	

Table 1: Experimental data collected of hardness value, using Rockwell and Vicker of Aluminum 2024, Steel 1018 and Cast Iron (Gray 20).

Test method	Material	Average	Standard Deviations	HB Brinell number	σ_y (kpsi)	σ_y % Error	σ_t (kpsi)	σ_t % Error
Rockwell	Aluminum 2024	78.75B	1.5	147	69.09	47 %	73.5	8.09 %
	Steel 1018	71B	0.816	127	59.69	11.15 %	63.5	0.47 %
	Cast Iron (Gray 20)	15.5B	0.577	203	95.41	582 %	101.5	361.4 %

Vicker	Cast Iron (Gray 20)	215.67 HV10	15.695	216	101.52	625.1 %	108	390.9 %

Table 2: Calculated values of average, Standard deviation, Brinell Number ([14]) yield strength (σ_y) and tensile strength (σ_t) and their respective error %.

Figure 1: Aluminum (bottom) and Cast Iron (top) Specimen after hardness test. Indent seen to the bottom left of the cast iron represent the indent due to Vicker tests. Larger indents seen in both specimen due to the Rockwell hardness test.

True yield strength and tensile strength of the material used to calculate % error in table 2:

Steel 1018: $\sigma_y = 53700\, psi$ $\sigma_t = 63800\, psi$ [11]
Cast Iron (Gray 20) $\sigma_y = 14000\, psi$ $\sigma_t = 22000\, psi$
Aluminum 2024 $\sigma_y = 47000\, psi$ $\sigma_t = 68000\, psi$ [12]

Gray 20 Cast Iron with Vicker Machine Calculations:

Where 3 test were done (n = 3)

$$\bar{x} = \frac{228 + 221 + 198}{3}$$
$$\bar{x} = 215.67$$
$$\bar{x} \approx 216$$
$$S = \sqrt{\frac{(228 - 216)^2 + (221 - 216)^2 + (198 - 216)^2}{3 - 1}}$$
$$S = 15.695$$

The Brinell Number is then found using (Appendix 3) and was found to be 216. That value is then used to calculate the σ_t and σ_y:

$$\sigma_y = 470 * 216$$

$$\sigma_y = 101.520\ kpsi$$

$$\sigma_y\ \%\ error = abs\ \left(\frac{14\ kpsi - 101.52\ \ kpsi}{14\ kpsi}\right) * 100\ \%$$

$$\sigma_y\ \%\ error = 625.1\ \%$$

$$\sigma_t = 500 * 216$$

$$\sigma_t = 108\ kpsi$$

$$\sigma_t\ \%\ error = abs\ \left(\frac{22\ kpsi - 108}{22\ kpsi}\right) * 100\ \%$$

$$\sigma_t\ \%\ error = 390.9\ \%$$

Discussions of Results

From this experiment it can be observed that under the B scale, Aluminum had a higher Brinell Hardness than that of Steel. However, this result is likely due to error in the indenture used. After converting from C scale to HB value, it can be seen that Cast Iron was at the highest hardness of the three specimens tested.

As seen in this lab, Hardness values can be used to find tensile and yield strength, however, the level of accuracy is highly dependent on the material, the conditions of the testing and the type of test. Generally, microhardness testing is more accurate than that of microhardness tests. As seen in figure 1, the microhardness test is seen to be less invasive. Although that is the case, the resultant % error for cast iron is higher for the Vicker test. The error can be due to processing error from the DiaMet software. Due to problems with the software detecting the surface, manually choosing the edge was needed. Such conclusion that there must be a high error is due to the high standard deviation found under the Vickers hardness test.

In comparing materials results in the Rockwell hardness testing, the softer materials, Steel and Aluminum, have a smaller error margin. This is due to the differences in the hardness testing. The Rockwell test works better for materials of finer grain due to its sensitivity to surface conditions. It must be noted that during the Rockwell hardness testing, there were multiple points of possible error in this experiment. Such error can come from possible surface debris and error in reaching equilibrium value when applying load.

Conclusion

Two methods of hardness testing was introduced in this lab, Rockwell and Vicker Hardness testing. The hardness values of Steel, Aluminum and Cast Iron was found and converted to tensile and yield strength. It was determined that conversion from hardness can give a rough approximation of yield and tensile strength though prone to error. High accuracy is not guaranteed for finding mechanical properties though such testing can save time, money and is not a destructive type testing like that of tensile tests.

Review Questions
Rockwell Hardness Testing:

1. What is the theory on which Rockwell hardness testing is based?

Rockwell hardness test works based on the principle of the difference between the force placed on by the indenter from the initial force prior to pushing the indenter into the specimen [4].

2. What is the purpose of the minor load in Rockwell hardness testing?

A minor load is used as the initial gage force to initialize the amount of force difference from the 2^{nd} applied force (major load).

3. What are the advantages of the Rockwell hardness testing method?

The Rockwell hardness test is often done as a way to quickly determine properties such as the tensile and yield strength without having to destroy the entire specimen. Hardness values can easily be converted to those mechanical properties through such method outlined in this lab. In addition, the size of the specimen do not matter as such testing can be done on any surface of the desired material [5]

4. What are the disadvantages of the Rockwell method?

Rockwell testing is highly dependent on surface condition and is prone to interference such as dirt on the specimen. This method of hardness testing may not be the most accurate as seen by the percent error of the values calculated from this test to the values tabulated as the true yield and tensile strength of the materials.

5. How thick must the specimen be in order to get an accurate Rockwell hardness reading?

While the surface area of the specimen do not necessary matter, the thickness of the Specimen should be at least 10 times the thickness of the indentation depth [5].

6. Based on what parameters is any hardness scale defined?

Hardness scales are all based on the principle of hardness, which the resistance of a material to indentations. Different tests may use different methods to test this value through indentation, scratching or rebound [6]. For different tests, the expected hardness is used to determine which scale to use and which load is used for the indenture type hardness reading. For Rockwell, the type of load, type of indenter and hardness excepted can categorize then into either A, B or C scales.

7. How is an appropriate hardness scale chosen for a given material?

The appropriate hardness scale is chosen based on the load used and the indenter type. The material itself can determine the hardness scale used. Based on what indenter will be appropriately create indentations, it can affect the resultant scale needed.

8. Does hardness have derived units?

Hardness is given in the same units as Stress and pressure as pascal or psi.

9. In what situations is hardness measurement more convenient than a tensile test?

Hardness testing is more convenient if the use of material after testing is desired. Hardness testing can create dents up to the microscopic levels. If high precision is not necessary, hardness testing can both decrease the time and cost of the testing.

10. Why can hardness be related to yield strength of a material? How?

Yield strength and hardness are both properties related to a material as it leads to plastic deformation. Yield strength is the point in which a material will enter its plastic deformation point and hardness measure a indenture which is formed by plastic deformation. The two values are roughly linear cand can be converted with a constant value.

11. How do hardness readings from different scales be related to each other?

While hardness readings are not directly related, they all rely on the same principle of hardness testing and can be related through their properties of obtaining mechanical properties like tensile strength.

12. Why should all the hardness tests be performed far away from specimen edges, other tests, and large scratches?

Hardness testing is highly dependent on the surface of the specimen. With imperfections, dirt, scratches or performing close to edges can affect the indenture reading by changing the actual indenture formation.

13. How close can a Rockwell hardness indentation be to another without getting an error in the reading?

An indenture should generally be at 2.5 diameter of the indenture away from the other tests or for lighter alloys, at least 3 diameters away from other tests.[7]

Vickers Hardness Testing:

1. Based on what parameters is any hardness scale defined?

As mentioned in the Rockwell review questions, hardness scales are all based on the principle of hardness, which the resistance of a material to indentations. Different tests may use different methods to test this value through indentation, scratching or rebound [6]. For different tests, the expected hardness is used to determine which scale to use and which load is used for the indenture type hardness reading. For Rockwell, the type of load, type of indenter and hardness excepted can categorize then into either A, B or C scales.

2. What must be measured to obtain the Knoop number?
For the Vicker Hardness scale, the HV number is obtained based on the indenter size found from the load of the indenter (often a pyramid diamond indenter) [8].

3. If Knoop tests are performed on the same material but using different forces will the HK numbers be comparable?

Different force load applied to the same material using HV cannot be compared as they do not obtain the same HV values. As seen in the tables for the HV values, HV5 and HV10 do not overlap in the values obtained.

4. How is the diagonal length related to the HK number?

Diagonal length is related to the HV number in a Vicker test through the equation HV = 1854.4 L/d^2, where L represent the length and d represents the mean diagonal.

5. Does hardness have derived units?
The unit of Hardness is the units of stress (Pascal or pounds per square inch).

6. In what situations is hardness measurement more convenient than a tensile test?

As mentioned earlier, Hardness testing is more convenient if the use of material after testing is desired. Hardness testing can create dents up to the microscopic levels. If high precision is not necessary, hardness testing can both decrease the time and cost of the testing.

7. In what situation would you perform a Micro-hardness test instead of a Macro-hardness test?

The type of hardness test done is dependent on the test specimen. For smaller specimens which cannot withstand as much force, a micro hardness test is done. In addition, microhardness testing is more often reproducible and accurate in its results. For harder materials where large force is needed to make an indentation, a macro hardness test is done. Vickers hardness testing is placed in the micro hardness category.

8. Why should all the hardness tests be performed far away from specimen edges, other tested locations, and large scratches?

Surfaces with imperfection as well as close proximity to edges and other testing sights can interfere with the testing due to the nature of the testing. Results depend on the indentations and such conditions can lead to inferences to the surface and overall indentations.

9. Why does the test surface need to be highly polished?
Similar to the reasoning for avoiding surface imperfections such as scratches, an polished surface is useful in avoiding interference to the testing towards its measured indentations in the material.

10. What is the main difference between a regular hardness (such as Rockwell) tester and a microhardness tester?

The main difference between micro and regular hardness testing is the amount of load used. A microhardness tester can only apply up to 1 N of load [10].

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