KU LEUVEN

FACULTY OF ENGINEERING TECHNOLOGY

CAMPUS GROUP T

Lab report Materials Science phase 1

Hardness measurements

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Replace ALL grey text in this fill-in document. Do not change black text, do not add titles. Copy tables and charts from your Excel file.

1 INTRODUCTION

Describe briefly, clearly and yet precisely the goal of the experiment / measurements and the strategy with which you will achieve that goal.

The objective of this experiment is to determine and compare the hardness of various metal samples using the Brinell, Vickers, and Rockwell methods. The study focuses on evaluating the influence of material treatment such as quenching and plastic deformation on hardness. Appropriate loads and indenters are applied for each method, and multiple indentations are conducted to ensure accuracy.

Results are analyzed using standardized conversion tables to establish correlations between hardness and tensile strength, as well as to assess the suitability of each testing method for different materials and applications.

2 BACKGROUND/ THEORY

The hardness of metals is measured via standardized tests, in which a small indenter of a defined shape is pressed into the material with a certain force. The hardness is then deduced from the dimensions of the indentation remaining after the test (Vickers and Brinell methods). In the Rockwell methods, one reads the hardness directly on the device on a dial gauge, which actually measures the depth of this indentation.

3 METHOD & MATERIALS

A hardness apparatus is used for the test, in which one mounts the desired indenter, and one adjusts the desired force. A pre-load of 10 kgf is manually applied to the sample beforehand by turning a wheel, pushing the sample against the indenter with a force of 10 kgf. The rest of the measurement is performed automatically: via a mechanism, the main load is applied, held for a few seconds, and then removed.

4 RESULTS

4.1 Measurements

First add one or more sentences that already provide the main measurement results as text or refer to a table. Then add the measurement results in a compact and clear table, possibly clarified by appropriate graphs. If legibility is compromised due to the large number of measurement results, certain measurements in the table can also be included in the appendices. A table always has a caption above it and is numbered. Provide an informative, clear caption.

The header of a table consists of at least 2 lines:

- 1st line: the default symbol for the quantity
- 2nd line: the unit used in brackets, possibly preceded by a prefix or an appropriate power of 10. Only SI units are allowed.

Numbers are presented as simply as possible. Make a suitable choice of the unit and use prefixes such as mega or giga. Only significant figures are mentioned.

Avoid spreading a table over two pages. If a table does not fit on one page due to its size, repeat the header of the table on the next page.

4.1.1 Vickers measurements

Mention the main load used and the measurement uncertainty of the microscope's scale value. Complete the tables below, give the result in standard notation.

Table no: Title

Measurement	$d_{horizontal}$ (mm)	$d_{vertical}$ (mm)
$\text{Steel}_{\text{unhardened},1}$		
$\text{Steel}_{\text{unhardened},2}$		
$\text{Steel}_{\text{unhardened},3}$		
$\text{Steel}_{\text{hardened},1}$		
$\text{Steel}_{\text{hardened},2}$		
$\text{Steel}_{\text{hardened},3}$		
Brass_1		
Brass_2		
Brass_3		

Table no: Title

Material	d_{avg} (mm)	HV (-)	ΔHV (-)	$HV_{standard\ notation}$ (-)
$\text{Steel}_{\text{unhardened}}$				
$\text{Steel}_{\text{hardened}}$				
Brass				

4.1.2 Rockwell measurements

Complete the tables below, give the result in standard notation.

Table no: Title

Measurement	$\text{Steel}_{\text{unhardened}}$ (-)	$\text{Steel}_{\text{hardened}}$ (-)	Brass (-)
1			
2			
3			
4			
5			

Table no: Title

Material	HR_{avg} (-)	ΔHR (-)	$HR_{standard\ notation}$ (-)
$\text{Steel}_{\text{unhardened}}$			
$\text{Steel}_{\text{hardened}}$			
Brass			

4.1.3 Rockwell B measurements for tensile samples

Complete the tables below, give the result in standard notation.

Table no: Title

Measurement	$Sample_{original}$ (-)	$Sample_{drawn}$ (-)
1		
2		
3		
4		
5		

Table no: Title

Sample	HRB_{avg} (-)	ΔHRB (-)	$HRB_{standard\ notation}$ (-)
Original			
Drawn			

4.1.4 Brinell for brass

First, calculate the necessary main load. Then fill in the tables, state the result in standard notation.

Table no: Title

Measurement	$d_{\text{indentation}}$ (mm)
1	
2	
3	
4	
5	
6	

Table no: Title

$d_{\text{indentation,avg}}$ (mm)	HB (-)	ΔHB (-)	$HB_{standard\ notation}$ (-)

4.2 Calculations

Present the calculations of the measurements in an orderly manner. If several similar calculations are performed, give at least 1 complete, clearly worked out example calculation and an error calculation for all calculated quantities. Clearly indicate for which measurement value from the table the calculations are made. First work out the calculations using variables/symbols, only then enter the numbers. If necessary, provide explanations (for example, textually explain the mathematical technique used). Always put the final result in standard notation.

4.2.1 Vickers measurements

*Calculate the Vickers hardness for the hardened steel sample using the average value of the diagonal. Give a complete example calculation. Also determine the error on the measured hardness for this sample, taking into account the uncertainty on the microscope scale factor: the 1% error on the scale factor gives rise to an **equally large additional percentage error** on the length of the diagonal.*

Eq. (1) calculates the Vickers hardness number (HV) by dividing the applied load (P) by the square of the average diagonal length (d) of the indentation, scaled by a constant factor (1.85) to account for the geometry of the diamond pyramid indenter.

$$HV = 1.85 \cdot \frac{P}{d^2}$$

Because Vickers hardness depends on the square of the diagonal length, a relative error in the diagonal measurement results in twice that relative error in the calculated hardness value:

$$\Delta HV = HV\left(2 \cdot \frac{\Delta d}{d}\right) \quad (2)$$

Contributing to a final result of :

$$HV = (\ldots \pm \cdots)$$

4.2.2 Rockwell measurements

Give the example calculation for the error on the Rockwell B hardness. Clearly indicate for which measurement you make the calculation.

$$\Delta HRB = \frac{s}{\sqrt{n}}$$

4.2.3 Brinell for brass

Using the average value, give the example calculation for the Brinell hardness and the error.

Eq. (3) determines the Brinell hardness number (HB) by calculating the applied load (P) divided by the curved surface area of the indentation, based on the indenter diameter (D) and the measured indentation diameter (d).

$$HB = \frac{2P}{\pi D(D-\sqrt{D^2-d^2})} \quad (3)$$

5 DISCUSSION

In this section, repeat the central questions / goals from the lab assignment and formulate an answer, possibly grouped per sub-experiment. Interpret your results and decide: has the purpose of the experiment been achieved? Try to explain any discrepancies. For example, discuss the following:

• Accuracy and precision of the measuring method (s): Which method affects the measurement error of the final result most significantly? What causes the biggest uncertainty?

• Correctness of the final result: Avoid terms such as "reasonably good" or "about"; either a measurement is correct with the expected value within the measurement error, or not.

• Give a final assessment of the obtained results in comparison with the results of others, for example from previous experiments, other students or previous literature.

If your research concerns a relationship between 2 or more physical quantities, describe the shape and strength of the relationship found and, as far as possible, explain the comparison with the theoretically expected relationship. Point out the slope of the line and / or its physical interpretation. Beware of terms such as "directly proportional", "inversely proportional", "exponentially increasing/ decreasing". These have one specific physical meaning; use it correctly!

Suggestions: If necessary, formulate tips for improving the measurement methods and / or alternative measurement setups. Be sure to give suggestions for better measuring methods or accuracy of the calculations if the test did not go as expected.

Specifically for this experiment:

- Summarize the results in a table, with the different methods for each of the materials. Use standard notation.

Table no: Title

Material	HV (-)	HRB (-)	HRC (-)	HB (-)
$\text{Steel}_{\text{unhardened}}$				
$\text{Steel}_{\text{hardened}}$				
Brass				
$\text{Tensile sample}_{\text{original}}$				
$\text{Tensile sample}_{\text{drawn}}$				

- Discuss the mutual consistency of the results for the different methods based on the tables or graphs in the lab text

- Discuss the difference between the materials, the effect of quenching the sample and the effect of plastic deformation

- Compare with reference values if possible

- Are there any peculiarities in your results? Which ones? Can you explain them?

- ...

Also answer the following questions (in a continuous text, as learned in writing skills):

1. *What is the approximate mathematical relationship (formula!) between the hardness and tensile strength of metals? Apply for your steel sample.*
2. *Why should you never start with a Brinell or Rockwell B measurement on an unknown material?*
3. *Which hardness measurement would you use and explain why:*
   a) *for thin copper plates?*
   b) *for series products made of hardened steel (i.e. large numbers) where each sample has to be measured?*
   c) *for determining the overall (i.e. average hardness) hardness of a cast bronze bearing (inhomogeneous material)?*
4. *Why are there so many different types of hardness measurements and types of indenters? Be sufficiently specific in your answer!*
5. *Which Rockwell method should you use for steel with a Brinell hardness of 175? Take the value of this Rockwell hardness and tensile strength from the graph below. Indicate your reasoning clearly on the graph and state the tensile strength in SI units.*

There exists an approximate empirical relationship between the hardness of a material and its tensile strength, particularly for steels. A commonly used formula is:

Tensile Strength (MPa) ≈ 3.45 × Brinell Hardness (HB).
For example, if the Brinell hardness of a steel sample is 175, then its estimated tensile strength would be 3.45 × 175 = 603.75 MPa. This relationship allows us to make a quick estimate of a material’s strength from a non-destructive hardness test.

When testing an unknown material, it's important not to start with Brinell or Rockwell B measurements, because these methods use relatively large indenters and high loads. If the material is very soft or thin, it might deform excessively or be damaged. Additionally, if the material is hard, the indenters (especially the steel ball) might be damaged themselves or fail to produce a measurable indentation. Therefore, starting with a method like Vickers, which uses a smaller, more precise diamond pyramid and a controllable load, is safer and more informative for unknowns.

For thin copper plates, the Vickers hardness test is most suitable. It uses a small diamond pyramid indenter and is capable of accurately measuring thin sections without penetrating completely or deforming the sample excessively. In contrast, the Brinell or Rockwell methods might not be applicable due to their larger indenters and greater force. For series production of hardened steel parts, Rockwell C is typically preferred because it is fast, easy to automate, and the results can be read directly from the machine. It is practical for quality control in industrial settings. For determining the overall hardness of a cast bronze bearing, which is an inhomogeneous material, the Brinell test is ideal. Its large steel ball indenter samples a broader area, making it suitable for averaging out the variation in material properties over a larger surface.

The reason there are many different hardness measurement methods and types of indenters is because materials differ widely in terms of their mechanical properties, geometry, surface condition, and intended application. For instance, soft materials require lower forces and larger indenters to avoid unrealistic results, while hard and thin materials need more precise and localized measurements. The choice of method also depends on whether the testing is destructive, non-destructive, automated, or used for lab versus production environments.

Finally, for steel with a Brinell hardness of 175, we should use the Rockwell B method. According to standard hardness conversion charts and graphs, this Brinell hardness value falls in the range typically measured by Rockwell B, which uses a steel ball indenter and is intended for softer steels and non-ferrous metals. From the conversion chart or graph, we can estimate the corresponding Rockwell B value (e.g., around 85 HRB), and using the earlier formula, we again get a tensile strength of approximately 604 MPa, stated in SI units.

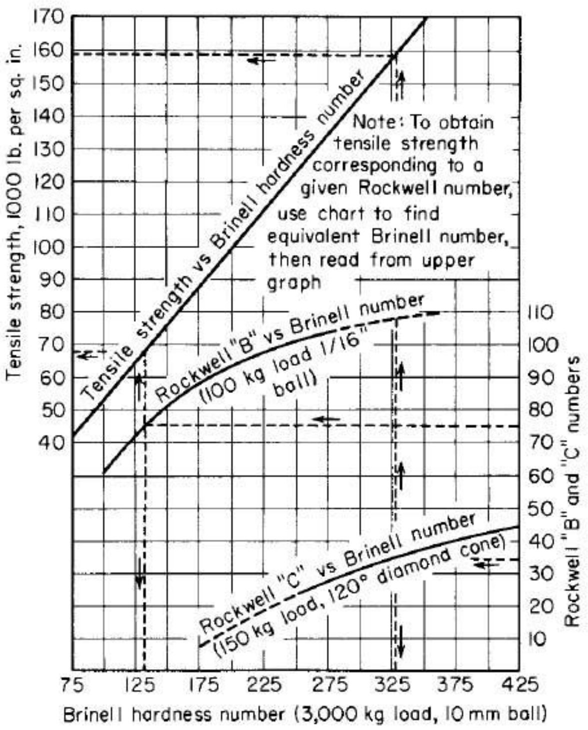

Figure 1: Conversion graph hardness methods

6. *Why shouldn't you make an indentation that is too close to a previous one? Will your measured value be too high or too low in that case? Why?*
7. *In the literature, find a method to determine the hardness of rubber and explain the principle briefly. Indicate your source. What is a principle difference here in terms of measurement method compared to those seen with metals?*

6 CONCLUSION

Briefly repeat the most important finding and / or final assessment of the results obtained in comparison with results from previous experiments, from others or from literature. Do not put new information here.

7 BIBLIOGRAPHY

Put the list of sources here. Use a reference manager. The default reference style is IEEE or APA. However, this can be deviated from for the various assignments if the teacher mentions this explicitly. So always check this carefully.

[1] J. Loeckx, “Hardness measurements”, not published.

[2] W. Dewulf, “Structure, Behaviour and Sustainability of Materials”, not published.