Material Testing and Standards

Reference Books:

G. E. Dieter, Mechanical Metallurgy, McGraw Hill Book Company, 1987.

Testing of metallic materials by A.V.K Suryanarayana, PHI

ASTM standards

Unit II

- Hardness test: Introduction, Brinell, Vickers and rockwell hardness tests, meyers hardness test, analysis of indentation by an indenter. Relationship between hardness and the flow curve, micro-hardness tests, hardness conversion, hardness of elevated temperature.
- Impact Testing: Types of impact tests and their relative merits and demerits, Ductile-brittle transition behavior and its significance

Hardness Testing

- Hardness measurements widely used in laboratory and as industrial tests (widely used on castings and forgings) as a tool characterizing the mechanical properties of materials.
- It can be used to classify the materials or to identify a material in a group.
- Hardness tests are employed at a very large scale to assess the useful properties of materials.

DEFINITION

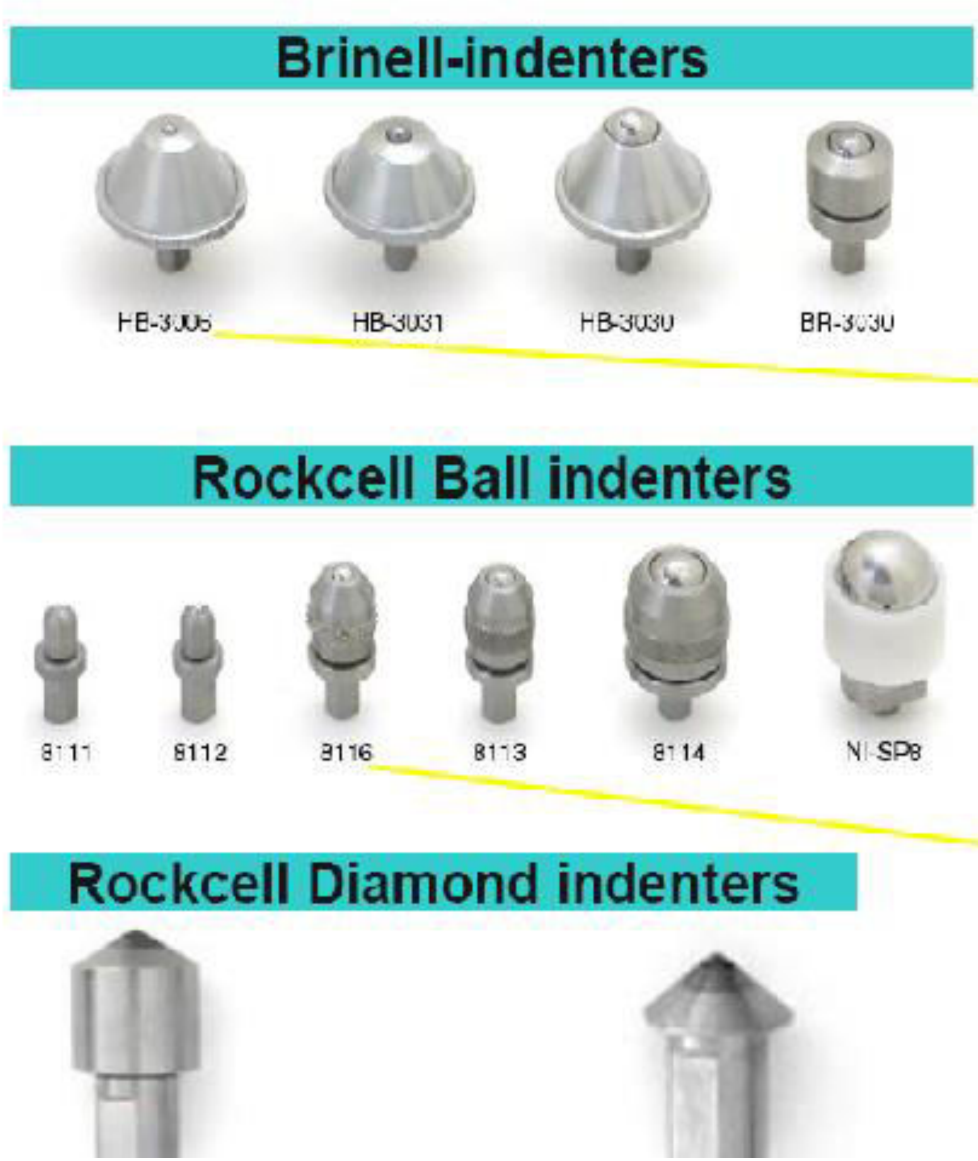
- Hardness is defined as the resistance of a material to permanent deformation such as:
  - Indentation
  - Wear
  - Abrasion
  - Scratch

- Hardness is a mechanical property that is related to:
  - Wear resistance of a material
  - Its ability to abrade or indent another material or
  - Its resistance to permanent or plastic deformation

- There are many hardness tests currently in use.
- The necessity for all these different hardness tests is due to the need for categorizing the great range of hardness from soft rubber to hard ceramics.
- Selection of the appropriate hardness test is dependent upon the:
  - Relative hardness of the material being tested and
  - Amount of damage that can be tolerated on the surface of the specimen (or material)

- The types of hardness testers in use of product are based on a number of “arbitrary definitions” of hardness.
- Some of these definitions are:
  1. Resistance to permanent indentation (indentation test)
  2. Resistance to scratching (scratch test)
  3. Energy absorption under impact loads (dynamic hardness test)
  4. Rebound of a falling weight (rebound test)
- 3rd and 4th : Same principle collision & absorbed energy of one hard metal by the other soft metal

- Of these methods, indentation test is employed the most. For this type of test, hardness is defined as the resistance of a material to permanent indentation.
- The general principle of the indentation test:
  1. A hard indenter (a small sphere, pyramid or cone) is pressed into the surface of the material to be tested under a specific load for a definite interval of time,
  2. The size or the depth of the indentation is measured.



2.5 mm carbide ball indenter

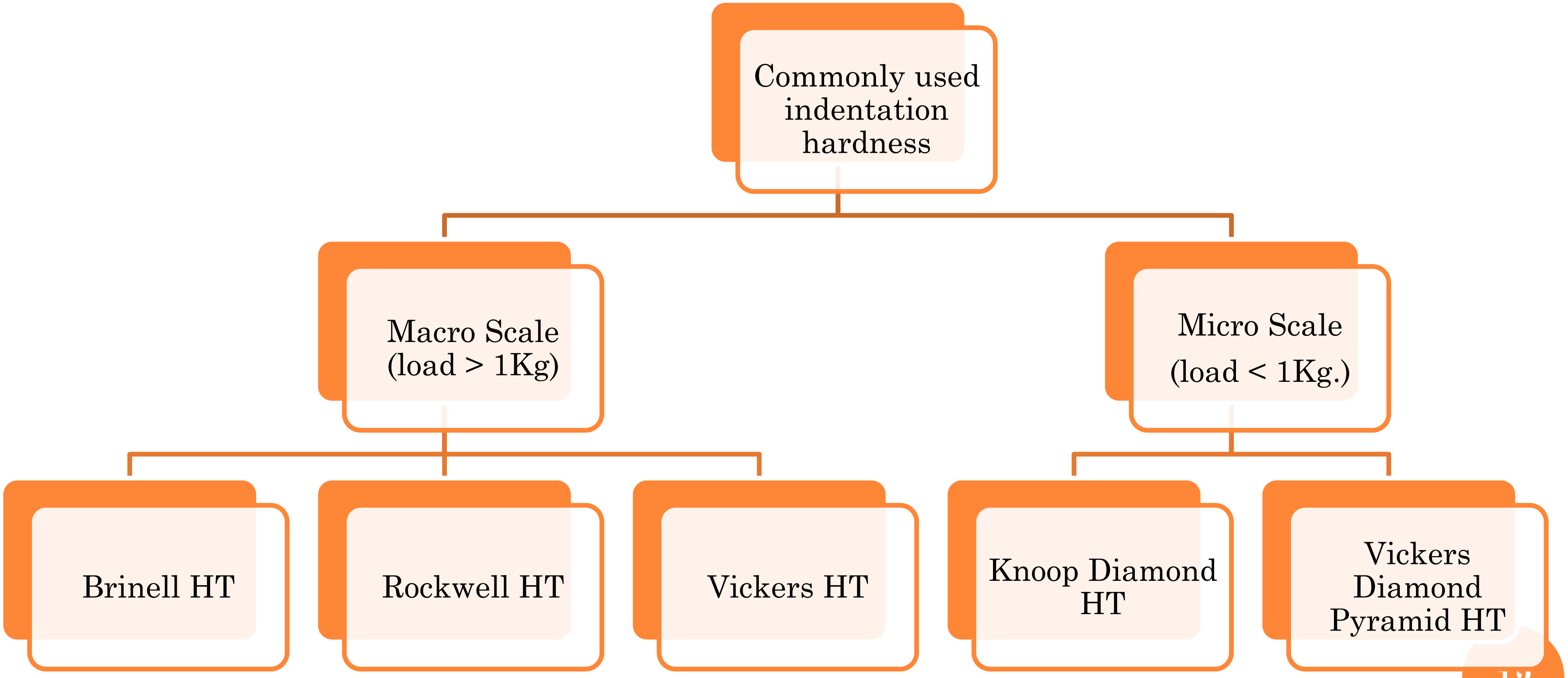
5 mm carbide ball indenter

- The general principle of the indentation test:
  - A hard indenter (a small sphere, pyramid or cone) is pressed into the surface of the material to be tested under a specific load for a definite interval of time,
  - The size or the depth of the indentation is measured.

- Hardness test is one of the prominent tests in determining the properties of materials.
  - Because, a reasonable relationship exists between the hardness and other physical properties of a material.
  - For example, hardness and the tensile test both measure the resistance of a material to plastic deformation. Therefore a correlation exists between the hardness and tensile strength of the steels :
    - $\mathbf{S_t = 0.33 \times BHN}$

- However, hardness is not a fundamental property of a material.
- It depends upon the particular treatment to which the material has been subjected.
- Hardness values are actually arbitrary and there are no absolute standards of hardness.
- The hardness tests are also popular in the sense that they are easy, simple and relatively non-destructive tests (compared to tensile, bending and torsion test)

- The indentation type hardness testers are classified into two main categories based on the level of the destruction of the surface of the the specimen.



- In indentation type of testers, the shape and size of the indenter and the magnitude of the load applied are selected in accordance with the :
- Purpose of the test
  - The structural properties of the material being tested
  - The state of its surface and
  - The size of the part or specimen

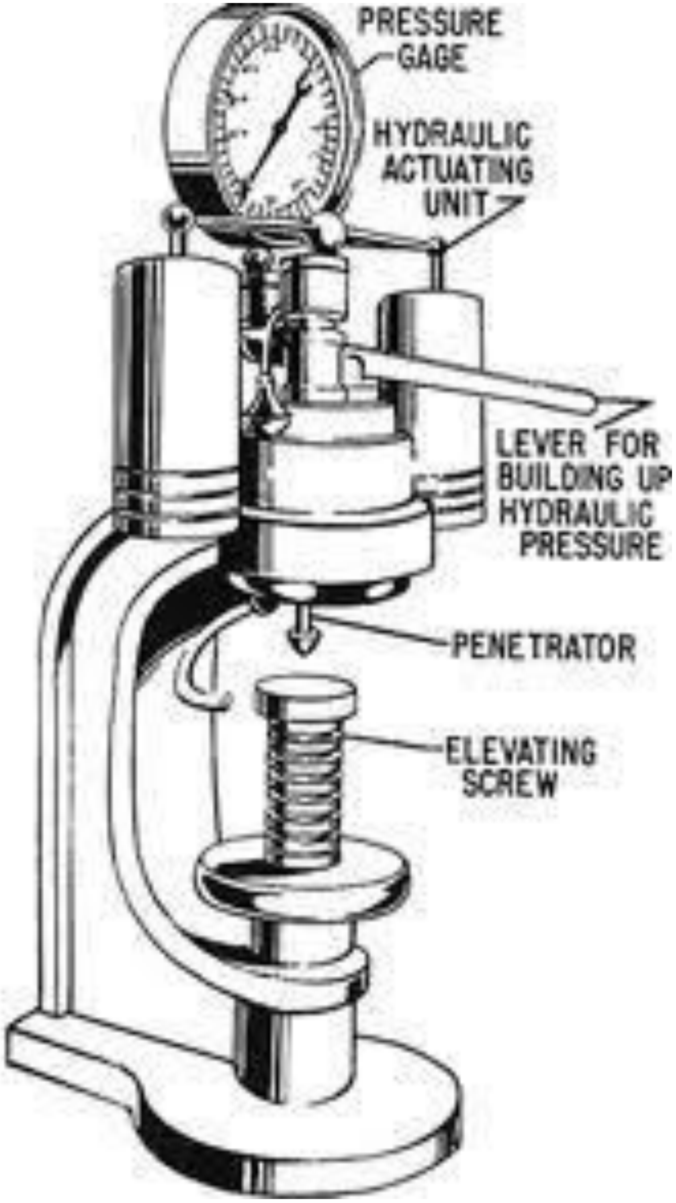
Advantages of Hardness Test

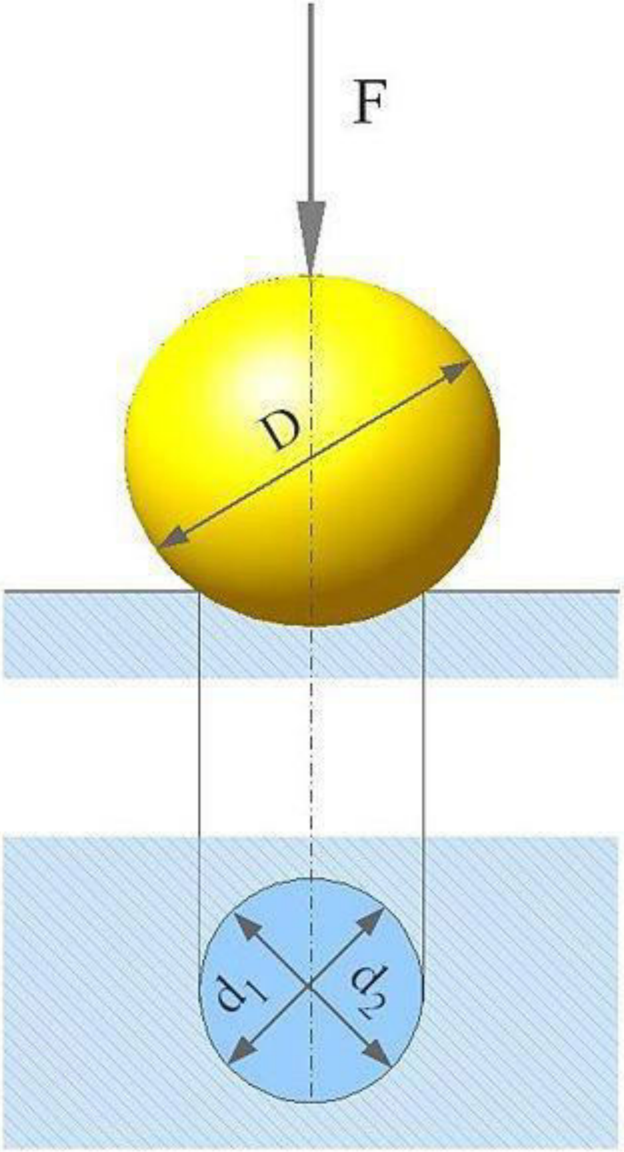
1. The hardness of a Ductile Material:
   - Determined by the indentation test, is related with its other mechanical properties (in particular with the ultimate tensile strength).
2. Hardness tests are substantially simpler than other mechanical tests.
   - Specially prepared specimens are not needed. The machine parts can usually be tested directly. Though depends on the size of the part and type of test, the parts tested are not damaged. Furthermore, hardness tests can be made quickly, taking about in the order of seconds to few minutes

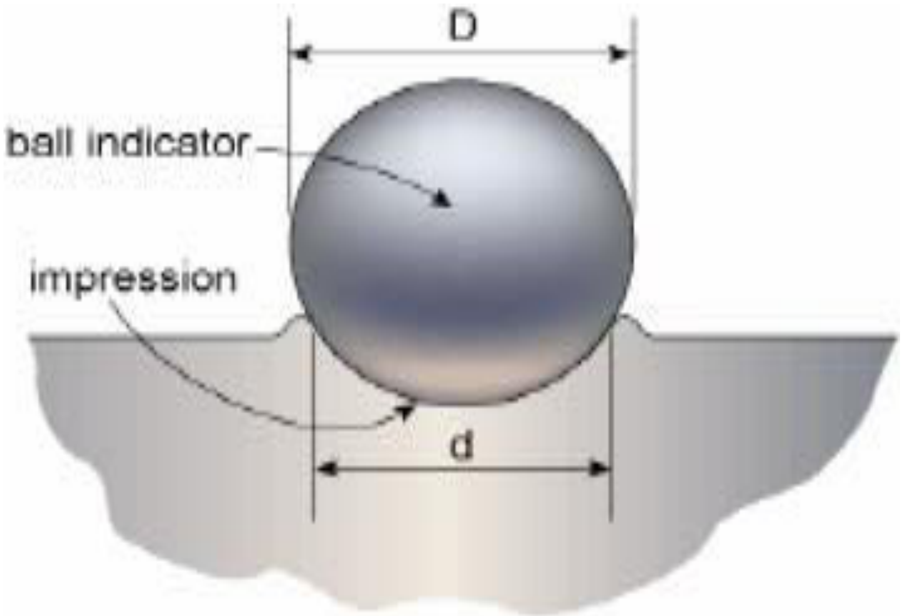
3. Similar materials may be graded according to hardness, thus making specifications for a certain type of application clear-cut. Likewise, the quality level of materials or products may be controlled effectively by hardness tests.
4. Hardness can be measured on parts of small thickness and in very thin layers, or over microscopic sections.

BRINELL HARDNESS TEST

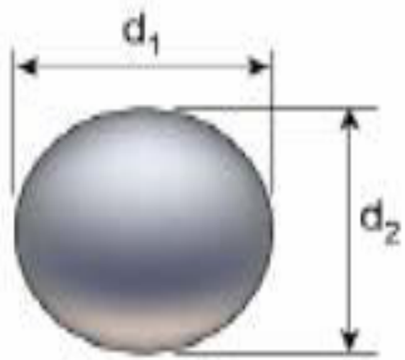
- The Brinell methods consists of indenting the metal (usually) with a 10 mm diameter steel ball subjected to a load of 3000 kg.
- For soft materials the load is reduced to 1500 or 500 kg, as may be required to avoid too deep an indentation.
- In Brinell Test, the BHN (Brinell Hardness Number) of nearly all materials is influenced by the
  - The magnitude of the indenting load,
  - Diameter of the ball indenter and
  - The elastic characteristics of the indenter ball.


PRESSURE GAGE
HYDRAULIC ACTUATING UNIT
LEVER FOR BUILDING UP HYDRAULIC PRESSURE
PENETRATOR
ELEVATING SCREW


F
D
d_1
d_2



(a) Brinell indentation



(b) measurement of impression diameter


OPTIC
?
STOP
SET

- Different ball diameter and load values can be used for the Brinell Test as long as the ratio (F/D^2) is a constant value where;
  - F = indenting load.
  - D= diameter of the ball.
- In general, a ball of 10 mm diameter is used with the standard loads of 3000, 1500 and 500 kg. However, there are also commercial Brinell hardness testers which employ other test loads and use smaller ball indenters.

- The Brinell Hardness Number is calculated by:

$$BHN = \frac{F}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$$

  - F : applied load, kg
  - D : Diameter of the ball indenter, mm
  - d : mean diameter of impression, mm

Care to be taken:

- For a reliable Brinell hardness test result the following must be observed during testing and the evolution of the results.

1. It is essential that the load is not applied too rapidly for this will add an extra load to the nominal load, resulting from the inertia of the load application system.
    - An additional error would also result from allowing insufficient (not enough) time for plastic flow to take place. The rate of loading should be uniform and should not exceed 500 kg/sec. Many of the testers are equipped with dash pots to ensure the load is applied slowly

2. Measurement of the impressionshould be accurate enough.
3. Thickness of the test piece must be such that no bulge or other marks should appear on the other side. The thickness (t) must be at least ten times the depth (h) of indentation ($t > 10h$).
4. Spacing of indentation : The distance of the center of indentation from the edge of the specimen or edge of another indentation should be at least 2.5 times the diameter of indentation.(distance >2.5 d).

5. Radius of curvature :When indentations are produced on a curved surface, the minimum radius of curvature of the surface should not be less than 25 mm for a 10 mm ball. The diameter of indentation shall be taken as the mean of the two principal diameters.
6. Selection of test load : The load in the standard Brinell test is 3000, 1500, or 500 kg. The load should be seleceted to keep the ratio of the indentation to the diameter of the ball (d/D), greater than 0.25 and less than 0.60

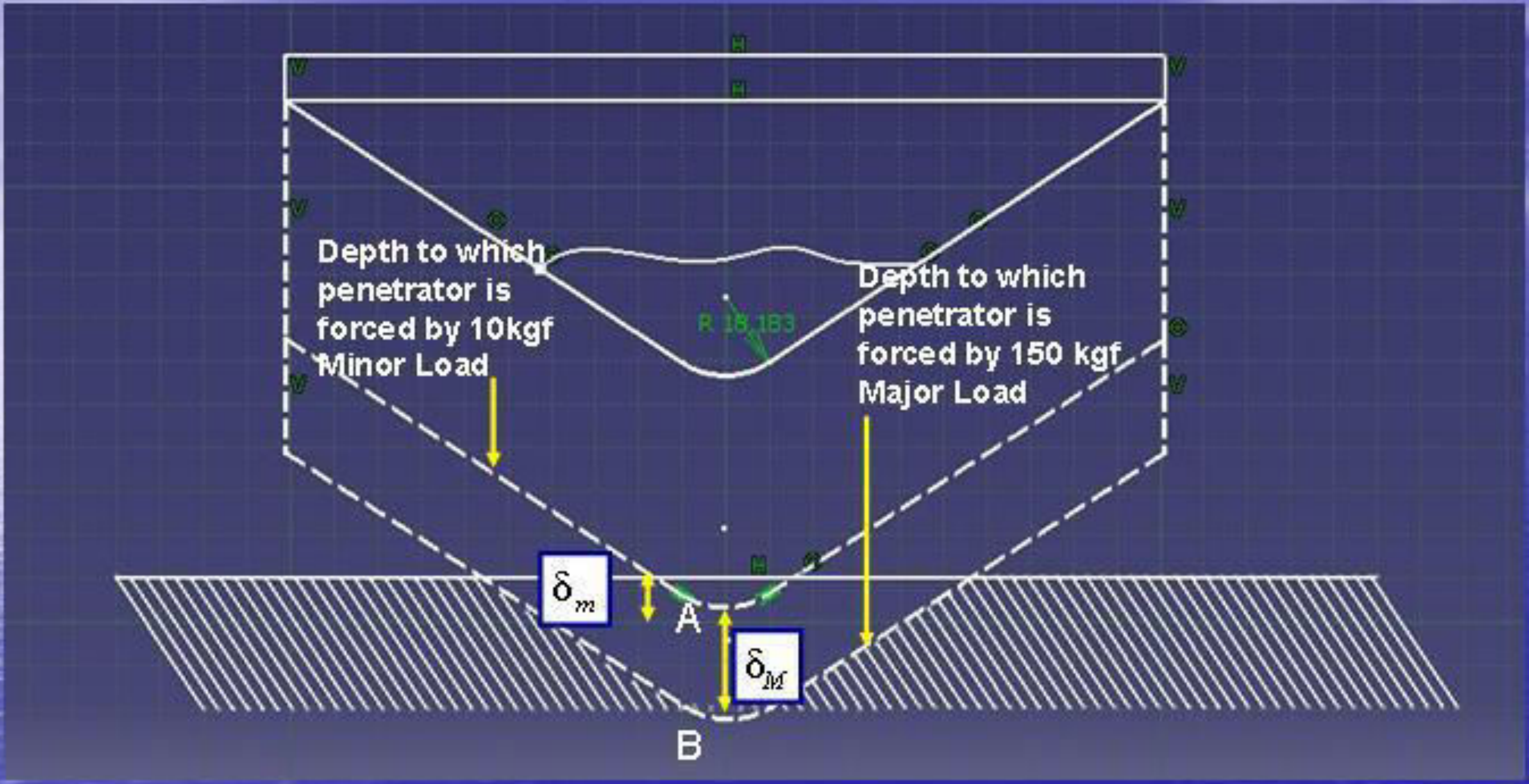
- The lower limit is dictated by the diameter of the indentation. If the diameter is very small, the edges of the impression are not defined well enough. For a ratio greater than 0.60, the test becomes supersensitive.

Rockwell hardness testing

- The Rockwell test consists of measuring the additional depth to which a steel ball or "Brale" diamond penetrator is forced by a heavy (major) load beyond the depth of previously applied light (minor) load.

- The two superimposed impressions is a special design feature of the tester, aimed at elimination of errors in measurement due to surface imperfections or distortions around the periphery of the indentation.

BRALE SPHERO-CONICAL DIAMOND PENETRATOR



- As the result of application of the minor load, an initial indentation of depth (δ_m) is made on the specimen. The depth of this impression serves also as **the datum line, (for the dial gauge is "SET" to zero) before the major load is applied.**
- Since the major load is applied without removing the minor load the penetrator is forced beyond the depth of previously applied load by the depth δ_m
- After the major load is applied and removed, reading is taken while the minor load is still in position.

- Removal of the additional load allows a partial recovery, so reducing the depth of penetration.
- The permanent increase in depth of penetration, e, resulting from application and removal of the major load is used to deduce the Rockwell hardness number by means of equations.

$$HR = K - e$$

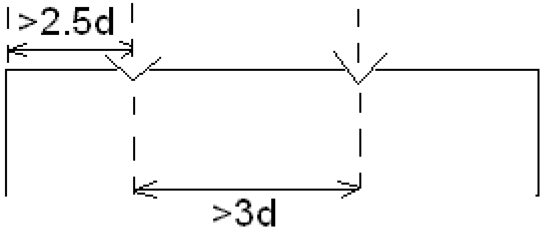
- HR :Rockwell Hardness Number
- K : a constant depending on the hardness scale

THE TYPES OF ROCKWELL TEST

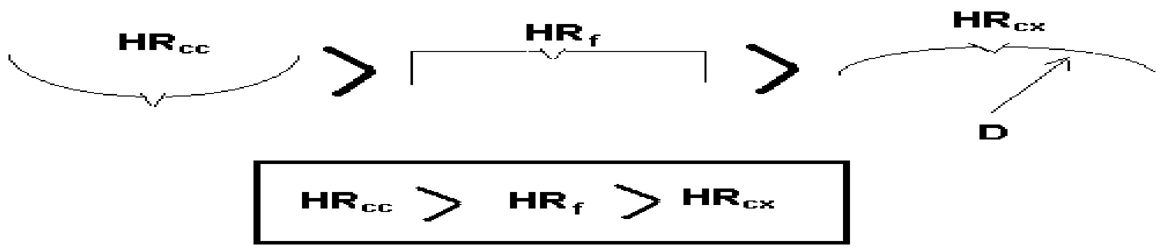
- The Rockwell testing falls into two categories:
  - Normal (regular) Rockwell Testing (e.g. B and C scales)
  - Rockwell Superficial Testing (e.g. 30N and 30T scales)
- In normal testing the minor load is always 10 kg. The major load, however can be either 60, 100 or 150 kg and we use 1/16"", 1/8"",1/4"" and 1/2"" ball penetrators.

- The superficial testing is used when the depth of penetrator has to be small. This is achieved by using a smaller minor load, smaller major load and a more sensitive depth measuring. In superficial testing, the minor load is always 3 kg. The major load, however, can be either 15, 30, or 45 kg.

- In choosing the right scale (A,B,C,etc) there are four basic consideration.
  - 1-Type of material
  - 2-Thickness of specimen
  - 3-Spacing of indentations
  - 4-Scale limitations



- Rockwell hardness numbers (HR) will be lower on the convex surfaces than on a flat surface for the same material. For a concave surface the opposite is true.
- If D is larger than 25 mm the difference between actual and measured values are negligible but for diameter of 25 mm or smaller a correction factor, supplied by the manufacturer, must be applied



TYPICAL APPLICATION OF SCALES

Scale Symbol	Load (kg)	Application
B	100	Copper alloys, soft steels, aluminum alloys, malleable iron, etc.
C	150	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel, and other materials harder than B100.
A	60	Cemented carbides, thin steel, and shallow case-hardened steel.
D	100	Thin steel, medium case-hardened steel, and pearlitic malleable iron.
E	100	Cast iron, aluminum and magnesium alloys, bearing metals.
F	60	Annealed copper alloys, thin soft metals.
G	150	Malleable irons, copper-nickel-zinc and cupro-nickel alloys. Upper limit G-92 to avoid possible flattening of ball.
H	60	Aluminum, zinc, lead
OTHER SCALES		Bearing metals and other very soft or thin materials. Smallest ball and heaviest load must be used whenever possible.

- Rockwell hardness is never shown by numbers alone but by letters showing the scale. For example:
- •C60 or 60RC means a Rockwell hardness value of 60 with scale C and a major load of 150 kg forcing a brale diamond penetrator

Meyers hardness

- Meyer suggested that hardness should be expressed in terms of the mean pressure between the surface of the indenter and the indentation, which is equal to the load divided by the projected area of the indentation.

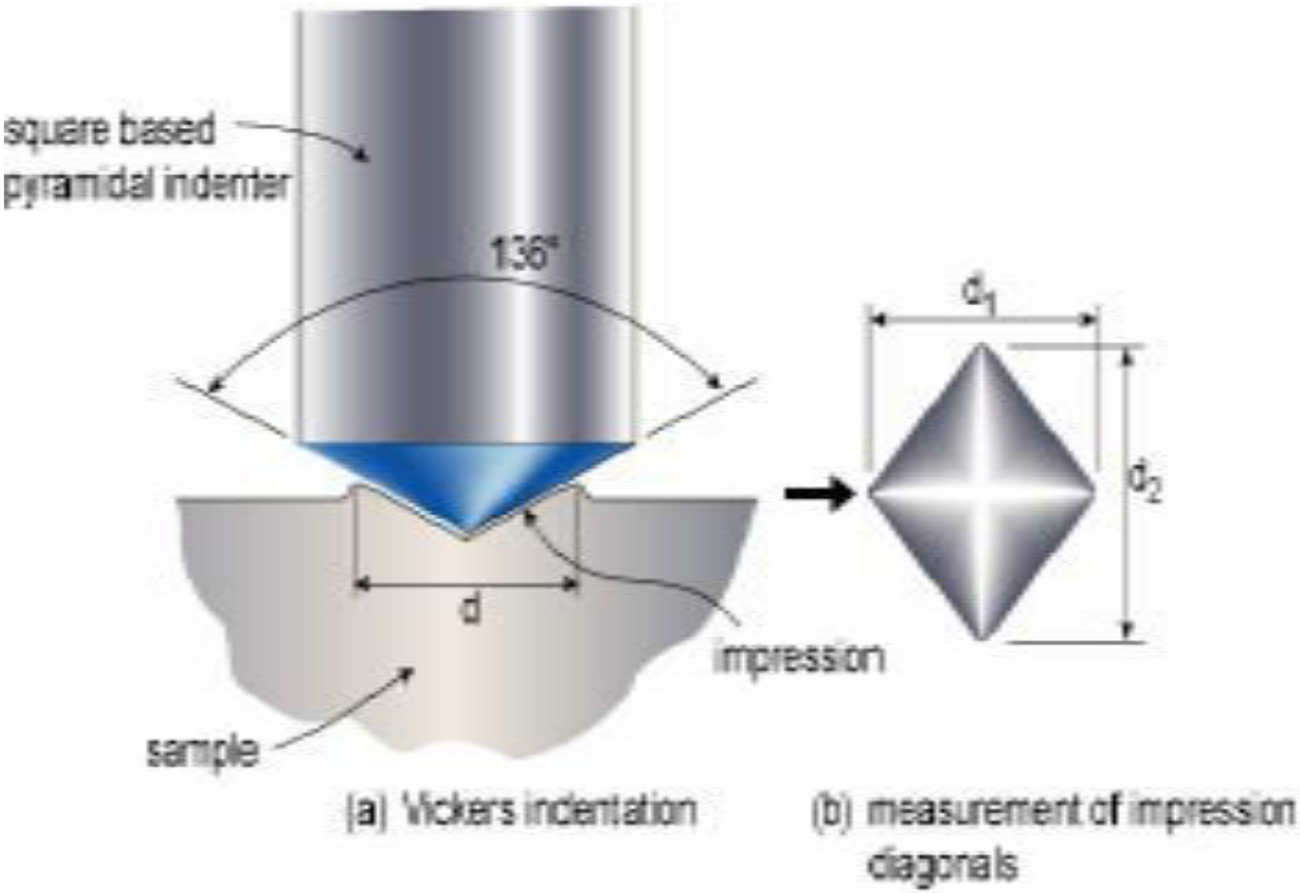
$$p_m = \frac{P}{\pi r^2}$$

$$Meyer\ hardness = \frac{4P}{\pi d^2}$$

- Meyer hardness is less sensitive to the applied load than Brinell hardness.
- Meyer hardness is a more fundamental measure of indentation hardness but it is rarely used for practical hardness measurement.

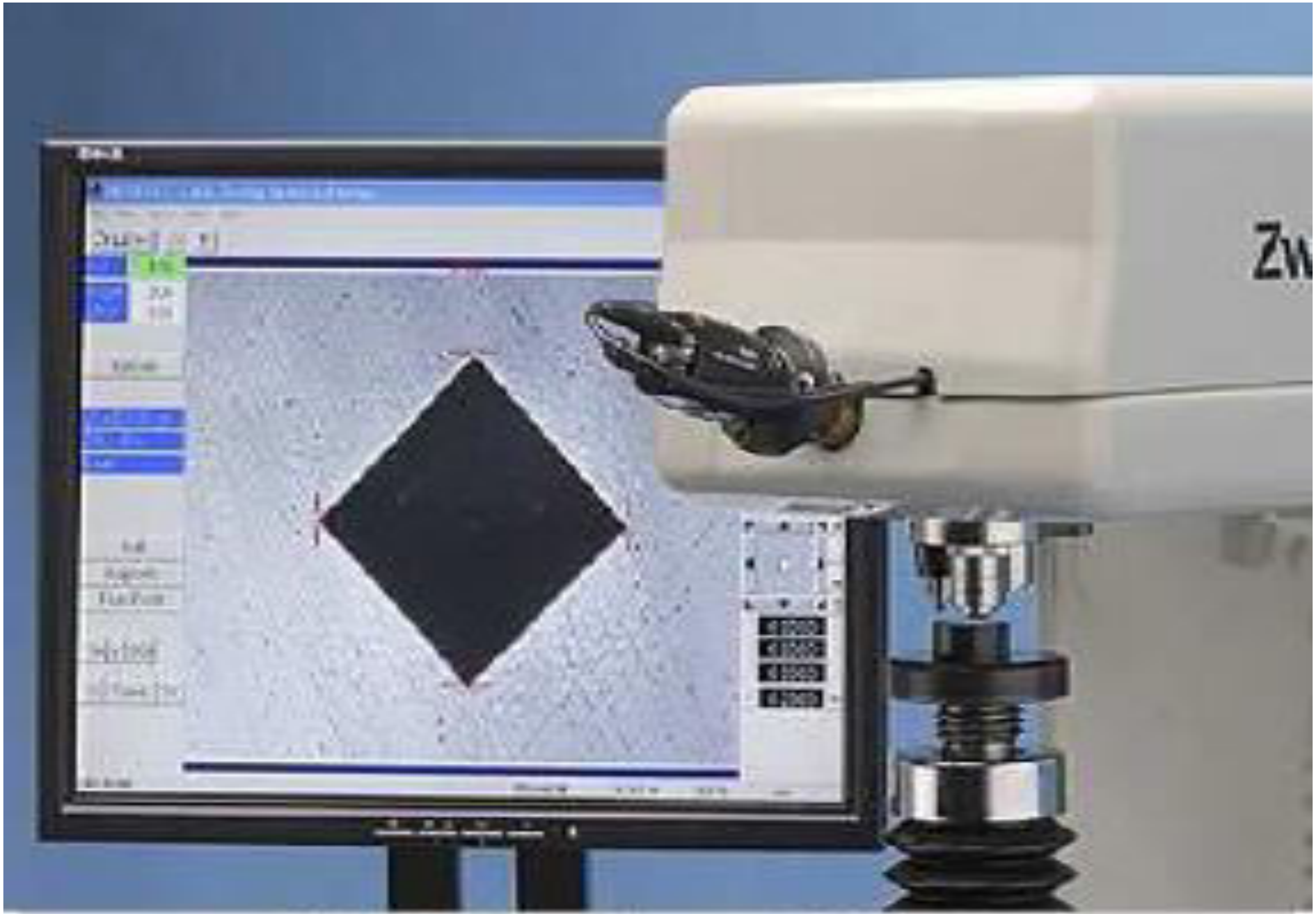
Vicker's Test

- Vickers hardness test uses a square-base diamond pyramid as the indenter with the included angle between opposite faces of the pyramid of 136^o.
- The Vickers hardness number (VHN) is defined as the load divided by the surface area of the indentation.


square based
pyramidal indenter
136°
d
impression
sample
d_1
d_2
(a) Vickers indentation
(b) measurement of impression
diagonals

$$VHN = \frac{2P\sin(\theta/2)}{L^2} = \frac{1.854P}{L^2}$$

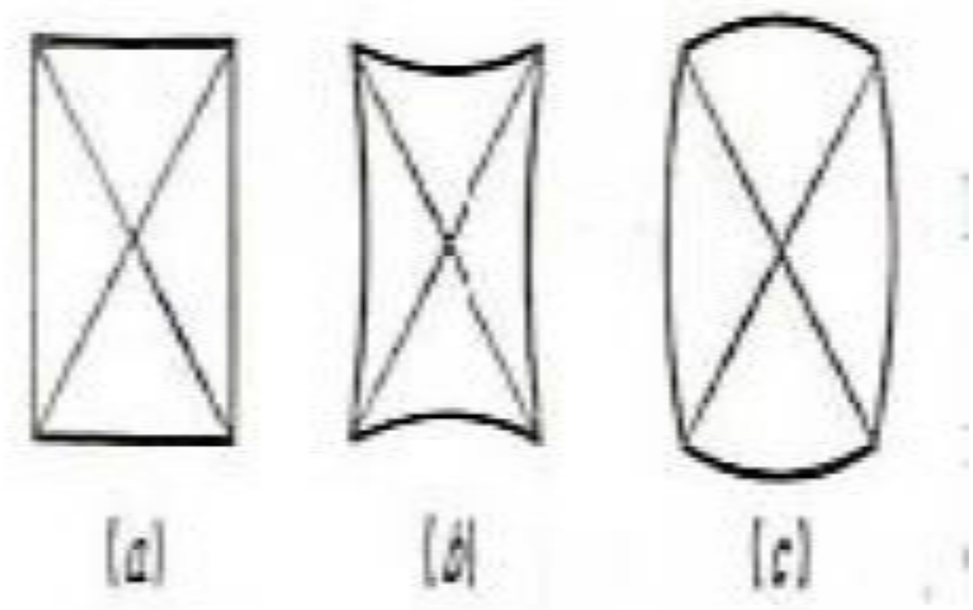
- Where
  - P is the applied load, kg
  - L is the average length of diagonals, mm
  - θ is the angle between opposite faces of diamond = 136°.



ZHV30 micro and macro Vickers with automatic impression measurement

- Vickers hardness test uses the loads ranging from 1-120 kgf, applied for between 10 and 15 seconds.
- Provide a fairly wide acceptance for research work because it provides a continuous scale of hardness, for a given load.
- VHN = 5-1,500 can be obtained at the same load level (easy for comparison).

IMPRESSIONS MADE BY VICKERS HARDNESS



Types of diamond-pyramid indentation
(a) perfect indentation

(b) pincushion indentation due to sinking in

(c) barrelled indentation due to ridging.

- A perfect square indentation (a) made with a perfect diamond pyramid indenter would be a square.
- The pincushion indentation (b) is the result of sinking in of the metal around the flat faces of the pyramid. This gives an overestimate of the diagonal length (observed in annealed metals).
- The barrel-shaped indentation (c) is found in cold-worked metals, resulting from ridging or piling up of the metal around the faces of the indenter. Produce a low value of contact area giving too high value.

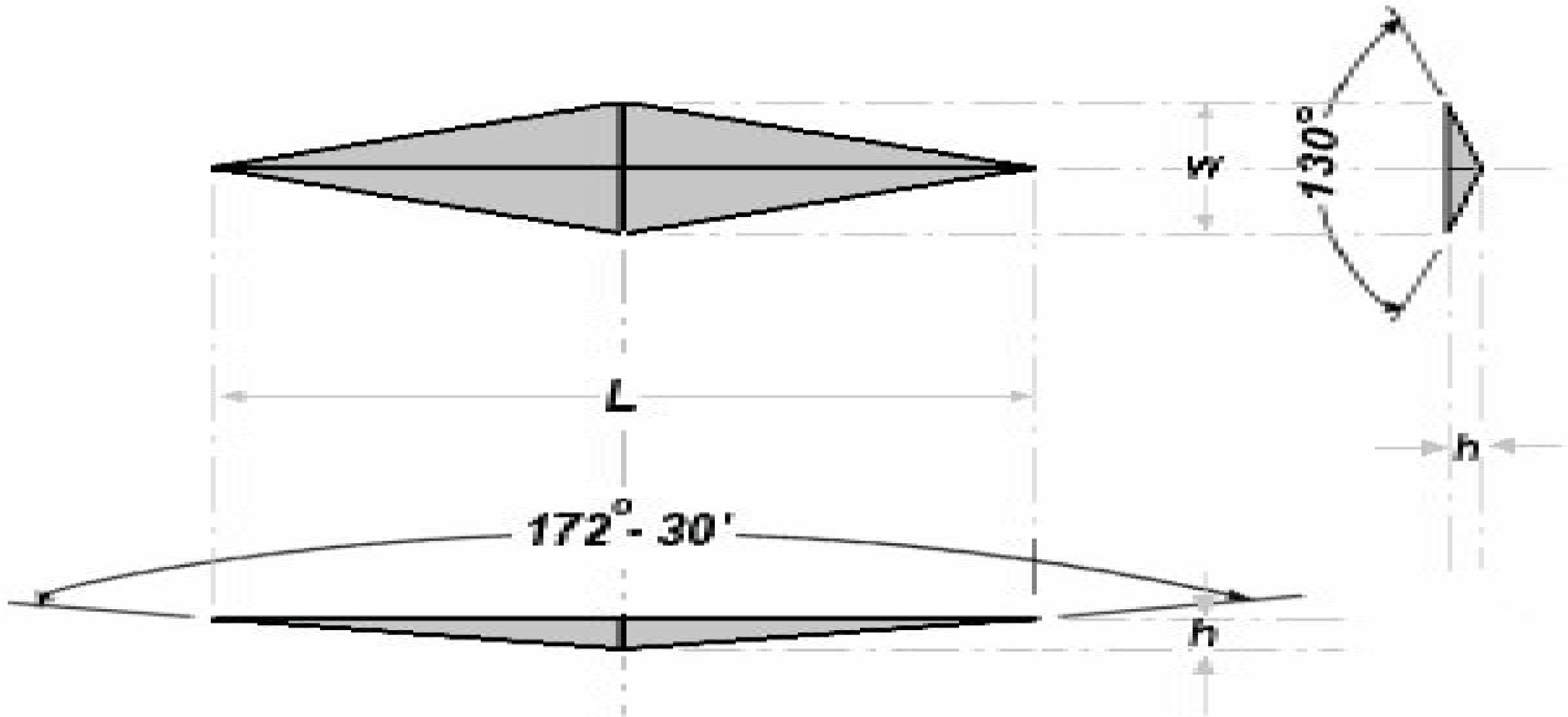
Vickers hardness

- Materials H_v
  - Tin 5
  - Aluminum 25
  - Gold 35
  - Copper 40
  - Iron 80
  - Mild steel 230
  - Full hard steel 1000
  - Tungsten carbide 2500

Microhardness

- Determination of hardness over very small areas for example individual constituents, phases, requires hardness testing machines in micro or sub-micro scales.
- Vickers hardness can also be measured in a microscale, which is based on the same fundamental method as in a macroscale.

KNOOP HARDNESS



- The Knoop indenter (diamond shape) is used for measuring in a small area, such as at the cross section of the heat-treated metal surface.
- The Knoop hardness number (KHN) is the applied load divided by the unrecovered projected area of the indentation.

$$KHN = \frac{P}{A_p} = \frac{P}{L^2C}$$

- Where,
  - P = applied load, kg
  - A_p = unrecovered projected area of indentation, mm2
  - L = length of long diagonal, mm
  - C = a constant for each indenter supplied by manufacturer.

HARDNESS CONVERSION RELLATIIONSHIIPS

- Hardness conversions are empirical relationships for Brinell, Rockwell and Vickers hardness values.
- This hardness conversions are applicable to heat-treated carbon and alloy steels in many heat treatment conditions (or alloys with similar elastic moduli).
- For soft metals, indentation of hardness depends on the strain hardening behaviour of the materials.
- Special hardness-conversion tables for cold-worked aluminium, copper, and 18-8 stainless steel are given in the ASM Metals Handbook.

HARDNESS AT ELEVATED TEMPERATURES

- Hot hardness gives a good indication of potential usefulness of an alloy for high-temperature strength applications.
- Hot hardness testers use a Vickers indenter made of sapphire and with provisions for testing in either vacuum or an inert atmosphere.
  - $H = Ae^{-BT}$
    - Where H = hardness, kgf.mm-2
    - T = test temperature, K
    - A,B = constants
- The temperature dependence of hardness could be expressed as shown above

IMPACT TESTING

- As taught in class
- Use George Dieter as reference.
- Feel free to contact me for any difficulties.