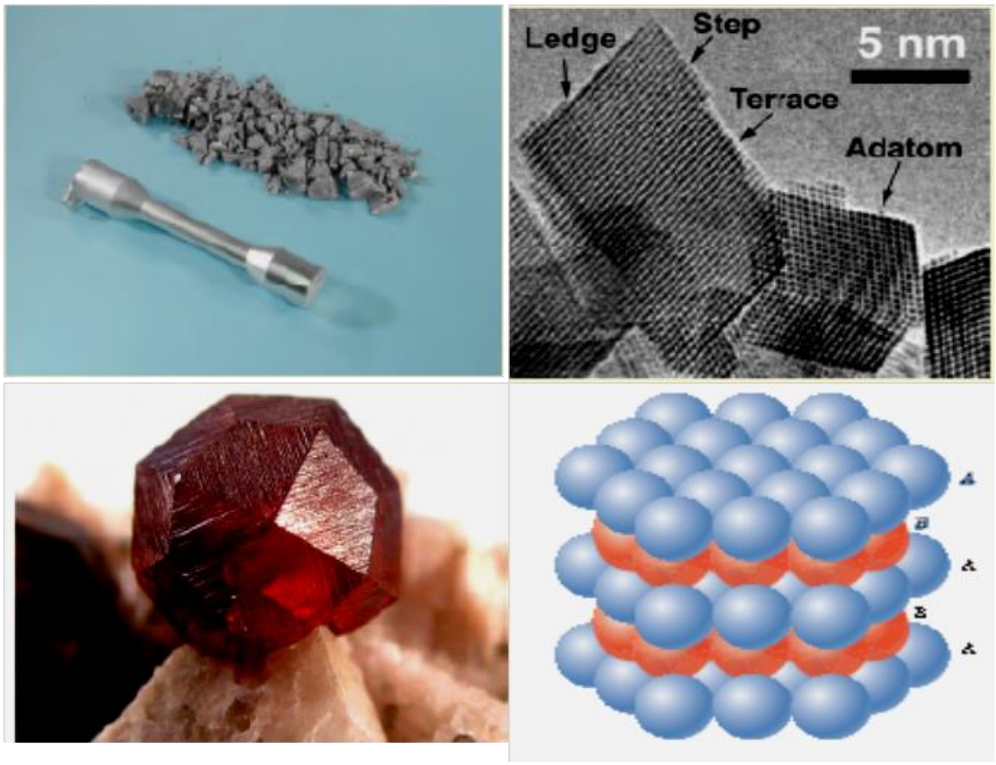
# Material Engineering, ME 254

# Lab Manual

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# Experiment #1

# Sample Preparation for Microscopic Examination

## I. Objectives:

- Familiarization with the procedure for preparation of a material specimen surface for microscopic examination.
- Familiarization with compound optical microscopes and metallography.
- Examination of surface characteristics of engineering materials.

## II. Background:

The preparation of a metallurgical specimen generally can be divided into a series of stages: sectioning, mounting, grinding/polishing, and etching.

### *1) Sectioning:*

Sectioning is the removal of a small representative volume of material from the parent piece. The microstructure of the material must not be altered in the process. Cold work and heat are the two most likely conditions that can quickly bring about structure changes. Quite obviously operations such as sawing that generates heat or shearing that introduces cold work are not preferable for sectioning. Cutting using a bonded abrasive wheel with coolant offers the best solution to minimize or eliminate heat and deformation.

### *2) Mounting:*

Metallurgical specimens are mounted primarily for (1) convenience in handling and (2) protection and preservation during subsequent grinding and polishing. Two methods are frequently used: compression mounting and cold mounting.

A. **Compression mounting** is done by mounting the specimen in a cylinder of hard polymer under pressure and elevated temperature in a molding machine (Figure 1). The method is often preferred when speed and a relatively hard mounting is required. For metallurgical examination, specimens are usually molded in cylinders 1, 11/4, or 11/2 inches in diameter.

Compression molding materials are (1) thermosetting or (2) thermoplastic polymers. Bakelite and diallyl phthalate fall into the first category while transoptic material into the second. By definition, thermosetting materials require heat and pressure during the molding cycle, and therefore may be ejected at high molding temperature. Transoptic materials remain molten at high temperature and become transparent with increasing pressure and decreasing temperature.

Molding pressure, temperature, and time duration are the major variables involved in compression mounting. By equipment design, temperature may be held constant leaving pressure and time duration as variables.

B. **Cold mounting** is done by placing the specimen at the center of a metal or pyrex ring on a glass plate and pouring liquid mounting material into the ring to cover the specimen. Allow the mounting material to cure at room temperature for 60 to 90 minutes before removing the ring. The method offers particular advantages when a specimen is too delicate to withstand the pressure and heat involved in compression molding. With cold mounting, large groups of specimens may be easily prepared in a short time.

Common types of cold mounting material include (1) epoxides (2) polyesters and (3) acrylics. These materials are two-component types consisting of a resin and a hardener. Since the curing process (polymerization) is an exothermic reaction the mixing by volume or weight ratios of each type is critical.

### *3) Grinding/Polishing*

Grinding and polishing are accomplished by sequential coarse grinding, medium grinding, and rough and final polishing. The specimen should be carefully rinsed before proceeding from one operation to the next.

Coarse grinding is done on a wet-belt grinder with 120 and 240 grit belts. The purpose of coarse grinding is to obtain a flat surface free from previous cutting tool marks.

Medium grinding is accomplished using successively finer grits of metallographic grinding paper. The paper is supported on a hard, flat surface such as glass or steel. The specimen is moved along the length of grinding paper without rotation or a rocking motion. When grinding is completed on one grit the scratches should all run in the same direction. Before proceeding to

the next finer grit the specimen should be washed to avoid brining large particles to the finer grit. The specimen is rotated 90 degrees between grits so that scratches from each successively finer grit run at right angles to those from the previous one. The polishing on a grit is complete when coarser scratches from previous grit have been totally removed.

Rough and final polishing is accomplished on cloth-covered wheels charged with fine abrasive alumina particles suspended in water. Nylon cloth and 1.0-mm alumina particle size are used for the rough polish; a velvet cloth and 0.05-mm particle size for the final polish. A few drops of water are added to the rotating wheel to improve polishing action and cleanliness. Initially the specimen is held at one position on the wheel, without rotation, until most of the previous grinding marks are removed. The specimen can then be rotated slowly, counter to the wheel rotation, until only scratches from the alumina are visible. The final polish should be completed at a slow speed on a different polishing wheel.

### *4) Etching*

The specimen surface is fairly smooth immediately after the final polish. A smooth surface deflects lights from the illuminator in the metallurgical microscope along the same direction showing no contrast and cannot reveal surface characteristics. Surface characteristics such as different phases, inclusions, porosity, cracks, intergranular corrosion can be revealed by etching. Etching is defined as the process to reveal structural details by preferential attack of a metal surface with an acid or other chemical solutions.

## III. Methods/Experiment

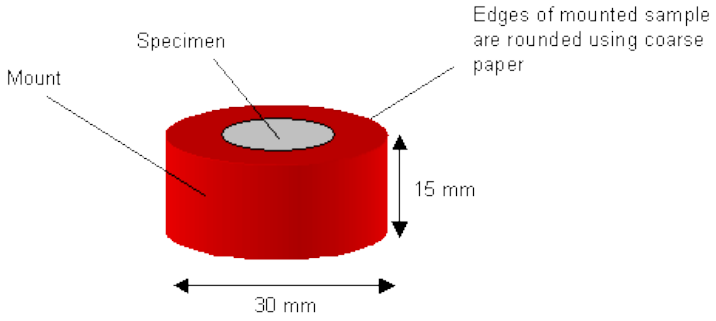
### 1. Lab Procedure for Mounting:

#### 1.1. Required Materials for Mounting:

- Resin and Hardener
- Plastic Mounting Ring with Removable Bottom
- 8 Ounce Paper Cup with Stirrer
- Weight Scale
- Liquid Soap

#### 1.2. Steps:

- Apply liquid soap to the inner walls and base of the mounting ring.
- Place the specimen in the center/bottom of the plastic mounting ring base with the examination surface face-down.
- Attach the mounting ring cylinder to the base by simple pressing firmly in place.
- Mix the appropriate amount of (2/1 Powder/Liquid - 15 grams of Powder/7.5 grams of Liquid per Sample) in a paper cup.
- Simply pour the epoxy mixture into the mounting ring; sample should be approximately 0.75" thick.
- After one hour, remove the sample from the mounting ring and proceed with course grinding.



## 2. Procedure for Coarse Grinding

*Note: Safety Glasses must be worn when operating the Course Grinding Equipment !

1. Label the specimen with your name so that it can be easily identified.
2. Turn the Motor On, then the water, adjust the flow to obtain a good film of water. Too much water will cause a spray when it contacts the sample.
3. Beginning with the 120 grit belt and using both hands to hold the specimen, carefully place the sample face onto the exposed area of the belt being careful not to contact the rotating surface with a sharp edge of the specimen or your hand.
4. Applying moderate pressure evenly, move the sample left-and-right across the belt surface to obtain uniform grinding. Use both hands to hold the specimen; unsecured specimens can "Catch an Edge and FLY"!
5. Lift the sample from the wheel periodically to determine the progress of grinding but do not rotate the sample. The 120 grit stage is complete when all the lines scratched in by the grinder are parallel on the specimen surface. If any line or scratch is not in the same direction as the other lines, continue grinding until all of the lines are parallel.
6. When all of the sample's scratches are parallel, carefully wash all of the debris from sample using tap water and dry the specimen immediately using a paper towel or pressurized air to avoid corrosion
7. Proceed to the 180 grit stage with the scratches oriented approximately perpendicular to the intended grinding direction and repeat steps 3 thorugh 6.
8. When the 180 grit stage is complete, you're ready to move on to the medium/fine grinding station

## 3. Lab Procedure for Fine Grinding

"The sample MUST be washed thoroughly before proceeding from one fine grinding stage to the next!!!"

1. Manual Fine Grinding is performed by drawing the specimens in one direction across the surface of the water lubricated abrasive paper. (Back to front is recommended) Use of backward and forward motion is less desirable because there is a tendency to rock the sample, producing a curved rather than a flat surface.
2. Begin with the lowest grade abrasive paper (240 grit) and proceed to the highest (600 grit).

3. To monitor progress, each fine grinding step should be performed in a direction off-angle with respect to the previous step.
4. Fine Grinding should be continued until the previous stage's scratches are gone, using a few extra strokes to assure complete scratch removal.
5. Sufficient water must be applied to provide lubrication and flush away the removal products. Too much water will result in a hydroplaning action where the sample rides on a film of water, thereby reducing the effectiveness of the abrasive. Use the valve at the top of the roll-grinder to increase and decrease the quantity of water needed or desired.
6. The specimen should be carefully rinsed after each step of Fine Grinding; debris from one step must not contaminate the next step! Rinse the specimen very thoroughly before proceeding to polishing

## 4. Lab Procedure for Mechanical Polishing

1. Safety goggles must be worn when using the Polishers!
2. Make sure your specimen and hands have been thoroughly cleaned before Polishing!
3. Begin with the 25-micron, nylon cloth polishing station!
4. Turn the water on adjusting to less than one drop per second!
5. Apply a small amount of the aluminum oxide abrasive solution to the polishing cloth.
6. When polishing the specimen, hold it with both hands, apply a moderate amount of pressure, and don't let it go. The Rough Polishing Stages (5-25 microns) should take between 1 and 2 minutes each! If you let go of the specimen it may fly, harm you or others in the laboratory and become damaged forcing you to start over again with coarse grinding - hold it tight and be careful!
7. Do not contaminate the polishing wheel; cover the wheel when it's not in use!
8. Before proceeding to the next polishing stage, wash and dry both the specimen and your hands thoroughly then rinse the specimen.
9. Repeat steps 4 through 8 for the 5-micron stage.
10. Proceed to the Final Polishing Station (1 micron) when all of the 25 micron marks are removed at the 5 micron stage.
11. Hold the specimen with both hands and apply a SMALL amount of pressure, and Don't Let Go!
12. The Final Polishing Stage (1-micron) should take between 1/2 and 1 minute!

13. Be very careful that you do not contaminate the polishing wheel! Cover the wheel when it's not in use!!!
14. Before proceeding to Etching, wash and dry both the specimen and your hands thoroughly then rinse the specimen with distilled water. DO NOT TOUCH THE SPECIMEN SURFACE!!

**Table I. Abrasive Blade Selection Guidelines Chart**

| Materials (alloys) | Classification | Abrasive/Bond |
|---|---|---|
| Aluminum, brass, zinc, etc. | Soft non-ferrous | SiC/ Rolled rubber |
| Heat treated alloys | Hard non-ferrous | Alumina/ Rubber resin |
| <Rc 45 steel | Soft ferrous | Alumina/ Rubber resin |
| >Rc 45 steel | Hard ferrous | Alumina/ Rubber resin |
| Super alloys | High Ni-Cr alloys | SiC/ Rolled rubber |

## 5. Lab Procedure for Etching Steel Specimens

Note: Always wear Acid Resistant gloves when Etching!

1. Place the specimen on the table under the Fume Hood with the polished surface up.
2. Turn on the Fume Hood.
3. Without touching the specimen surface, clean the surface with alcohol and let it dry using the hot air gun. Do not let anything but the alcohol touch the specimen surface!
4. Using the Eye-Dropper, apply a few drops of Etchant to the specimen surface covering the entire metallic surface of the specimen.
5. After about 20 to 30 seconds, rinse the Etchant into the sink with water and quickly rinse the specimen with alcohol, but do not touch the surface!
6. Use the Hot Air Gun to dry the sample.
7. Proceed to Microscopic Examination; if further etching is required you may return and proceed through steps 1 through 6 varying the time in step 5 depending on the results.
8. If the specimen has many scratches and marks or the microstructure cannot be seen after several etches, return to fine grinding and go back through the necessary steps

## Table XI. Common Chemical Etchants

**CAUTION:** Safety is very important when etching. Be sure to wear the appropriate protective clothing and observe all **WARNINGS** on chemical manufacturers MSDS. Also review **COMMENTS** Section for each etchant.

| Etchant | Composition | Application | Conditions | Comments |
|---|---|---|---|---|
| **Kellers Etch** | 190 ml Distilled water<br>5 ml Nitric acid<br>3 ml Hydrochloric acid<br>2 ml Hydrofluoric acid | Aluminum alloys | 10-30 second immersion. Use only fresh etchant | |
| **Kroll's Reagent** | 92 ml Distilled water<br>6 ml Nitric acid<br>2 ml Hydrofluoric acid | Titanium | 15 seconds | |
| **Nital** | 100 ml Ethanol<br>1-10 ml Nitric acid | Carbon steels, tin, and nickel alloys | Seconds to minutes | |
| **Kallings Reagent** | 40 ml Distilled water<br>2 grams Copper chloride ($CuCl_2$)<br>40 ml Hydrochloric acid<br>40-80 ml Ethanol (85%) or Methanol (95%) | Wrought stainless steel, Fe-Ni-Cr alloys | Immerse or swab for few seconds to a few minutes | |
| **Lepito's Reagent** | 50 ml Acetic acid<br>50 ml Nitric acid | High temperature steels | Swab | |
| **Marble's Reagent** | 50 ml Distilled Water<br>50 ml Hydrochloric acid<br>10 grams Copper sulfate | Stainless steels, Nickel alloys | Immersion or swab etching for a few seconds | |
| **Murakami Reagent** | 100 ml Distilled Water<br>10 grams $K_3Fe(CN)_8$<br>10 grams NaOH or KOH | Wrought Stainless steel, tungsten alloys, silver alloys, SiC, $B_4C$ | Immerse or swab for seconds to minutes | Use fresh |
| **Picral** | 100 ml Ethanol<br>2-4 grams Picric acid | Iron and steel, tin alloys | Seconds to minutes | Do not let etchant crystallize or dry - **explosive** |
| **Vilella's Reagent** | 45 ml Glycerol<br>15 ml Nitric acid<br>30 ml Hydrochloric acid | Stainless steel, carbon steel, cast iron | Seconds to minutes | |

## IV. Results and Discussion

Prepare a metallographic brass, steel or aluminum specimen going through the course grinding, fine grinding, polishing and etching stages of specimen preparation. Clearly label your specimen and submit it with the lab report.

## V. Assignments

1. Describe the steps involved in the preparation of your sample including the following:
   a. Sectioning
   b. Mounting
   c. Course Grinding
   d. Fine Grinding
   e. Polishing
   f. Etching

2. Why must metallographic samples be washed and carefully dried before proceeding from one grinding or polishing operation to the next?

3. What is the purpose of etching metallographic samples?

4. Why metallographic samples are sometimes mounted in plastic?

# Experiment # 2

## Quantitative and qualitative analysis of microstructure using optical microscopy and scanning electron microscopy

## I. Objectives:

The main objectives of this experiment is to

1) Inspect the internal structure (or called microstructure) of metallic samples using optical microscopy and scanning electron microscopy, and
2) Determine the grain size of the samples using and an intercept method and ASTM (American Society for Testing and Materials) method.

## II. Background:

Metallography consists of the study of the constitution and structure of metals and alloys. Much can be learned through specimen examination with the naked eye, but more refined techniques require magnification and preparation of the material's surface. Optical microscopy is sufficient for general-purpose examination; advanced examination and research laboratories often contain electron microscopes (SEM and TEM), x-ray and electron diffractometers and possibly other scanning devices.

Incorrect techniques in preparing a sample may result in altering the true microstructure and will most likely lead to erroneous conclusions. It necessarily follows that the microstructure should not be altered. Hot or cold working can occur during the specimen preparation process if the metallurgist is not careful. Expertise at the methods employed to produce high-quality metallographic samples requires training and practice. The basic techniques can be learned through patient persistence in a matter of hours. This module takes the student through the metallographic sample preparation process step-by-step with demonstrations and explanations of sectioning, mounting, course & fine grinding, polishing, etching and microscopic examination.

Quantitative metallography plays very important role in materials science and engineering. It can provide quantitative relationships between processes, microstructures and physical as well as mechanical properties and supply the first hand data necessary to establish a reasonable mathematical model for microstructure. It enables the costly trial and error method to be replaced by a scientifically based experimental procedure resulting in the improvement of known materials and the development of new ones. In many cases, we need to have information of the grain size, surface area and volume fraction of phases present in the microstructure. During this laboratory practice, you will be exposed to

one of the most important quantitative metallographic techniques, namely grain size measurement of single-phase material. Other important measurements include volume fraction and surface area for two-phase material (not covered in this lab). Grain size is a very important parameter to characterize the microstructure. It can set up the quantitative relationship between the microstructure and mechanical properties. A famous example is the Hall-Patch equation.

$$\sigma = \sigma_0 + kd^{-\frac{1}{2}}$$

where σ is flow stress, $\sigma_o$ is lattice friction stress, *k* is constant and *d* is grain size. Therefore, grain size measurement can provide us a good estimate of yield strength of different material.
Grain size measurement also provides information regarding ductile–to-brittle transition, creep behavior of materials etc.

There are many ways one can measure grain size in a single-phase microstructure. You will use the method known as 'Linear Intercept method'. This method involves the following steps:

- Draw a straight line on the single-phase microstructure
- Count number of intersection the line makes with the grain boundaries.
- Calculate the average grain size of the material given the length of line.
  By carrying out such measurement for large number of grains (approximately 80), you can get a better statistics.

**Grain Size Calculation**

For a single-phase material, the ASTM grain size of the metal can be estimated by comparing the image at 100X with standard microstructure examples corresponding to standard grain sizes from 1 to 10. The ASTM grain size number, n, can be calculated using the following relationship:

$$N\,(M/100)^2 = 2^{(n-1)}$$

N = number of grains per square inch at 100X

n = ASTM grain size number

M = Magnification

For single phase materials, ASTM grain size number is given to denote the grain sizes. These are not the actual grain size values, but the latter can be derived from the ASTM grain size number, n; the larger the grain size number, the smaller the grains.

If there are N grains per square inch at a magnification M then there are $(N)^{1/2}$ grains along a 1 inch length. The size of each grain at magnification M is then $1/(N)^{1/2}$ inches.

The actual size of the grain is given by Actual Grain Size = $1/(N\ M)^{1/2}$

## III. Methods/Experiment:

1) Obtain a metallic specimen (steel) from the instructor. Prepare the samples for optical microscopy following the procedure described in Experiment-1.

2) Examine the specimen under optical microscope using the following procedure:

- Initially the lowest power objective lens is used for focusing the specimen. Turn the lowest-power objective lens into place. If necessary, turn the coarse stage height control to lower the sample stage to make room so the objective lens can be turned into place.
- Turn the stage height focusing control to position the specimen about half a centimeter under the objective lens.
- Look through the eyepieces and use the focusing controls (coarse and fine stage height controls) to bring the specimen into appropriate focus.
- Scan the specimen surface by moving the stage using the stage position controls and select the areas that may warrant more complete study at higher magnification.
- Turn the higher-power objective into place.
- Adjust the stage height using the fine control until the specimen comes into sharp focus. Be sure that the objective lens does not touch the specimen surface at any time. Otherwise, the objective lens may be scratched and permanently damaged.
- Take a photograph of the microstructure if the microscope is equipped with a camera.

3) Measure the grain size using an intercept method and ASTM method:

**Intercept Method:**

a. Using the photograph of the microstructure that show the grain structure, draw straight lines with the same length
b. Count the grains intersected by each line
c. Divide the line length by an average of the number of grains intersected

d. Find the the average grain diameter by dividing this result by the linear magnification of the photomicrographs.

**ASTM Method:**

A grain size number, n (range from 1 to 10) is used to describe the average grain size in ASTM method. . The grain size number can be computed from the following relation:

$$N = 2^{n-1}$$

where N is the the average number of grains per square inch at a magnification of 100X. Thus to compute n, the grain structure should be photographed at a magnification of 100X.

## IV. Assignments

1) Describe the main parts of optical microscopy and scanning electron microscopy.
2) What is the meaning of 100X magnification?
3) Briefly explain how optical and scanning electron microcopy work.
4) Record the important features you inspect under optical microcopy and scanning electron microscopy
5) Attach a photograph of the microstructure of your sample in the report.
6) Determine the average grain size of your sample using both intercept and ASTM methods. Show the measurement and calculation in the report.

# Experiment # 3

# Hardness Tests

## Objectives:

1. To learn about principles and different methods of hardness measurement.
2. To learn about the correlations among different types of hardness measurement and correlations of hardness with tensile strength.
3. To acquire experience of using various types of hardness testers.

## Background:

Hardness is resistance of a material to plastic indentation, scratching, surface penetration, or wear. These properties are all related to the resistance against plastic flow (permanent deformation) in the material.

There are different approaches and criteria for hardness measurement. Some test methods for certain material provide convenient correlation of hardness to other mechanical properties. For example, hardness from indentation tests on steel and copper alloys can be used as a rough guide to estimate tensile strength. Hardness tests, in most cases, are rapid and repeatable, and in many instances nondestructive. Therefore, hardness test represents an important means of quality control.

All the widely used hardness measurements adopt one of the two general methods: static indentation and rebound testing. Static indentation involves pressing a ball, diamond, or other types of indenter under a specified constant load into the surface of material and measuring the length, width, or depth of the indentation. Each hardness test method, or scale, is defined with a particular type of indenter, a specified minor load, and a specified major load. The measured indentation size is then converted to a hardness number specific to the scale adopted. In general, the harder the material, the better the resistance, and thus the smaller the indentation.

Rebound testing involves dropping an indenter onto the surface of specimen and measuring rebound height of the indenter. The potential energy at the initial height is converted to kinetic energy when the indenter is released. A fraction of the kinetic energy is consumed for plastic deformation on impact, leaving some kinetic energy after impact to convert back to potential energy and achieve a certain rebound height of the indenter. The rebound height measured by the instrument is then converted to a hardness number.

**Brinell Hardness Testing**

Brinell test is performed by pressing a hardened steel ball, 10 mm in diameter, into the flat surface of a sample under a constant load. The load is usually 3000 kg (both dead weights on holder) held for 10 to 15 s for steel and hard metals or 500 kg (only the smaller dead weight on holder) held for about 30 s for soft non-ferrous metals such as copper and aluminum alloys. The specified time period is necessary to ensure that plastic flow during indentation in the metal has stopped. A Brinell hardness tester is shown in Figure 1.

The Brinell hardness number (HB or BH number) is determined by dividing the load by the surface area of the circular indentation seen on the surface according to the formula:

$$\mathrm{HB} = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \qquad (1)$$

where $P$ is the applied load in *kg*, $D$ is the diameter of the indenter ball in *mm*, $d$ is the mean diameter in *mm* of the indentation, and HB is in *kg/mm2*. The mean diameter of the indentation (two readings at right angles to each other) is measured using a microscope.

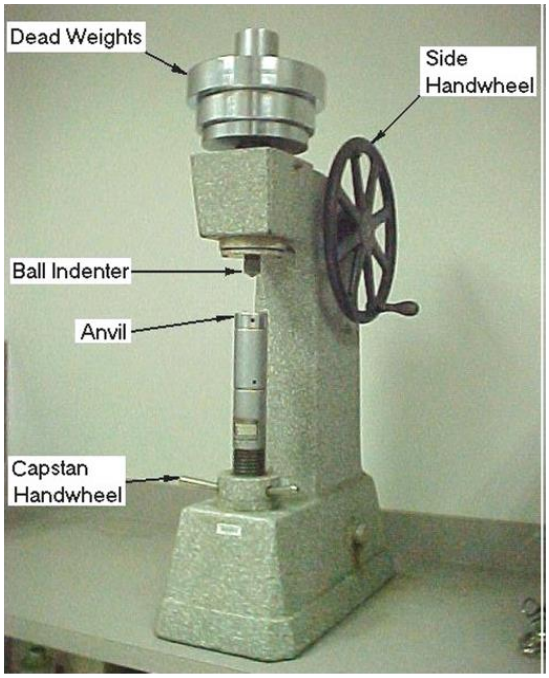



**Figure 1 – A Brinell hardness tester.**

The indentation is a result of plastic deformation under the applied load. Unfortunately, different metals respond somewhat differently to a given load exceeding their yield strength. Some metals, for example, work harden more easily during plastic deformation than others. Such metals may give hardness readings lower than that of a material that shows little work hardening when the two are compared under light loads yet give higher hardness readings when compared under heavy loads.

For Brinell hardness test the sample should be flat and securely supported. The sample should be thick enough so that no bulge appears on the opposite (bottom) face during indentation. To ensure accurate

results, indentations should not be made too close to the edge of the test piece. Lack of supporting material from one side of the test piece may result in larger and unsymmetrical indentations. Similarly, indentations should not be made too close to one another. Otherwise, the metal may work harden and affect the second indentation or there may not be sufficient supporting material for the second indentation.

**Procedure for Brinell hardness test:**

1. Place the specimen on the anvil with its surface normal to the direction of applied load.
2. Place the correct weights (two for 3000 kg and only the small one for 500 kg) on the yoke.
3. Turn the large side handwheel in counterclockwise direction until it stops. Hold it in place with right hand.
4. Using left hand, raise the anvil with the capstan handwheel tuning in clockwise direction until the specimen just makes contact with the ball indenter. See that the ball is at least 5 mm from the edges of the specimen or existing indentations.
5. Apply load by slowly turning the side handwheel clockwise until the yoke and weights rise and float for 15 s (under 3000 kg weight) or 30 s (under 500 kg weight).
6. Release the load gradually with the side handwheel slowly turning in the opposition (counter-clockwise) direction. Make sure this is done gently to avoid dynamic load from rapid descend of the weights and the holder.
7. 7. Lower the specimen by turning the capstan handwheel counter-clockwise until it clears the indenter.
8. Measure the diameter of the indentation to the nearest 0.1 mm using a microscope.
9. Calculate the Brinell hardness numbers using Equation (1) with measured parameters in correct units.

**Rockwell Hardness Testing**

A typical Rockwell hardness tester is shown in Figure 2.

Rockwell hardness test differs from Brinell hardness test in that the hardness is determined from the depth of indentation made by the indenter under a constant load. Various types of indenters may be used in Rockwell hardness tests: diamond indenter and steel-ball indenters of diameter 1/16, 1/8, 1/4, or 1/2 in. In the test the indenter is pressed into the specimen surface under an initial minor (light) load followed by a major (heavy) load. The additional depth of indentation made by the indenter under the

major load beyond that by the minor load is measured and converted to a hardness number (see Table 1). The hardness number is inversely related to the depth of indentation.

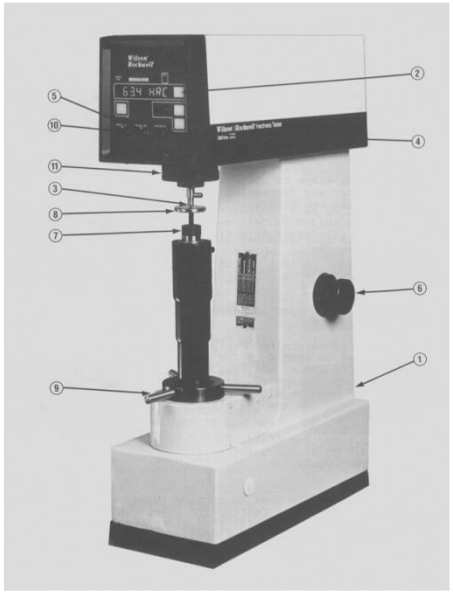



Figure 2 – A Wilson Rockwell Model 520 hardness tester.

1. Power switch 2. Test scale scroll key 3. Indenter 4. Indenter display
5. Major load (kg) display 6. Weight selector dial 7. Anvil 8. Specimen
9. Capstan handwheel 10. Minor load (kg) display

There are two basic types of Rockwell hardness tests: regular hardness test and superficial hardness test. Both use hardness tester of similar basic mechanical principles and measure similar criteria with a diamond or a steel ball indenter. In regular Rockwell hardness tests, the minor load is always 10 kg while the major load can be 60, 100, or 150 kg. A letter is assigned to each scale that employs a particular combination of indenter and major load as shown in Figure 5. A hardness number is suffixed by first the letter H (for hardness), then the letter R (for Rockwell), and finally the letter that indicates the scale used. For example, a value of 45 on the Rockwell C scale is expressed as 45 HRC.

In superficial hardness measurement, the minor load is 3 kg and the major load 15, 30, or 45 kg. The superficial hardness scale is designed by a number indicating the major load and a letter N for diamond indenter, T for 1/16-in. ball indenter, W for 1/8-in. ball indenter, X for 1/4-in. ball indenter, or Y for 1/2-in. ball indenter. A superficial hardness number is suffixed by first the letter H (for hardness), then the letter R (for Rockwell), and finally the scale designation. For example, 50 HR30T means a value of 50 is obtained using a 1/16-in. ball indenter with 30 kg major load.

The Rockwell test is more rapid and leaves a smaller and less conspicuous indentation on the workpiece than does the Brinell test. To ensure accuracy, the test surface should be flat and free from scale, pits, and foreign materials. Oiled surfaces generally give slightly lower readings than dry ones because of reduced friction under the indenter. The bottom surface also should be free from scale, dirt, or other foreign substances that might crush or flow under the test pressure and so affect the results.

When the Rockwell hardness tester is used to test the hardness of polymers, a 15-second delay during loading of major load and before the measurement of indenter penetration is allowed to account for the viscoelastic property of polymers. The scale is also specified with a user-selected indenter and a specified major load (60, 100, or 150 kg). For hardness comparison, the same types of indenter and applied load should be used.

Procedure for regular Rockwell hardness test (Wilson/Rockwell tester):

1. Turn power switch located in lower rear panel "ON".
2. Select desired scale by means of the "TEST SCALE SCROLL". This key may be depressed for each scale advancement or held in for rapid scrolling.
3. Select and install the proper indenter, as indicated in the "PENETRATOR" display.
4. Select the proper major load, as indicated in the "MAJOR LOAD kg" display, by means of the weight selector dial.
5. Place the specimen on the anvil.
6. Raise specimen into contact with the indenter by turning capstan handwheel clockwise slowly. The bar LEDs (red) will light up and the read display will show "MINOR LD".
7. Continue to slowly turn the capstan handhweel. Stop the handwheel when the bar LEDs
8. reach the "SET" zone. The major load will automatically be applied and then removed.
9. The read display will show "TESTING" and then the numerical value and the scale tested.
10. 8. Remove the minor load by turning the capstan handwheel counter-clockwise. Continue to lower the specimen until it clears the indenter. The test is concluded.

Procedure for superficial Rockwell hardness test (Kentrell hardness tester):

1. Select proper indenter and anvil.
2. Put gage level pin in “S” position.
3. Screw in upper pins (minor load for superficial hardness test).
4. Select proper major load (lower pins).
5. Select proper gage index.
6. Set depth knob on side of yester (make one test holding indenter bar down until two seconds after dial gage needle comes to rest, set depth knob in accordance with dial gage reading for continuous testing).
7. Place the specimen on the anvil.
8. Raise specimen into contact with the indenter by turning handwheel clockwise slowly until the short gage needle roughly points to the black short downward arrow and the long gage needle points to the start arrow (red or green depending on the selected dial index). Use the adjusting ring to line up the gage index with the needle, if necessary. DO NOT TURN THE CAPSTAN HANDWHEEL COUNTERCLOCKWISE TO MOVE THE NEEDLE BACKWARD.
9. Press the indenter bar to applied the major load. The long gage needle points to the measured hardness after a few seconds.

10. Remove the minor load by turning the capstan handwheel counter-clock, and continue until the specimen clears the indenter.

## Microhardness Testing

The term microhardness is generally referring to the size of indentation. In the test, a minute indenter and small constant loads (no more than 1000 g) are usually employed.

Dimensions of the indentation and the load are both used in the determination of the hardness number. There are two similar indenters for microhardness testing: Vickers and Knoop microhardness indenters (Figure 3 - b). Both hardness tests follow the Brinell principle, in that the indenter is pressed under a constant load into the material, the load removed, the size of the indentation measured, and the hardness number calculated by dividing the load by the surface area of indentation. They differ, however, in the shape of the indenter and indentation as shown in Figure 3-b. The Vickers indenter generates a square impression while Knoop indenter creates an elongated impression.

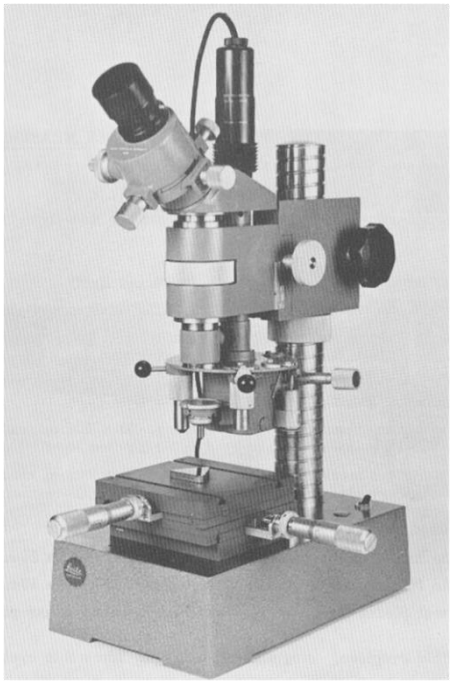


**Figure 3– A Leitz microhardness tester.**

### Vickers Microhardness Testing

A Vickers indenter is used in the Vickers microhardness test. The Vickers microhardness indenter is made of diamond in the form of a square-base pyramid having an angle of 136° between faces as shown in Figure 4. The indenter should be applied under a predetermined constant load for 10 to 15 s. The diagonals of the square indentation are measured using the microscope and a mean value is calculated. The Vickers hardness number (VHN) is then calculated according to the formula:

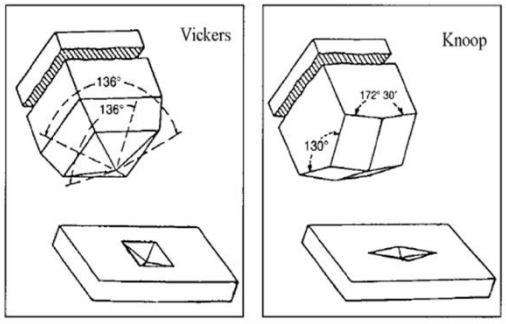



**Figure 3-b – Diamond indenters for Vickers and Knoop microhardness testers. The Vickers indenter has two identical 136° angles to form a pyramidal indentation; the Knoop indenter has two unique angles to from an elongated indentation.**

$$VHN = 2P\sin(\theta/2)/d^2 = 1854.4\ P/d^2 \quad (2)$$

where P is the applied load in grams (*g*), q is the

indenter face angle of 136°, and d is the mean diagonal length in m*m*. The constant 1854.4 incorporates the value of *sin*(q/2) and other conversion factors to give VHN a unit of *kg/mm2*.

**Knoop Microhardness Testing**

The Knoop microhardness indenter is made of diamond in the form of pyramid that has an included longitudinal angle of 172° 30' and an included transverse angle of 130°. The indenter generates a diamond-shape indentation having an approximate ratio of 7 to 1 between long and short diagonals. The Knoop hardness number (KHN) is calculated using the formula:

$$KHN = P/A = 14229\ P/d^2 \qquad (3)$$

where P is the applied load in grams (*g*), A is the indentation area, d is the measured length of long diagonal of the indentation in mm, and 14229 is the constant relating projected area of the indentation to the square of the length of the long diagonal.

**Procedure for microhardness test:**

1. Turn on the tester.
2. Select and install the indenter (Vickers or Knoop), if not already installed.
3. Place the weights selected on the loading pan.
4. Place the specimen in the tester and turn the 40´ objective lens into place. Focus on the specimen surface with the focusing control until surface features can be seen.
5. Gently turn the loading handle clockwise to raise the weights and the indenter, and turn the indenter into place. Slowly release the loading handle counter-clockwise to apply the load. Leave the indenter on the specimen for 10 to 15 s.
6. Raise the indenter by turning the loading handle clockwise gently, and turn the objective lens back into place.
7. Focus on the specimen surface to view the indentation. Measure length of the long diagonal (Knoop) or both diagonals (Vickers) of the indentation with the scale in the microscope. The numbers on the scale are length measured in 0.001 mm. Alternatively, the diagonal lengths can be determined by moving a point on the scale from a corner to the opposite corner of the impression under microscope and noting the difference in micrometer readings (numbers on the fine scale are in 0.01 mm).
8. Calculate microhardness number using the appropriate formula.

**Hardness-Tensile Strength Correlations:**

It is difficult to develop precise correlations between hardness from different measuring methods, or with other mechanical properties. Approximate relations, however, can be found for the same material using different hardness tests. Tables 2 and 3 are useful for approximate conversion of hardness from various hardness testing methods. There is also no direct correlation between indentation hardness and yield strength from a tension test since far more plastic deformation is involved in the hardness tests than that involved before yielding of material in tension test. However, because the plastic deformation involved in the tests for ultimate tensile strength is similar to that in hardness tests, empirical relations exist between these two properties. Based on Brinell hardness, for steels:

$$\text{Ultimate Tensile Strength } (MPa) \approx 3.5 \times (\text{Brinell Hardness}) \qquad (4)$$

and for brass:

$$\text{Ultimate Tensile Strength } (MPa) \approx 80 + 2.9 \times (\text{Brinell Hardness}) \qquad (5)$$

Table 1 – Various hardness testing methods.

| Test | Indenter | Shape of Indentation: Side View | Shape of Indentation: Top View | Load | Formula for Hardness Number |
|---|---|---|---|---|---|
| | | Macro-hardness tests | | | |
| Brinell | 10-mm sphere of steel or tungsten carbide | D (mm); d (mm) | d (mm) | P (kg) | $BH = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$ (kg/mm²) |
| Rockwell | | | | | |
| A, C, D | Diamond tip cone | 120°; t (mm) | | 60 (kg) for A; 150 (kg) for C; 100 (kg) for D | $R_A$ =, $R_C$ =, $R_D$ = 100-500t* |
| B, F, G | $\frac{1}{16}$-in. diameter steel sphere | t (mm) | | 100 (kg) for B; 60 (kg) for F; 150 (kg) for G | $R_B$ =, $R_F$ =, $R_G$ = 130-500t* |
| E | $\frac{1}{8}$-in. diameter steel sphere | | | 100 (kg) | $R_E$ = |
| | | Micro-hardness tests | | | |
| Vickers | Diamond pyramid | 136°; $d_1$, $d_1$ (mm) | | P (g) | VHN = 1854.4P/d² (kg/mm²) ** |
| Knoop | Diamond pyramid | t; l/b = 7.11; b/t = 4.00 | b (mm) | P (g) | KHN = 14229P/d² (kg/mm²) *** |

* t is the penetration (in mm) of indenter between the applied minor and major loads.

** See Equation (2) for correct units for applied load and measured lengths.

*** See Equation (3) for appropriate units for applied load and measured lengths.

**Table 2 - Hardness Conversion for Hardened Steel and Hard Alloys**

| C<br>150 kg Brale<br>Rockwell | A<br>60 kg Brale<br>Rockwell | D<br>100 kg Brale<br>Rockwell | 15-N<br>15 kg N Brale<br>Superficial | 30-N<br>30 kg N Brale<br>Superficial | 45-N<br>45 kg N Brale<br>Superficial | HV<br>Vickers 10 kg<br>Vickers | HK<br>500 gm & over<br>Knoop | HB<br>3000 kg 10-mm Ball<br>Brinell | G<br>150 kg 1/16" Ball<br>Rockwell | ksi<br>1000 psi<br>Tensile Strength |
|---|---|---|---|---|---|---|---|---|---|---|
| 80 | 92.0 | 86.5 | 96.5 | 92.0 | 87.0 | 1865 | --- | | | |
| 79 | 91.5 | 85.5 | 96.3 | 91.5 | 86.5 | 1787 | --- | | | |
| 78 | 91.0 | 84.5 | 96.0 | 91.0 | 85.5 | 1710 | --- | | | |
| 77 | 90.5 | 84.0 | 95.8 | 90.5 | 84.5 | 1633 | --- | | | |
| 76 | 90.0 | 83.0 | 95.5 | 90.0 | 83.5 | 1556 | --- | | | |
| 75 | 89.5 | 82.5 | 95.3 | 89.0 | 82.5 | 1478 | --- | | | |
| 74 | 89.0 | 81.5 | 95.0 | 88.5 | 81.5 | 1400 | --- | | | |
| 73 | 88.5 | 81.0 | 94.8 | 88.0 | 80.5 | 1323 | --- | Note 1 | | Note 2 |
| 72 | 88.0 | 80.0 | 94.5 | 87.0 | 79.5 | 1245 | --- | | | |
| 71 | 87.0 | 79.5 | 94.3 | 86.5 | 78.5 | 1160 | --- | | | |
| 70 | 86.5 | 78.5 | 94.0 | 86.0 | 77.5 | 1076 | 972 | | | |
| 69 | 86.0 | 78.0 | 93.5 | 85.0 | 76.5 | 1004 | 946 | | | |
| 68 | 85.6 | 76.9 | 93.2 | 84.4 | 75.4 | 940 | 920 | | | |
| 67 | 85.0 | 76.1 | 92.9 | 83.6 | 74.2 | 900 | 895 | | | |
| 66 | 84.5 | 75.4 | 92.5 | 82.8 | 73.3 | 865 | 870 | N/A | | |
| 65 | 83.9 | 74.5 | 92.2 | 81.9 | 72.0 | 832 | 846 | 739 | | |
| 64 | 83.4 | 73.8 | 91.8 | 81.1 | 71.0 | 800 | 822 | 722 | | |
| 63 | 82.8 | 73.0 | 91.4 | 80.1 | 69.9 | 772 | 799 | 706 | | |
| 62 | 82.3 | 72.2 | 91.1 | 79.3 | 68.8 | 746 | 776 | 688 | | |
| 61 | 81.8 | 71.5 | 90.7 | 78.4 | 67.7 | 720 | 754 | 670 | | |
| 60 | 81.2 | 70.7 | 90.2 | 77.5 | 66.6 | 697 | 732 | 654 | | N/A |
| 59 | 80.7 | 69.9 | 89.8 | 76.6 | 65.5 | 674 | 710 | 634 | | 351 |
| 58 | 80.1 | 69.2 | 89.3 | 75.7 | 64.3 | 653 | 690 | 615 | | 338 |
| 57 | 79.6 | 68.5 | 88.9 | 74.8 | 63.2 | 633 | 670 | 595 | | 325 |
| 56 | 79.0 | 67.7 | 88.3 | 73.9 | 62.0 | 613 | 650 | 577 | | 313 |
| 55 | 78.5 | 66.9 | 87.9 | 73.0 | 60.9 | 595 | 630 | 560 | | 301 |
| 54 | 78.0 | 66.1 | 87.4 | 72.0 | 59.8 | 577 | 612 | 543 | | 292 |
| 53 | 77.4 | 65.4 | 86.9 | 71.2 | 58.8 | 560 | 594 | 525 | | 283 |
| 52 | 76.8 | 64.6 | 86.4 | 70.2 | 57.4 | 544 | 576 | 512 | | 273 |
| 51 | 76.3 | 63.8 | 85.9 | 69.4 | 56.1 | 528 | 558 | 496 | | 264 |
| 50 | 75.9 | 63.1 | 85.5 | 68.5 | 55.0 | 513 | 542 | 481 | | 255 |
| 49 | 75.2 | 62.1 | 85.0 | 67.6 | 53.8 | 498 | 526 | 469 | | 246 |
| 48 | 74.7 | 61.4 | 84.5 | 66.7 | 52.5 | 484 | 510 | 455 | N/A | 238 |

| C<br>150 kg Brale<br>Rockwell | A<br>60 kg Brale<br>Rockwell | D<br>100 kg Brale<br>Rockwell | 15-N<br>15 kg N Brale<br>Superficial | 30-N<br>30 kg N Brale<br>Superficial | 45-N<br>45 kg N Brale<br>Superficial | HV<br>Vickers 10 kg<br>Vickers | HK<br>500 gm & over<br>Knoop | HB<br>3000 kg 10-mm Ball<br>Brinell | G<br>150 kg 1/16" Ball<br>Rockwell | ksi<br>1000 psi<br>Tensile Strength |
|---|---|---|---|---|---|---|---|---|---|---|
| 47 | 74.1 | 60.8 | 83.9 | 65.8 | 51.4 | 471 | 495 | 443 | ▲ | 229 |
| 46 | 73.6 | 60.0 | 83.5 | 64.8 | 50.3 | 458 | 480 | 432 | \| | 221 |
| 45 | 73.1 | 59.2 | 83.0 | 64.0 | 49.0 | 446 | 466 | 421 | \| | 215 |
| 44 | 72.5 | 58.5 | 82.5 | 63.1 | 47.8 | 434 | 452 | 409 | \| | 208 |
| 43 | 72.0 | 57.7 | 82.0 | 62.2 | 46.7 | 423 | 438 | 400 | \| | 201 |
| 42 | 71.5 | 56.9 | 81.5 | 61.3 | 45.5 | 412 | 426 | 390 | \| | 194 |
| 41 | 70.9 | 56.2 | 80.9 | 60.4 | 44.3 | 402 | 414 | 381 | \| | 188 |
| 40 | 70.4 | 55.4 | 80.4 | 59.5 | 43.1 | 392 | 402 | 371 | \| | 182 |
| 39 | 69.9 | 54.6 | 79.9 | 58.6 | 41.9 | 382 | 391 | 362 | \| | 177 |
| 38 | 69.4 | 53.8 | 79.4 | 57.7 | 40.8 | 372 | 380 | 353 | \| | 171 |
| 37 | 68.9 | 53.1 | 78.8 | 56.8 | 39.6 | 363 | 370 | 344 | \| | 166 |
| 36 | 68.4 | 52.3 | 78.3 | 55.9 | 38.4 | 354 | 360 | 336 | \| | 161 |
| 35 | 67.9 | 51.5 | 77.7 | 55.0 | 37.2 | 345 | 351 | 327 | \| | 156 |
| 34 | 67.4 | 50.8 | 77.2 | 54.2 | 36.1 | 336 | 342 | 319 | \| | 152 |
| 33 | 66.8 | 50.0 | 76.6 | 53.3 | 34.9 | 327 | 334 | 311 | \| | 149 |
| 32 | 66.3 | 49.2 | 76.1 | 52.1 | 33.7 | 318 | 326 | 301 | \| | 146 |
| 31 | 65.8 | 48.4 | 75.6 | 51.3 | 32.5 | 310 | 318 | 294 | N/A | 141 |
| 30 | 65.3 | 47.7 | 75.0 | 50.4 | 31.3 | 302 | 311 | 286 | 92.0 | 138 |
| 29 | 64.6 | 47.0 | 74.5 | 49.5 | 30.1 | 294 | 304 | 279 | 91.0 | 135 |
| 28 | 64.3 | 46.1 | 73.9 | 48.6 | 28.9 | 286 | 297 | 271 | 90.0 | 131 |
| 27 | 63.8 | 45.2 | 73.3 | 47.7 | 27.8 | 279 | 290 | 264 | 89.0 | 128 |
| 26 | 63.3 | 44.6 | 72.8 | 46.8 | 26.7 | 272 | 284 | 258 | 88.0 | 125 |
| 25 | 62.8 | 43.8 | 72.2 | 45.9 | 25.5 | 266 | 278 | 253 | 87.0 | 123 |
| 24 | 62.4 | 43.1 | 71.6 | 45.0 | 24.3 | 260 | 272 | 247 | 86.0 | 119 |
| 23 | 62.0 | 42.1 | 71.0 | 44.0 | 23.1 | 254 | 266 | 243 | 84.5 | 117 |
| 22 | 61.5 | 41.6 | 70.5 | 43.2 | 22.0 | 248 | 261 | 237 | 83.5 | 115 |
| 21 | 61.0 | 40.9 | 69.9 | 42.3 | 20.7 | 243 | 256 | 231 | 82.5 | 112 |
| 20 | 60.5 | 40.1 | 69.4 | 41.5 | 19.6 | 238 | 251 | 226 | 81.0 | 110 |

Note 1: A 10-mm steel ball is used for 450 HB and below. A carbide ball is used above 450HB.

Note 2: The tensile strength relation to hardness is inexact, even for steel, unless it is determined for a specific material.

## Table 3 – Hardness Conversion for Soft Steel, Grey and Malleable Cast Iron and Most Non-ferrous Alloys

| B<br>100 kg<br>1/16" Ball | F<br>60 kg<br>1/16" Ball | G<br>150 kg<br>1/16" Ball | 15-T<br>15 kg<br>1/16" Ball | 30-T<br>30 kg<br>1/16" Ball | 45-T<br>45 kg<br>1/16" Ball | E<br>100 kg<br>1/8" Ball | H<br>60 kg<br>1/8" Ball | K<br>150 kg<br>1/8" Ball | A<br>60 kg<br>Brale | HK<br>500 gm &<br>over | HB<br>500 kg<br>10 mm Ball | HB/<br>HV<br>3000 kg/<br>10 kg | ksi<br>1000 psi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rockwell | Rockwell | Rockwell | Superficial | Superficial | Superficial | Rockwell | Rockwell | Rockwell | Rockwell | Knoop | Brinell | Brinell 10 mm Vickers 136° | Tensile Strength |
| 100 | ▲ | 82.5 | 93.1 | 83.1 | 72.9 | ▲ | ▲ | ▲ | 61.5 | 251 | 201 | 240 | 116 |
| 99 | | 81.0 | 92.8 | 82.5 | 71.9 | | | | 60.9 | 246 | 195 | 234 | 114 |
| 98 | | 79.0 | 92.5 | 81.8 | 70.9 | | | | 60.2 | 241 | 189 | 228 | 109 |
| 97 | | 77.5 | 92.1 | 81.1 | 69.9 | | | | 59.5 | 236 | 184 | 222 | 104 |
| 96 | | 76.0 | 91.8 | 80.4 | 68.9 | | | | 58.9 | 231 | 179 | 216 | 102 |
| 95 | | 74.0 | 91.5 | 79.8 | 67.9 | | | | 58.3 | 226 | 175 | 210 | 100 |
| 94 | | 72.5 | 91.2 | 79.1 | 66.9 | | | | 57.6 | 221 | 171 | 205 | 98 |
| 93 | | 71.0 | 90.8 | 78.4 | 65.9 | | | N/A | 57.0 | 216 | 167 | 200 | 94 |
| 92 | | 69.0 | 90.5 | 77.8 | 64.8 | | | 100 | 56.4 | 211 | 163 | 195 | 92 |
| 91 | | 67.5 | 90.2 | 77.1 | 63.8 | | | 99.5 | 55.8 | 206 | 160 | 190 | 90 |
| 90 | | 66.0 | 89.9 | 76.4 | 62.8 | | | 98.5 | 55.2 | 201 | 157 | 185 | 89 |
| 89 | | 64.0 | 89.5 | 75.8 | 61.8 | | | 98.0 | 54.6 | 196 | 154 | 180 | 88 |
| 88 | | 62.5 | 89.2 | 75.1 | 60.8 | | | 97.0 | 54.0 | 192 | 151 | 176 | 86 |
| 87 | | 61.0 | 88.9 | 74.4 | 59.8 | | | 96.5 | 53.4 | 188 | 148 | 172 | 84 |
| 86 | | 59.0 | 88.6 | 73.8 | 58.8 | | | 95.5 | 52.8 | 184 | 145 | 169 | 83 |
| 85 | | 57.5 | 88.2 | 73.1 | 57.8 | | | 94.5 | 52.3 | 180 | 142 | 165 | 82 |
| 84 | | 56.0 | 87.9 | 72.4 | 56.8 | | | 94.0 | 51.7 | 176 | 140 | 162 | 81 |
| 83 | | 54.0 | 87.6 | 71.8 | 55.8 | | | 93.0 | 51.1 | 173 | 137 | 159 | 80 |
| 82 | | 52.5 | 87.3 | 71.1 | 54.8 | | | 92.0 | 50.6 | 170 | 135 | 156 | 77 |
| 81 | | 51.0 | 86.9 | 70.4 | 53.8 | | | 91.0 | 50.0 | 167 | 133 | 153 | 73 |
| 80 | | 49.0 | 86.6 | 69.7 | 52.8 | | | 90.5 | 49.5 | 164 | 130 | 150 | 72 |
| 79 | | 47.5 | 86.3 | 69.1 | 51.8 | | | 89.5 | 48.9 | 161 | 128 | 147 | 70 |
| 78 | | 46.0 | 86.0 | 68.4 | 50.8 | | | 88.5 | 48.4 | 158 | 126 | 144 | 69 |
| 77 | | 44.0 | 85.6 | 67.7 | 49.8 | | | 88.0 | 47.9 | 155 | 124 | 141 | 68 |
| 76 | N/A | 42.5 | 85.3 | 67.1 | 48.8 | | | 87.0 | 47.3 | 152 | 122 | 139 | 67 |
| 75 | 99.6 | 41.0 | 85.0 | 66.4 | 47.8 | | | 86.0 | 46.8 | 150 | 120 | 137 | 66 |
| 74 | 99.1 | 39.0 | 84.7 | 65.7 | 46.8 | | | 85.0 | 46.3 | 147 | 118 | 135 | 65 |
| 73 | 98.5 | 37.5 | 84.3 | 65.1 | 45.8 | | | 84.5 | 45.8 | 145 | 116 | 132 | 64 |
| 72 | 98.0 | 36.0 | 84.0 | 64.4 | 44.8 | N/A | | 83.5 | 45.3 | 143 | 114 | 130 | 63 |
| 71 | 97.4 | 34.5 | 83.7 | 63.7 | 43.8 | 100 | | 82.5 | 44.8 | 141 | 112 | 127 | 62 |
| 70 | 96.8 | 32.5 | 83.4 | 63.1 | 42.8 | 99.5 | | 81.5 | 44.3 | 139 | 110 | 125 | 61 |
| 69 | 96.2 | 31.0 | 83.0 | 62.4 | 41.8 | 99.0 | | 81.0 | 43.8 | 137 | 109 | 123 | 60 |
| 68 | 95.6 | 29.5 | 82.7 | 61.7 | 40.8 | 98.0 | | 80.0 | 43.3 | 135 | 107 | 121 | 59 |

| B<br>100 kg<br>1/16" Ball | F<br>60 kg<br>1/16" Ball | G<br>150 kg<br>1/16" Ball | 15-T<br>15 kg<br>1/16" Ball | 30-T<br>30 kg<br>1/16" Ball | 45-T<br>45 kg<br>1/16" Ball | E<br>100 kg<br>1/8" Ball | H<br>60 kg<br>1/8" Ball | K<br>150 kg<br>1/8" Ball | A<br>60 kg<br>Brale | HK<br>500 gm<br>& over | HB<br>500 kg<br>10 mm | HB/<br>HV<br>3000 kg/<br>10 kg | ksi<br>1000 psi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rockwell | Rockwell | Rockwell | Superficial | Superficial | Superficial | Rockwell | Rockwell | Rockwell | Rockwell | Knoop | Brinell | Brinell 10 mm<br>Vickers 136° | Tensile Strength |
| 67 | 95.1 | 28.0 | 82.4 | 61.0 | 39.8 | 97.5 | | 79.0 | 42.8 | 133 | 106 | 119 | 58 |
| 66 | 94.5 | 26.5 | 82.1 | 60.4 | 38.7 | 97.0 | | 78.0 | 42.3 | 131 | 104 | 117 | 57 |
| 65 | 93.9 | 25.0 | 81.8 | 59.7 | 37.7 | 96.0 | | 77.5 | 41.8 | 129 | 102 | 116 | 56 |
| 64 | 93.4 | 23.5 | 81.4 | 59.0 | 36.7 | 95.5 | | 76.5 | 41.4 | 127 | 101 | 114 | N/A |
| 63 | 92.8 | 22.0 | 81.1 | 58.4 | 35.7 | 95.0 | | 75.5 | 40.9 | 125 | 99 | 112 | |
| 62 | 92.2 | 20.5 | 80.8 | 57.7 | 34.7 | 94.5 | | 74.5 | 40.4 | 124 | 98 | 110 | |
| 61 | 91.7 | 19.0 | 80.5 | 57.0 | 33.7 | 93.5 | | 74.0 | 40.0 | 122 | 96 | 108 | |
| 60 | 91.1 | 17.5 | 80.1 | 56.4 | 32.7 | 93.0 | | 73.0 | 39.5 | 120 | 95 | 107 | |
| 59 | 90.5 | 16.0 | 79.8 | 55.7 | 31.7 | 92.5 | | 72.0 | 39.0 | 118 | 94 | 106 | |
| 58 | 90.0 | 14.5 | 79.5 | 55.0 | 30.7 | 92.0 | | 71.0 | 38.6 | 117 | 92 | 104 | Note 2 |
| 57 | 89.4 | 13.0 | 79.2 | 54.4 | 29.7 | 91.0 | | 70.5 | 38.1 | 115 | 91 | 103 | |
| 56 | 88.8 | 11.5 | 78.8 | 53.7 | 28.7 | 90.5 | | 69.5 | 37.7 | 114 | 90 | 101 | |
| 55 | 88.2 | 10.0 | 78.5 | 53.0 | 27.7 | 90.0 | | 68.5 | 37.2 | 112 | 89 | 100 | |
| 54 | 87.7 | 8.5 | 78.2 | 52.4 | 26.7 | 89.5 | | 68.0 | 36.8 | 111 | 87 | N/A | |
| 53 | 87.1 | 7.0 | 77.9 | 51.7 | 25.7 | 89.0 | | 67.0 | 36.3 | 110 | 86 | | |
| 52 | 86.5 | 5.5 | 77.5 | 51.0 | 24.7 | 88.0 | | 66.0 | 35.9 | 109 | 85 | | |
| 51 | 86.0 | 4.0 | 77.2 | 50.3 | 23.7 | 87.5 | | 65.0 | 35.5 | 108 | 84 | | |
| 50 | 85.4 | 2.5 | 76.9 | 49.7 | 22.7 | 87.0 | | 64.5 | 35.0 | 107 | 83 | | |
| 49 | 84.8 | N/A | 76.6 | 49.0 | 21.7 | 86.5 | | 63.5 | 34.6 | 106 | 82 | | |
| 48 | 84.3 | | 76.2 | 48.3 | 20.7 | 85.5 | | 62.5 | 34.1 | 105 | 81 | | |
| 47 | 83.7 | | 75.9 | 47.7 | 19.7 | 85.0 | | 61.5 | 33.7 | 104 | 80 | | |
| 46 | 83.1 | | 75.6 | 47.0 | 18.7 | 84.5 | | 61.0 | 33.3 | 103 | 80 | | |
| 45 | 82.6 | | 75.3 | 46.3 | 17.7 | 84.0 | | 60.0 | 32.9 | 102 | 79 | | |
| 44 | 82.0 | | 74.9 | 45.7 | 16.7 | 83.5 | | 59.0 | 32.4 | 101 | 78 | | |
| 43 | 81.4 | | 74.6 | 45.0 | 15.7 | 82.5 | | 58.0 | 32.0 | 100 | 77 | | |
| 42 | 80.8 | | 74.3 | 44.3 | 14.7 | 82.0 | | 57.5 | 31.6 | 99 | 76 | | |
| 41 | 80.3 | | 74.0 | 43.7 | 13.6 | 81.5 | | 56.5 | 31.2 | 98 | 75 | | |
| 40 | 79.7 | | 73.6 | 43.0 | 12.6 | 81.0 | | 55.5 | 30.7 | 97 | 75 | | |
| 39 | 79.1 | | 73.3 | 42.3 | 11.6 | 80.0 | | 54.5 | 30.3 | 96 | 74 | | |
| 38 | 78.6 | | 73.0 | 41.6 | 10.6 | 79.5 | | 54.0 | 29.9 | 95 | 73 | | |
| 37 | 78.0 | | 72.7 | 41.0 | 9.6 | 79.0 | N/A | 53.0 | 29.5 | 94 | 72 | | |
| 36 | 77.4 | | 72.3 | 40.3 | 8.6 | 78.5 | 100 | 52.0 | 29.1 | 93 | 72 | | |
| 35 | 76.9 | | 72.0 | 39.6 | 7.6 | 78.0 | 99.5 | 51.5 | 28.7 | 92 | 71 | | |
| 34 | 76.3 | | 71.7 | 39.0 | 6.6 | 77.0 | 99.0 | 50.5 | 28.2 | 91 | 70 | | |
| 33 | 75.7 | | 71.4 | 38.3 | 5.6 | 76.5 | 98.8 | 49.5 | 27.8 | 90 | 69 | | |
| 32 | 75.2 | | 71.0 | 37.6 | 4.6 | 76.0 | 98.5 | 48.5 | 27.4 | 89 | 69 | | |

| B<br>100 kg<br>1/16" Ball | F<br>60 kg<br>1/16" Ball | G<br>150 kg<br>1/16" Ball | 15-T<br>15 kg<br>1/16" Ball | 30-T<br>30 kg<br>1/16" Ball | 45-T<br>45 kg<br>1/16" Ball | E<br>100 kg<br>1/8" Ball | H<br>60 kg<br>1/8" Ball | K<br>150 kg<br>1/8" Ball | A<br>60 kg<br>Brale | HK<br>500 gm &<br>over | HB<br>500 kg<br>10 mm Ball | HB/<br>HV<br>3000 kg/<br>10 kg | ksi<br>1000 psi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rockwell | Rockwell | Rockwell | Superficial | Superficial | Superficial | Rockwell | Rockwell | Rockwell | Rockwell | Knoop | Brinell | Brinell 10 mm<br>Vickers 136° | Tensile<br>Strength |
| 31 | 74.6 | | 70.7 | 37.0 | 3.6 | 75.5 | 98.0 | 48.0 | 27.0 | 88 | 68 | | |
| 30 | 74.0 | | 70.4 | 36.3 | 2.6 | 75.0 | 97.8 | 47.0 | 26.6 | 87 | 67 | | |
| 29 | 73.5 | | 70.0 | 35.6 | 1.0 | 74.0 | 97.5 | 46.0 | 26.0 | 87 | 66 | | |
| 28 | 73.0 | | 69.3 | 34.5 | N/A | 73.5 | 97.0 | 45.0 | 25.5 | 86 | 66 | | |
| 27 | 72.5 | | 69.5 | 34.0 | | 73.0 | 96.5 | 44.5 | 25.0 | 85 | 65 | | |
| 26 | 72.0 | | 69.0 | 33.0 | | 72.5 | 96.3 | 43.5 | 24.5 | 84 | 65 | | |
| 25 | 71.0 | | 68.8 | 32.5 | | 72.0 | 96.0 | 42.5 | 24.3 | 83 | 64 | | |
| 24 | 70.5 | | 68.5 | 32.0 | | 71.0 | 95.5 | 41.5 | 24.0 | 82 | 64 | | |
| 23 | 70.0 | | 68.0 | 31.0 | | 70.5 | 95.3 | 41.0 | 23.5 | 82 | 63 | | |
| 22 | 69.5 | | 67.8 | 30.5 | | 70.0 | 95.0 | 40.0 | 23.0 | 81 | 62 | | |
| 21 | 69.0 | | 67.5 | 29.5 | | 69.5 | 94.5 | 39.0 | 22.5 | 81 | 62 | | |
| 20 | 68.5 | | 67.3 | 29.0 | | 68.5 | 94.3 | 38.0 | 22.0 | 80 | 61 | | |
| 19 | 68.0 | | 67.0 | 28.5 | | 68.0 | 94.0 | 37.5 | 21.5 | 79 | 61 | | |
| 18 | 67.0 | | 66.5 | 27.5 | | 67.5 | 93.5 | 36.5 | 21.3 | 78 | 60 | | |
| 17 | 66.5 | | 66.3 | 27.0 | | 67.0 | 93.0 | 35.5 | 21.0 | 78 | 60 | | |
| 16 | 66.0 | | 66.0 | 26.0 | | 66.5 | 92.8 | 35.0 | 20.5 | 77 | 59 | | |
| 15 | 65.5 | | 65.5 | 25.5 | | 65.5 | 92.5 | 34.0 | 20.0 | 76 | 59 | | |
| 14 | 65.0 | | 65.3 | 25.0 | | 65.0 | 92.0 | 33.0 | N/A | 75 | 59 | | |
| 13 | 64.5 | | 65.0 | 24.0 | | 64.5 | 91.8 | 32.0 | | 75 | 58 | | |
| 12 | 64.0 | | 64.5 | 23.5 | | 64.0 | 91.5 | 31.5 | | 74 | 58 | | |
| 11 | 63.5 | | 64.3 | 23.0 | | 63.5 | 91.0 | 30.5 | | 73 | 57 | | |
| 10 | 63.0 | | 64.0 | 22.0 | | 62.5 | 90.5 | 29.5 | | 72 | 57 | | |
| 9 | 62.0 | | 63.8 | 21.5 | | 62.0 | 90.3 | 29.0 | | 71 | 57 | | |
| 8 | 61.5 | | 63.5 | 20.5 | | 61.5 | 90.0 | 28.0 | | 71 | 56 | | |
| 7 | 61.0 | | 63.0 | 20.0 | | 61.0 | 89.5 | 27.0 | | 70 | 56 | | |
| 6 | 60.5 | | 62.8 | 19.5 | | 60.5 | 89.3 | 26.0 | | 69 | 55 | | |
| 5 | 60.0 | | 62.5 | 18.5 | | 60.0 | 89.0 | 25.5 | | 69 | 55 | | |
| 4 | 59.5 | | 62.0 | 18.0 | | 59.0 | 88.5 | 24.5 | | 69 | 55 | | |
| 3 | 59.0 | | 61.8 | 17.0 | | 58.5 | 88.0 | 23.5 | | 68 | 54 | | |
| 2 | 58.0 | | 61.5 | 16.5 | | 58.0 | 87.8 | 23.0 | | 68 | 54 | | |
| 1 | 57.5 | | 61.0 | 16.0 | | 57.5 | 87.5 | 22.0 | | 67 | 54 | | |
| 0 | 57.0 | | 60.5 | 15.0 | | 57.0 | 87.0 | 21.0 | | 67 | 53 | | |

**Assignments:**

1. Observe carefully the demonstration of the operation procedure of the various types of hardness testing machines. Take notes if necessary.
2. Obtain samples for each type of hardness testing from the instructor.
3. Measure the hardness of the samples and record results on the data sheet. Pay attention to units of measured parameters, if any.
4. Submit a report including the datasheet and calculation of hardness numbers and conversions.
5. Answer the following questions in the report:
    a. Compare the calculated Brinell hardness numbers for the same specimen under two different applied loads (500 kg and 3000 kg). Are the hardness numbers fairly close (within 20%)? If not, can you think of any reason for this obvious discrepancy?
    b. In Rockwell hardness testing of the brass specimen, estimate the penetration depth of indenter under the major load. Show your calculation.
    c. Did you notice any functional differences between the Rockwell hardness measurement of metals and that of polymers? Describe the differences, if any, and try to explain the purpose of the differences.

ME 254 – Materials Engineering Laboratory
Hardness Test Data Sheet

Date: _____ Name: _____

## I. Brinell Hardness Test

Material: _____ Thickness: _____

| |
|---|
| Applied Load: |
| Diameter of Impression (3 minimum): |
| Average Diameter: |
| Standard Deviation: |
| Brilnell Hardness Based on Average Diameter: |

Brinell hardness calculation:

Material: _____ Thickness: _____

| |
|---|
| Applied Load: |
| Diameter of Impression (3 minimum): |
| Average Diameter: |
| Standard Deviation: |
| Brinell Hardness Based on Average Diameter: |

Brinell hardness calculation:

## II. Regular Rockwell Hardness Test

Material: _____ Thickness: _____

| | |
|---|---|
| Scale: | Type of Indenter: |
| Minor Load: | Major Load: |
| Measured Hardness (3 minimum): | |
| Average Hardness: | |
| Standard Deviation: | |
| Equivalent Brinell Hardness From Average Rockwell Hardness: | |
| Estimated Tensile Strength: | |

Tensile strength calculation:

Material: _____ Thickness: _____

| | |
|---|---|
| Scale: | Type of Indenter: |
| Minor Load: | Major Load: |
| Measured Hardness (3 minimum): | |
| Average Hardness: | |
| Standard Deviation: | |
| Equivalent Brinell Hardness From Average Rockwell Hardness: | |
| Estimated Tensile Strength: | |

Tensile strength calculation:

Material: _____ Thickness:_____

| | |
|---|---|
| Scale: | Type of Indenter: |
| Minor Load: | Major Load: |
| Measured Hardness (3 minimum): | |
| Average Hardness: | |
| Standard Deviation: | |
| Equivalent Brinell Hardness From Average Rockwell Hardness: | |
| Estimated Tensile Strength: | |

Tensile strength calculation:

## III. Superficial Rockwell Hardness Test:

Material: _____ Thickness:_____

| | |
|---|---|
| Scale: | Type of Indenter: |
| Minor Load: | Major Load: |
| Measured Hardness (3 minimum): | |
| Average Hardness: | |
| Standard Deviation: | |
| Equivalent Brinell Hardness From Average Rockwell Hardness: | |
| Estimated Tensile Strength: | |

Material: _____ Thickness:_____

| | |
|---|---|
| Scale: | Type of Indenter: |
| Minor Load: | Major Load: |
| Measured Hardness (3 minimum): | |
| Average Hardness: | |
| Standard Deviation: | |
| Equivalent Brinell Hardness From Average Rockwell Hardness: | |
| Estimated Tensile Strength: | |

## IV. Scleroscope Hardness Test

Material: _____ Thickness:_____

| |
|---|
| Measured Shore Hardness (3 minimum): |
| Average Shore Hardness: |
| Standard Deviation: |
| Equivalent Brinell Hardness From Average Shore Hardness: |

Material: _____ Thickness:_____

| |
|---|
| Measured Shore Hardness (3 minimum): |
| Average Shore Hardness: |
| Standard Deviation: |
| Equivalent Brinell Hardness From Average Shore Hardness: |

Material: _____ Thickness:_____

| |
|---|
| Measured Shore Hardness (3 minimum): |
| Average Shore Hardness: |
| Standard Deviation: |
| Equivalent Brinell Hardness From Average Shore Hardness: |

## V. Microhardness Test

Material: _____ Thickness: _____

| | |
|---|---|
| Type: | Type of Indenter: |
| Applied Load: | |
| Diagonal Length (major)* (2 minimum): | |
| Diagonal Length (minor)* (2 minimum): | |
| Average Diagonal Length: | |
| Hardness Based on Average Diagonal Length: | |

* Measure both diagonal lengths for Vickers hardness, only major (long) diagonal length for Knoop hardness.

Calculation of hardness from average diagonal length:

# Experiment # 4

# Tensile Test

## 1. Objective:

The objective of this experiment is to evaluate the mechanical (tensile) properties of selected metallic materials using the tensile test method. These mechanical properties include modulus of elasticity, yield strength, ultimate tensile strength, failure strength, ductility, and strain to failure.

## 2. Background:

A simple tensile test consists of gradual application of an axial tensile load to a standard specimen by means of a suitable testing machine and measuring the corresponding dimensional changes. In this method, a strip or cylinder of the material, having length L and cross-sectional area A, is anchored at one end and subjected to an axial load P – a load acting along the specimen's long axis – at the other (see Fig. 1). As the load is increased gradually, the axial deflection δ of the loaded end will increase also. Eventually the test specimen breaks. We usually want to understand how the stretching or deformation is related to the applied load. We also wish to understand how these relationships are influenced by the internal structures (or called microstructure) of the material.

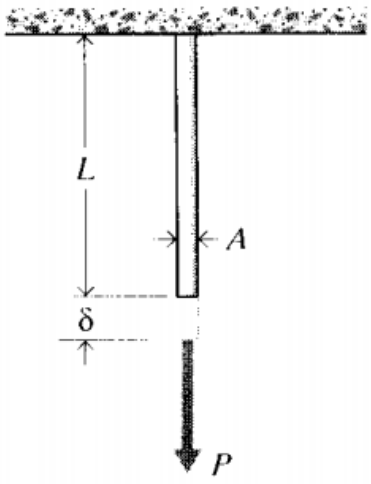



Fig. 1: The tension test

The load–deformation data obtained from a tensile test depends on the specimen geometry. To minimize the effect of sample geometry, load and elongation are usually converted to engineering stress and engineering strain, respectively. The engineering stress is calculated as follow:

Engineering stress: $$\sigma = \frac{F}{A_0}$$

where F is the instantaneous load applied perpendicular to the specimen cross section, in units of newtons (N) and $A_0$ is the original cross sectional area before any load is applied ($m^2$). The units of engineering stress are megapascals, MPa (where 1 MPa = $10^6$ $N/m^2$ = 1 $N/mm^2$). The following relation is used to compute the engineering strain:

Engineering strain: $$\epsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0}$$

in which $l_0$ is the original length before any load is applied, and $l_i$ is the instantaneous length. Engineering strain is unitless. Fig. 2 shows the typical stress-strain curve for a metallic material.

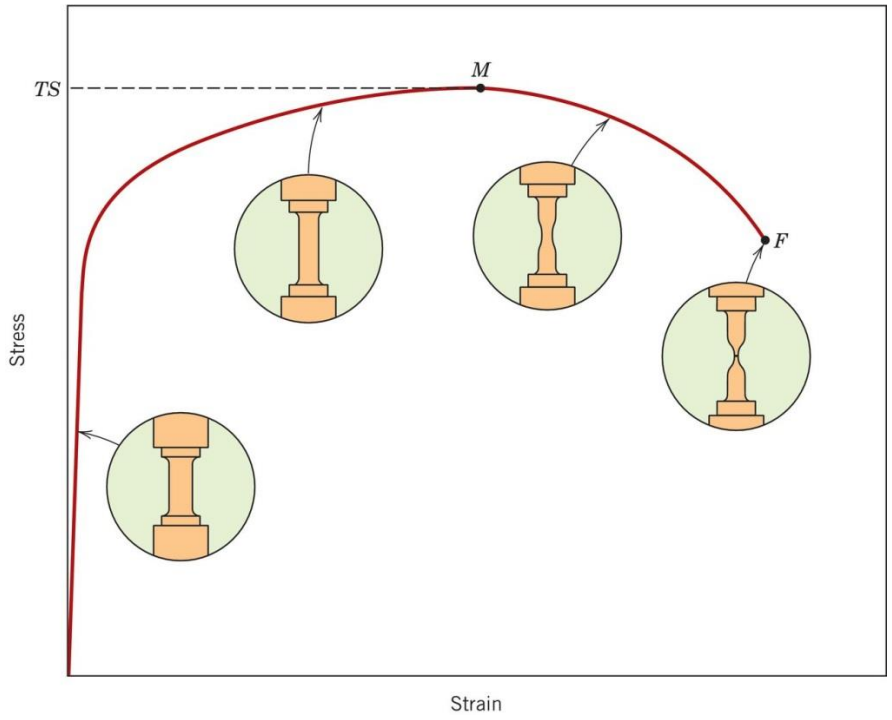



Fig. 2: Schematic of a typical stress-strain curve for a metal

Deformation in engineering materials can be classified into elastic and plastic deformation. The elastic deformation is nonpermanent, which means that when the applied load is released, the material returns to its original shape. For most metallic materials, elastic deformation is limited to small strains, < 0.5%. However, as the material is deformed beyond the elastic limit, the plastic deformation occurs where the deformation here is permanent or nonrecoverable. In other words, the sample will not return to its original shape if the plastic deformation occurs.

The tension test is the most common method for determining most of the elastic and plastic properties in engineering materials. Several useful mechanical (elastic and plastic) properties can be extracted from the measured stress-strain curves. Some of these parameters are briefly explained below:

- **Modulus of Elasticity**
  In elastic deformation (nonpermanent deformation), the stress σ and strain ε are linearly proportional to each other through the Hook's law:

$$\sigma = E\epsilon$$

  The constant of proportionality E is the modulus of elasticity, or Young's modulus. The slope of the initial linear segment in the stress-strain curve corresponds to the modulus of elasticity E, see Fig. 3. This modulus may be thought of as stiffness, or a material's resistance to elastic deformation

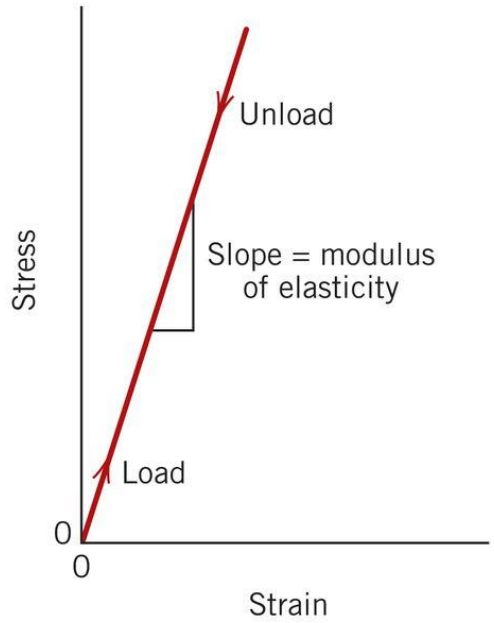



Fig. 3: Schematic of a stress-strain curve showing the initial linear elastic deformation

- **Yield Strength**

After elastic deformation, the phenomenon of yielding or plastic deformation occurs where the specimen experiences a permanent change in shape. The initial yielding point occurs when the stress-strain curve started to deviate from the initial linear elastic segment. The stress value at this point is sometimes called the proportional limit. Since the proportional limit sometimes cannot be determined precisely, the yield strength value is usually taken at a small strain after the proportional limit. The 0.2% offset method is commonly used to determine the value of the yield strength in metals, where a straight line is constructed parallel to the elastic portion of the stress–strain curve at a strain 0.002 (see Fig. 4).

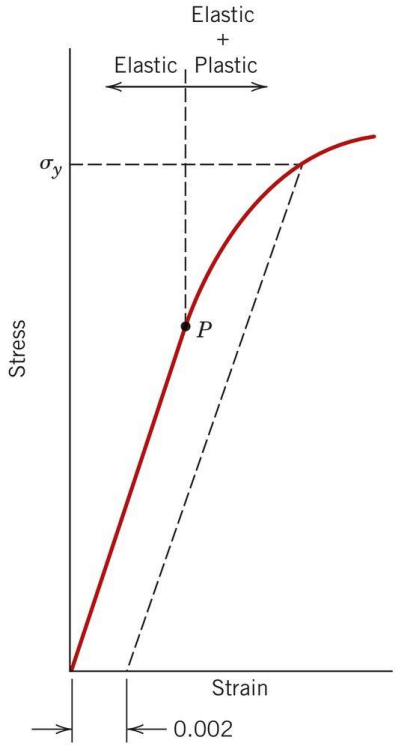



Fig. 4: Schematic of a typical stress-strain behavior for metals showing the transition from the elastic to the plastic deformation.

- **Ultimate Tensile Strength**

  The ultimate tensile strength is the stress at the maximum on the engineering stress–strain curve (see point M in Fig. 2). This corresponds to the maximum stress that can be sustained by a structure in tension. At this maximum stress, a small constriction or neck begins to form at some point in the tensile specimen, and all subsequent deformation is confined at this neck

- **Ductility**

It is a measure of the degree of plastic deformation that has been sustained at fracture. Ductility may be expressed quantitatively as either percent elongation %EL or percent reduction in area %RA as follow:

$$\%\,\mathrm{EL} = \left(\frac{l_f - l_0}{l_0}\right) \times 100 \qquad \%\,\mathrm{RA} = \left(\frac{A_0 - A_f}{A_0}\right) \times 100$$

- **Toughness**
  Toughness is a measure of the ability of a material to absorb energy up to fracture. For the static (low strain rate) situation, toughness may be determined from the area under a tensile stress–strain curve up to the point of fracture.

It is worth mentioning that the engineering stress-strain curve can be converted to a more meaningful scheme, called true stress-strain curve. The true stress $\sigma_T$ is calculated by normalizing the applied load on the instantaneous cross sectional area $A_i$ instead of the original cross-sectional area $A_0$ as in the engineering stress:

True stress: $$\sigma_T = \frac{F}{A_i}$$

The true strain $\varepsilon_T$ is computed as follow:

True strain: $$\epsilon_T = \ln \frac{l_i}{l_0}$$

From the above relations, it is clear that you need to measure the instantaneous cross sectional area and length during the tensile tests in order to plot the true stress-strain curves. Such measurements are not usually easy during the test. However, for most metals, we can use the assumption of constant volume during plastic deformation up to the point of necking. This is usually a reasonable assumption for most metals that deform mainly by dislocation slip, and it enables us to easily compute the true stress-strain data from the engineering stress-strain curve. In this case, we can use the following relations to convert the engineering stress-stress curves into true stress-strain curves:

$$\sigma_T = \sigma(1 + \epsilon)$$

$$\epsilon_T = \ln(1 + \epsilon)$$

## 3. Methods/Experiment:

The tensile test will be performed using the Instron universal testing machine available in the mechanical engineering lab. This machine is capable of measuring the applied load and extension during the tensile test. At least two metallic materials (e.g. steel and brass) will be tested in this

experiment to show the difference in mechanical responses between different materials. The samples will be pulled in the Instron machine until they break.

The samples will be prepared according to the ASTM E8 standard. It is important to precisely measure the dimensions of the samples, including thickness and gauge length, using a micrometer before conducting the test. The dimensions of the sample should also be measured at the end of the test after fitting the broken pieces together. The measurements will be used later to convert the measured load-deflection data into engineering stress-strain data.

## 4. Results and Discussion:

As mentioned above, the dimensions of the samples should be precisely measured before and after test. The following tables may be used:

| **Tensile Specimen #1** (Material: ……..) | | | |
|---|---|---|---|
| Before the test | | After the test | |
| Initial thickness | | Final thickness | |
| Initial Width | | Final Width | |
| Initial Area | | Final Area | |
| Initial Gauge Length | | Final Gauge Length | |

| **Tensile Specimen #2** (Material: ……..) | | | |
|---|---|---|---|
| Before the test | | After the test | |
| Initial thickness | | Final thickness | |
| Initial Width | | Final Width | |
| Initial Area | | Final Area | |
| Initial Gauge Length | | Final Gauge Length | |

## 5. Assignments:

Every student is required to answer and submit the following:

1) Collect the measured load-displacement data from the INSTRON machine for each sample

2) Calculate and plot the engineering stress-strain curves for each sample.
3) From the engineering stress-strain curves, determine the following quantities for each sample:
   - Modulus of elasticity
   - Yield strength using the 0.2% offset method
   - Tensile strength
   - Ductility using both the percent of elongation %EL and percent of reduction in area %RA
   - Toughness
   - Fracture stress and Fracture strain
4) Compare and comment on the values of the above quantities between the different samples
5) Calculate and plot the true stress-strain curves for each sample up to the point of necking.
6) Comment on the shape of the true stress-strain curves for each sample and compare with the engineering stress-strain curves.

# Experiment # 5

# Charpy Impact Test

## 1. Objective:

The purpose of this lab is to use the Charpy impact test to measure the values of the impact energy (also called notch toughness) of steel samples and examine the effect of heat treatment on these measured values.

## 2. Background:

Toughness can be defined as a measure of the ability of a material to absorb energy up to fracture. For static situation (low strain rate), toughness may be ascertained from the results of a tensile stress–strain test. However, for high strain rate (dynamic loading), the impact test can be used to measure the impact enery or notch toughness of the specimen. This impact energy or notch toughness is nothing but the energy absorbed during the fracture of a specimen of standard dimensions when subjected to very rapid loading. The impact testing techniques are used to study the mechanical behavior of materials under high strain rate and a triaxial stress states. There are two types of standard impact tests, the Charpy and Izod tests**.** The specimen for both tests is in the shape of a bar of square cross section with a notch which introduces the triaxility condition. A schematic drawing of the impact test is shown in Figure 1. The load is applied as an impact blow from a weighted pendulum hammer that is released from a certain height *h* to strike and fracture the specimen. The energy expended in fracture is reflected in the difference between *h* and the swing height h'. The results of the impact tests are qualitative and usually used for comparing the fracture properties between different materials. The other primary purpose of the Charpy and Izod tests is to

determine whether or not a material experiences a ductile-to-brittle transition with decreasing temperature.

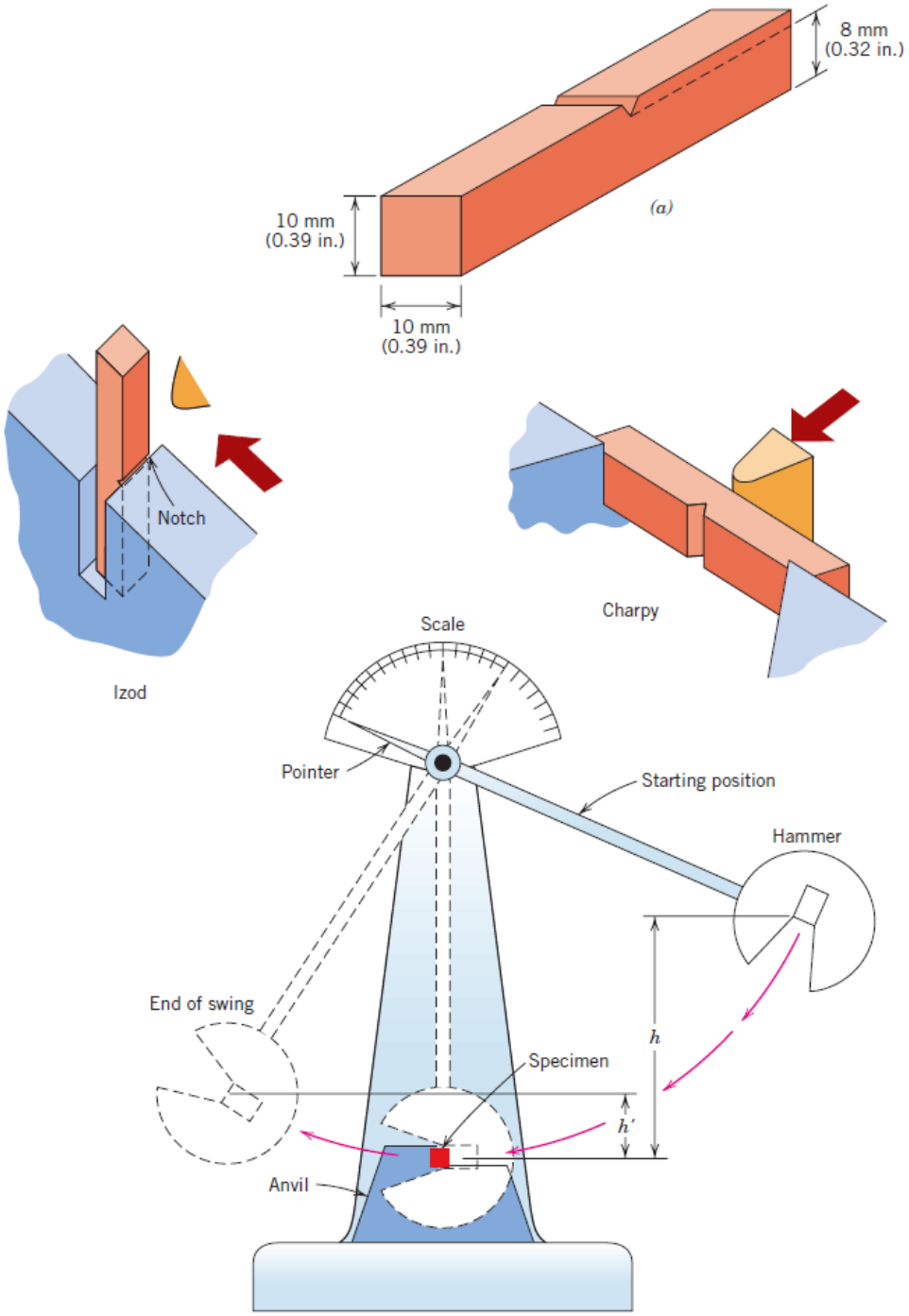


Figure 1: *a*) Specimen used for Charpy and Izod impact tests. (*b*) A schematic drawing of an impact testing apparatus (Callister 7th Edition)

## 3. Methods/Experiment:

In this experiment, we want to examine the effect of heat treatment on the notch toughness of steel samples using the standard Charpy impact test. Three steel samples will be subjected to the following heat treatments:

A. Heating in the furnace at ~900 $^{o}$C for 4 hr followed by furnace cooling.
B. Heating in the furnace at ~900 $^{o}$C for 4 hr followed by air-cooling.
C. Heating in the furnace at ~900 $^{o}$C for 4 hr followed by quenching in water.

The following steps summarize the Charpy impact test, which will be conducted at room temperature:

1. Raise the pendulum to the latch position
2. Put the test specimen on the supports against the anvils with the notch facing away from the pendulum.
3. Set the dial on the impact machine to zero
4. Release the pendulum to strike the test specimen
5. Read and record the impact energy
6. Examine the surface of the fractured specimen.

## 4. Results and Discussion:

Record the following values of the toughness in this experiment:

| Sample | Notch toughness (Unit: ……..) |
|---|---|
| Sample A: Heated in the furnace for ~900 $^{o}$C for 4 hr followed by furnace cooling. | |
| Sample B: Heated in the furnace for ~900 $^{o}$C | |

| | |
|---|---|
| for 4 hr followed by air cooling. | |
| Sample C: Heated in the furnace for ~900 $^{o}$C for 4 hr followed by quenching in water. | |

## 5. Assignments:

Please discuss the following items in your lab report:

1. What is the difference between toughness, notch toughness, and fracture toughness?
2. Briefly describe some techniques to measure the notch toughness of the materials?
3. What are the differences between the toughness calculated from a tensile test (e.g. by calculating the area under the tensile stress-strain curve) and the notch toughness measured in this experiment?
4. What is the difference between the Charpy and Izon tests?
5. Comment on the results obtained in this experiment and describe the effects of heat treatment on the notch toughness?

**Experiment # 6**

**Cooling curves for different compositions of Pb-Sn alloy**

**Experiment # 7**

**Effect of different heat treatments (annealing, quenching, and tempering) on the mechanical properties of low carbon steels**

**Experiment # 8**

**Materials Selection, Overview of CES EduPack Software**

# Lab Report Format

# ME-254 (Materials Engineering)

## Cover Page

The cover page should include the following:

- Course name
- Class section
- Experiment number
- Title of the experiment
- Student’s name and ID
- Date (date of submission)

# Title of Experiment

## 1. Abstract

*State very briefly, what you have done, why you have done it, and what the outcomes are. It is written as one paragraph (100-200 words). The abstract should be a concise summary of the experiment, containing general statements of the investigation, the methods used, materials tested, and the main results. It should not include procedural details.*

## 2. Introduction

*The Introduction section should include statements that clearly:*

A. *Define the purpose of the experiment;*
B. *Its significance;*
C. *Background information necessary to understand the concepts, methods, and procedures presented in the subsequent sections.*

*This section should not contain the details of the laboratory procedures and the data analyses.*

## 3. Materials

*List everything needed to complete the experiment (materials, instruments, etc.)*

## 4. Experimental Procedures:

*This section describes in details the methods you used to set up, calibrate, and run the experiment. In this section, define the materials used: type of material (e.g. steel, aluminum, etc.) and initial conditions (e.g. size, microstructure, etc.).*

## 5. Results and Discussion

*This section will be the majority of your report. All observations and data should be presented in chronological order (use tables and figures as possible). The interpretations and significance of the results should be discussed.*

*In this section, you should also answer the questions listed in the "Assignment" section in your lab manual.*

## 6. Conclusions

This section should be a brief summary of the important findings