Conversion chart

The Brinell hardness test is commonly used to determine the hardness of materials like metals and alloys. The test is achieved by applying a known load to the surface of the tested material through a hardened steel ball of known diameter. The diameter of the resulting permanent impression in the tested metal is measured and the Brinell Hardness Number calculated as

$$BHN = 2 P / (\pi D (D - (D^2 - d^2)^{1/2})) \qquad (1)$$

where

BHN = Brinell Hardness Number

P = load on the indenting tool (kg)

D = diameter of steel ball (mm)

d = measure diameter at the rim of the impression (mm)

It is desirable that the test load are limited to a impression diameter in the range of 2.5 to 4.75 mm.

Approximate loads and Brinell Hardness Numbers:

Brinell Hardness Number	Load *(kg)*
160 - 600	3000
80 - 300	1500
26 - 100	500

Typical Brinell Hardness Numbers for Metals

Material	Brinell Hardness Number
Soft brass	60
Mild steel	130

Material	Brinell Hardness Number
Annealed chissel steel	235
White cast iron	415
Nitrided surface	750

Steel Hardness versus Strength

Brinell		**Vickers**	**Rockwell**		**Equivalent *Rm***		
Impression Diameter *(mm)*	**Hardness HB**	**Hardness HV**	**Hardness B**	**Hardness C**	***(ton$_f$/in^2)***	***(kg$_f$/mm^2)***	***(N/mm^2)***
2.50	601	640	-	57.0	-	-	-
2.55	578	615	-	56.0	-	-	-
2.60	555	591	120	54.5	-	-	-
2.65	534	569	119	53.5	-	-	-
2.70	514	547	119	52.0	-	-	-
2.75	495	528	117	51.0	-	-	-
2.80	477	508	117	49.5	-	-	-
2.85	461	491	116	48.5	101	160	1569
2.90	444	474	115	47.0	98	155	1520
2.95	429	455	115	45.5	95	150	1471
3.00	415	440	114	44.5	92	145	1422
3.05	401	425	113	43.0	88	139	1363
3.10	388	410	112	42.0	85	134	1314
3.15	375	396	112	40.5	82	129	1265
3.20	363	383	110	39.0	80	126	1236
3.25	352	372	110	38.0	77	121	1187
3.30	341	360	109	36.5	75	118	1157
3.35	331	350	109	35.5	73	114	1118
3.40	321	339	108	34.5	71	111	1089
3.45	311	328	108	33.0	68	107	1049
3.50	302	319	107	32.0	66	104	1020

Brinell		Vickers	Rockwell		Equivalent *Rm*		
Impression Diameter *(mm)*	**Hardness HB**	**Hardness HV**	**Hardness B**	**Hardness C**	***(ton_f/in^2)***	***(kg_f/mm^2)***	***(N/mm^2)***
3.55	293	309	106	31.0	64	101	990
3.60	285	301	105	30.0	63	99	971
3.65	277	292	104	29.0	61	96	941
3.70	269	284	104	27.5	59	93	912
3.75	262	276	103	26.5	58	91	892
3.80	255	269	102	25.5	56	89	873
3.85	248	261	102	24.0	55	87	853
3.90	241	253	100	23.0	53	84	824
3.95	235	247	99	22.0	51	81	794
4.00	229	241	98	20.5	50	79	775
4.05	223	235	97	-	49	77	755
4.10	217	228	96	-	48	76	745
4.15	212	223	96	-	46	73	716
4.20	207	218	95	-	45	71	696
4.30	197	208	93	-	43	68	667
4.40	187	197	91	-	41	65	637
4.50	179	189	89	-	39	62	608
4.60	170	179	87	-	36	57	559
4.70	163	172	85	-	35	55	539
4.80	156	165	83	-	34	54	530
4.90	149	157	81	-	32	51	500
5.00	143	150	79	-	31	49	481
5.10	137	144	77	-	31	49	481
5.20	131	138	74	-	30	47	461
5.30	126	133	72	-	29	46	451
5.40	121	127	70	-	28	44	431
5.50	116	122	68	-	27	43	422
5.60	111	117	66	-	26	41	402
5.70	107	113	64	-	25	39	382
5.80	103	108	61	-	24	38	373

Brinell Test Example

- Brinell Test Method (continued)
  - Units: pressure per unit area
  - Brinell Hardness Number (BHN) = applied load divided by area of the surface indenter

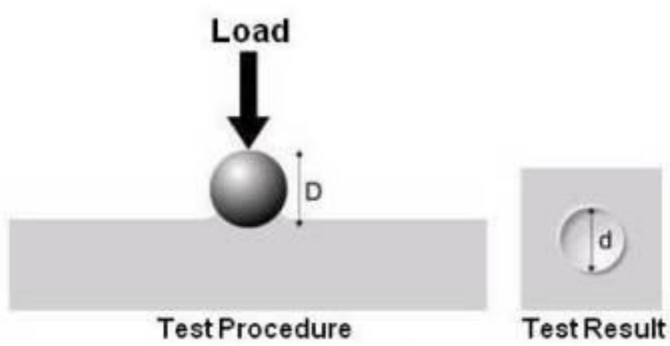
$$BHN = \frac{2L}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

Where:	BHN	= Brinell Hardness Number
	L	= applied load (kg)
	D	= diameter of the ball (10 mm)
	d	= diameter of indentation (in mm)

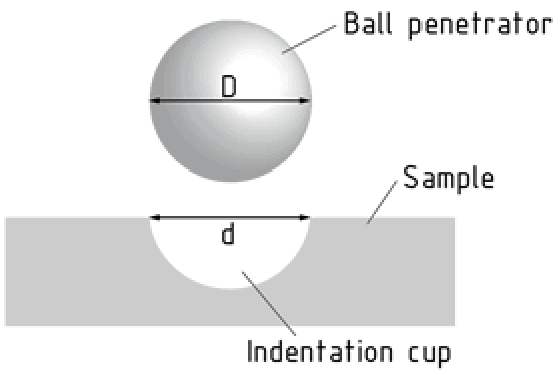
• Example: What is the Brinell hardness for a specimen with an indentation of 5 mm is produced with a 3000 kg applied load.

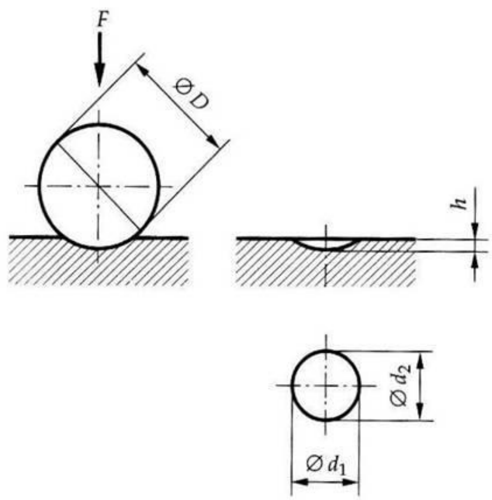
•Ans: $$BHN = \frac{2(3000kg)}{\pi(10mm)\left(10mm - \sqrt{(10mm)^2 - (5mm)^2}\right)} = 142.6kg/mm^2$$

22



Brinell Testing





Key:

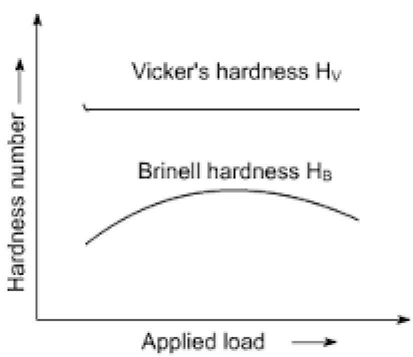
F	= Test force, in N
D	= Diameter of the ball, in mm
d_1 and d_2	= Diameters of the indentation, in mm, in two directions at right angles to each other
h	= Depth of the indentation, in mm

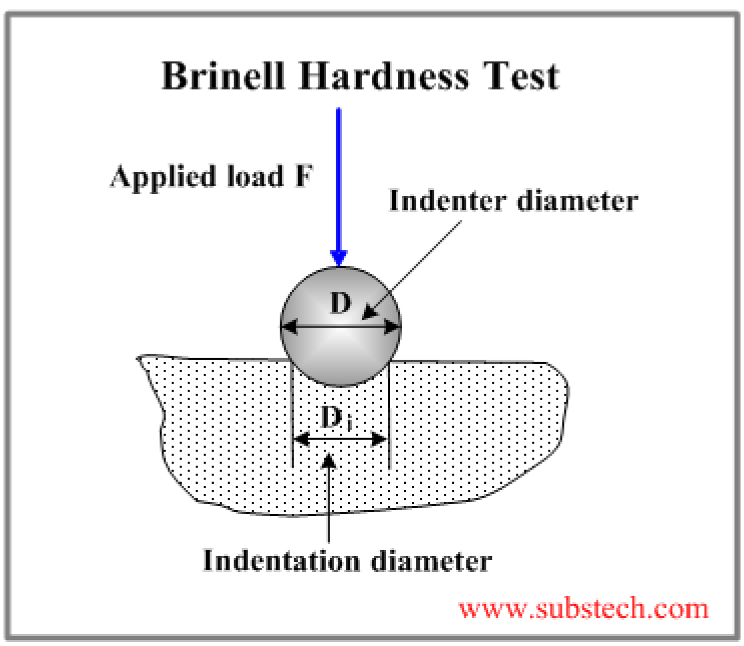
Advantages & Disadvantages of the Brinell Hardness Test

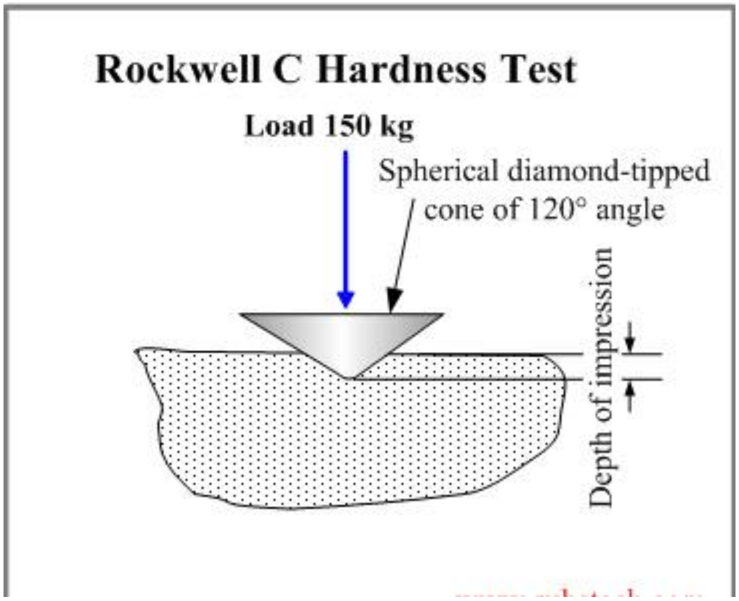
- Advantages
  - Well known throughout industry with well accepted results
  - Tests are run quickly (within 2 minutes)
  - Test inexpensive to run once the machine is purchased
  - Insensitive to imperfections (hard spot or crater) in the material

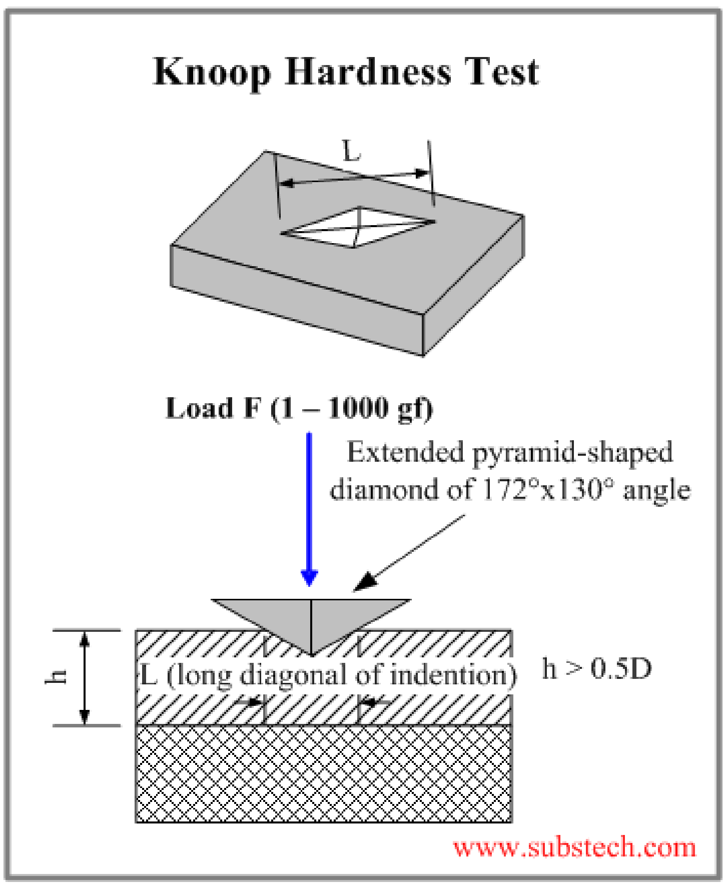
- Limitations
  - Not well adapted for very hard materials, wherein the ball deforms excessively
  - Not well adapted for thin pieces
  - Not well adapted for case-hardened materials
  - Heavy and more expensive than other tests ($5,000)

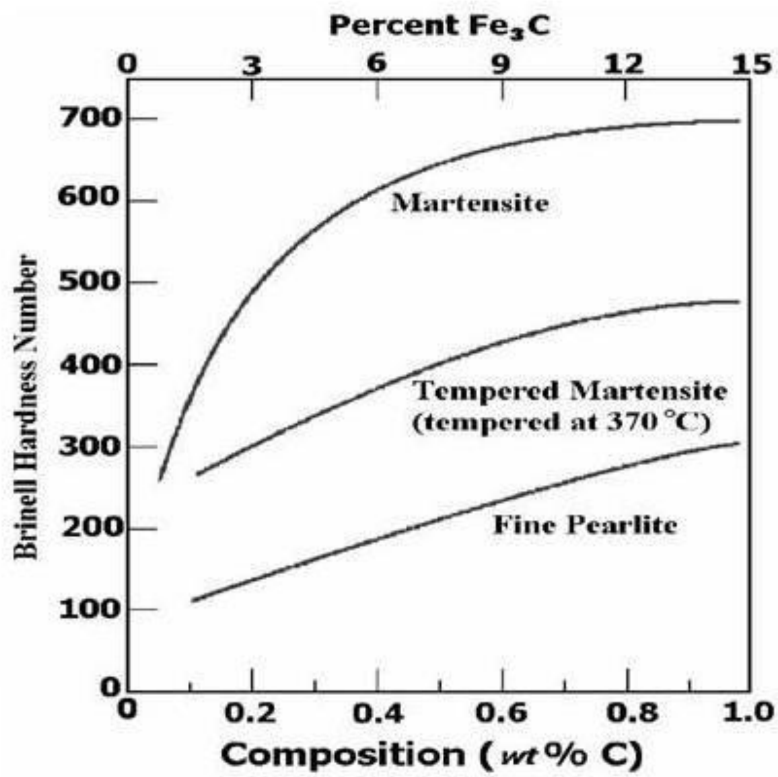
24



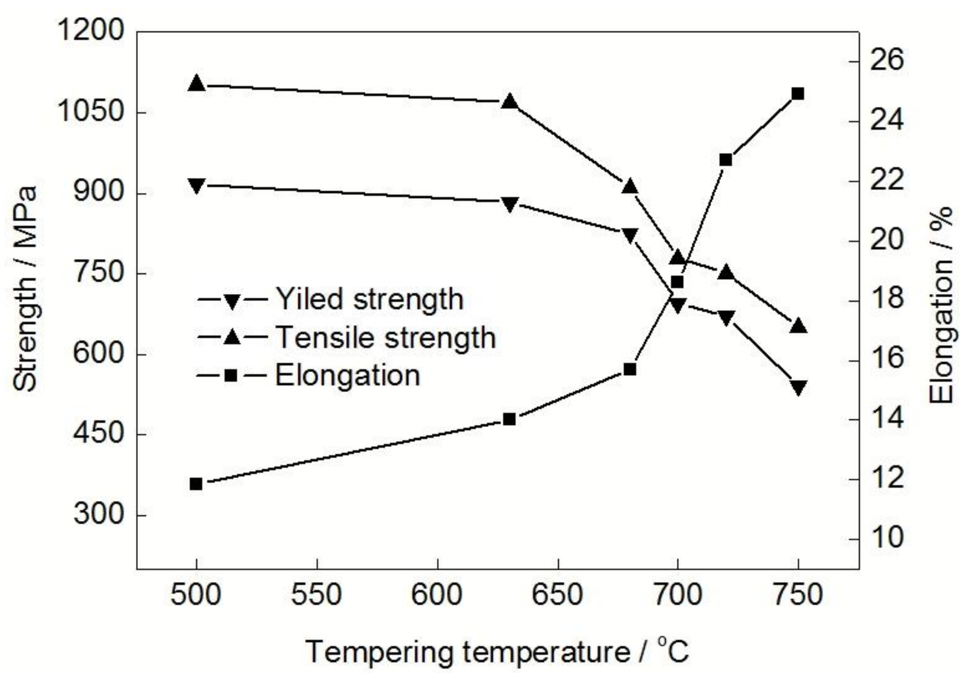



Rockwell C Hardness Test
Load 150 kg
Spherical diamond-tipped
cone of 120° angle
Depth of impression


Knoop Hardness Test
L
Load F (1 – 1000 gf)
Extended pyramid-shaped
diamond of 172°x130° angle
h
L (long diagonal of indention)
h > 0.5D
www.substech.com



Effect of carbon on hardness for various microstructures

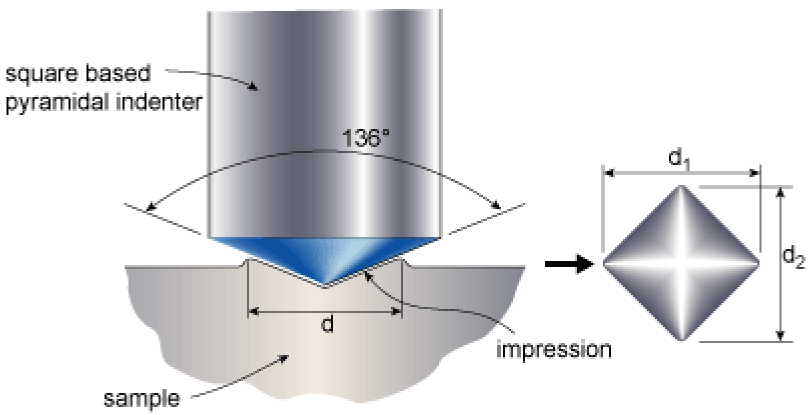


Vickers hardness test:

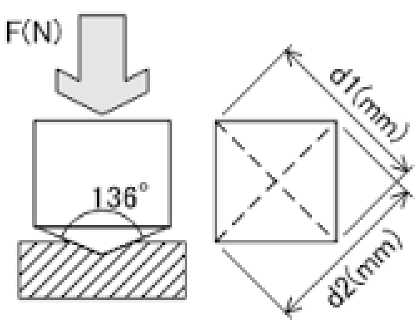
By formula $HV = \dfrac{2P \sin \frac{\theta}{2}}{D^2}$

Where:

P = applied load (kgf)
D = mean diagonal of the indentation (mm)
θ = angle between opposite faces of the diamond = 136°



(a) Vickers indentation (b) measurement of impression diagonals



$$HV = 0.102 \frac{2F \sin \frac{136^\circ}{2}}{d^2}$$

$$HV = \frac{F}{S}$$

$$= \frac{2F\sin\frac{\theta}{2}}{d^2}$$

$$= 1.8544\ \frac{F}{d^2}$$

http://www.slideshare.net/missazza/material-technology-46132454 for below

CHAPTER 4 : MECHANICAL TESTING

4.0 The Purpose of Mechanical Testing and types of defects

- The purposes of material testing :
    1. to determine quality of certain material for controlling process aspect in plant production
    2. to determine mechanical properties such as strength, hardness, ductility and toughness.
    3. to trace defects/ flaws inside the material, example for welding job
    4. to evaluate material performance in certain service condition, example for automobile industries such as in engine block testing
- Types of defects :
    1. existent defects
        - defects caused by solidifies process such as in casting
    2. process defects
        - defects formed by various of process such as machining, heat treatment and rolling
    3. service defects
        - defects caused by situation in services such as corrosion, stress and fatigue
- Method selection of material testing :
    1. types and defects origin
        - example : crack, porosity and impurities
    2. component manufacturing process
        - example : welding, machining and casting
    3. component capability
        - easier or harder to tested
    4. testing equipment availability
        - equipment for testing is available to the user
    5. accessible rate as needed
        - accuracy
    6. testing cost
        - comparable with ability and component tested

4.1 Mechanical Properties

Mechanical properties	Ability
1. Tensile Strength	withstand/ resist tensile (stretching) force/ loads without fractured/ breaking
2. Compressive Strength	withstand/ resist compressive (squeezing) force/ loads without crushed/ broken
3. Shear Strength	withstand/ resist offset force/ loads or transverse cutting or crosswise cutting (shearing actions)
4. Hardness	withstand scratching (abrasion) or indentation by another hard body
5. Elasticity	deform under load and return to its original size/ shape/ dimensions when the force/ load is removed
6. Plasticity	deformed permanently under a force and will not return/ recover to its original size/ shape/ dimensions when the load is removed
7. Ductility	extend (plastic deformation) under a tensile force before fractured
8. Toughness	withstand/ resist shatter/ impact force without fractured
9. Brittleness	to fractured for sudden impact without changing/ plastic deformation
10. Rigidity/ Stiffness	resist plastic deformation and stay to its original deformation
11. Malleability	have plastic deformation as the result of applying a compressive load before fracture occurs

4.2 The Comparison between Destructive Test and Non-Destructive Test

Testing / Comparison Item	**Destructive Test DT**	**Non-destructive Test NDT**
Definition	Implies to the sample of a material and the process will cause damage the tested part	Implies for finding defective parts inside or on the surface of a material and does not damage or ruined tested part/ specimen
Types	i. Tensile Test ii. Hardness Test : Brinell, Vickers, Rockwell and Knoop iii. Impact Test : Izod and Charpy iv. CreepTest v. FatigueTest vi. Bending Test vii. Compression Test viii. Torsion Test	i. Visual Inspection ii. Liquid Penetrant Inspection iii. Magnetic Particle Inspection iv. Eddy Current Inspection v. Ultrasonic Inspection vi. Radiography Inspection

Activity 1 :

1. Tensile Test	To gain stress and yield values until the material are torque before it is fractured.
2. Creep Test	Indicates an index of ductility.
3. Fatigue Test	Indicates the strength, ductility and toughness of a metal. It can measure stress strain curve, tensile strength, yield strength, reduction in area, Young's modulus, resilience and toughness.
4. Bending Test	The material is elastic until certain stress amount and having plastic deformation after reaching the stress amount limit. Usually done before forging, rolling and extrusion processes.
5. Compression Test	Indicates the metals that subjected to reserved or repeated stresses fail at loads that are far below their ultimate tensile or compressive strength.
6. Torsion Test	Indicates slow and progressive deformation of a material with time under a constant stress.

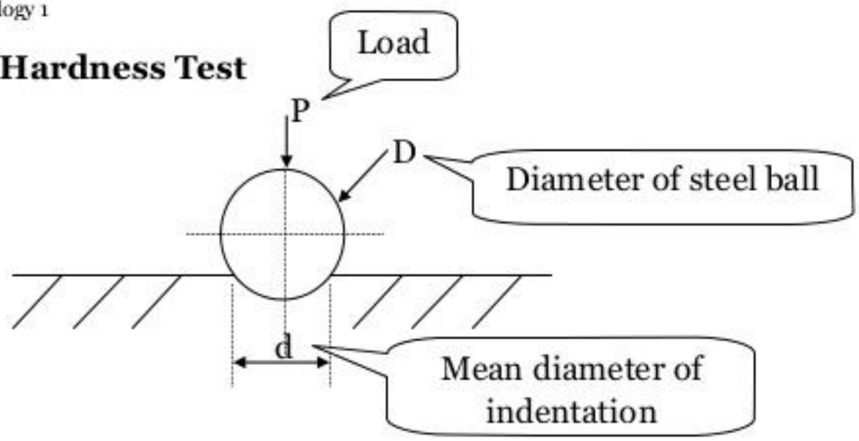
4.3 Hardness Test

- The hardness of a material usually implies the resistance to deformation or indentation.
- Types of hardness measurements depend on the manner in which the test is conducted :
    i. Scratch hardness
    ii. Indentation hardness
    iii. Rebound hardness

- Scratch hardness determines scratching and abrasion ability of a metal when scratched by standard substance. Ceramics hardness can be determine by this method.
- The indentation hardness testing methods are based on the principle of forcing a hard material called an indenter, against a flat surface of the metal, under a fixed load. Only can be applied for material that implies plastic deformation which it is metal and thermo plastic.
- Rebound hardness testing is applied for hardness measurements on large work pieces or for applications in which visible or sharp impressions in the test surface cannot be tolerated.

- Hardness Test methods :
    (a) Brinell Test
    (b) Vickers Test
    (c) Rockwell Test
    (d) Scleroscope Shore Test
    (e) Knoop Test

4.3.1 Brinell Hardness Test



- The hardness is measured by pressing a hard steel ball into the surface of the test piece using a known load.

- Basic principle of Brinell hardness measurement :
  1. A steel ball indenter of 10mm diameter, indent into the surface of a metal with fixed load of 500kg (4.905kN), 1500kg (14.715kN) or 3000kg (29.43kN) and maintained for 10 to 15 seconds.
  2. Combination of load (P) and ball size (D) must be accurated to avoid distortion.

$$\frac{\mathbf{P}}{\mathbf{D^2}} = \mathbf{K} \text{ where K is constant}$$

- Typical values of K are :

Material	K value
Ferrous metals	30
Copper and copper alloys	10
Aluminium and aluminium alloys	5
Lead (Pb), Tin (St)	1

- **Surface area of indentation** with diameter d (mm) indented by ball indenter D (mm) is given by the following formula :

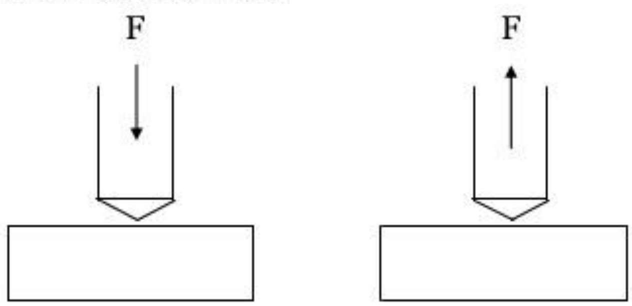
$$\text{Area} = \frac{\pi D \left[D - \sqrt{(D^2 - d^2)} \right]}{2} \quad mm^2$$

- **Brinell Hardness Number (HB)** given by :

$$HB = \frac{\text{test load}}{\text{surface area of indentation}}$$

$$= \frac{2P}{\pi D \left[D - \sqrt{(D^2 - d^2)} \right]}$$

4.3.2 Vickers Hardness Test



- Diamond pyramid (6000 HB) test indentor with an angle of 136°, gives an indentation that appears as a square. Indented with static loads for 10 to 15 minutes.
- Static loads applied for materials used :

Materials	Loads (kg)
Steel and cast iron	30
Cuprum alloys	10
Pure cuprum, aluminium alloys	5
Pure aluminium	2.5
Lead (PB), tin (St) and tin alloys	1

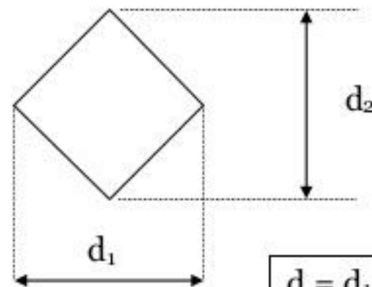
The Vickers Hardness Number (HV) given by the formula below :

$$HV = \frac{\text{Test loads}}{\text{Surface area of the indentation}}$$

$$= \frac{F\,(kg)}{d^2 / [2 \sin \theta / 2]} \qquad \text{where } \theta = 136^\circ$$

$$= \frac{2\,F \sin 68^\circ}{d^2}$$

$$= \frac{1.8544\,F}{d^2}$$



F = test load (kg)
d = average length of diagonals (mm)

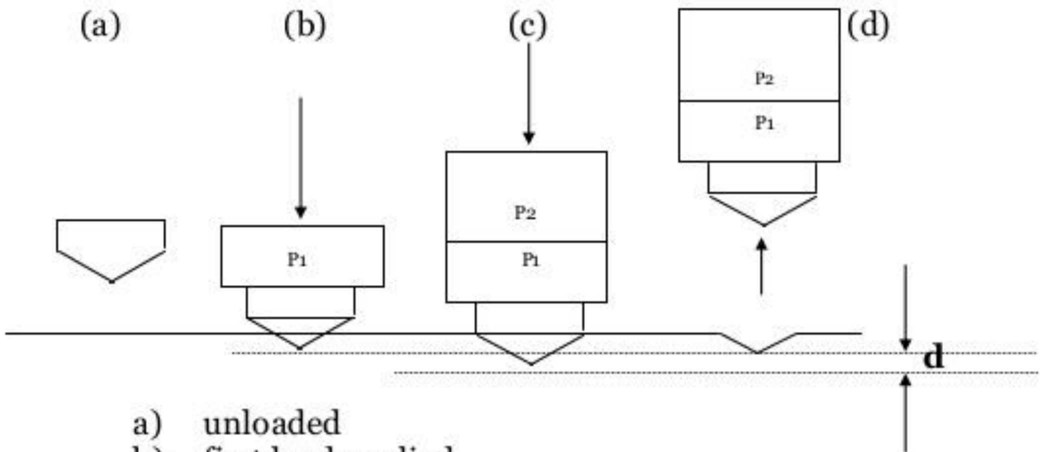
$$d = \frac{d_1 + d_2}{2}$$

- The main advantages of the Vickers hardness testing machine are :
  1. Automatically timing
  2. Small-sized indentation
  3. Accurate method of reading the diagonal of the indentation
  4. Constancy of indentation shape produced by the pyramidal diamond indenting tool

4.3.3 Rockwell Hardness Test

- Principle :
  Comparing the difference of indenter depth when using 2 difference forces. A minor force is first applied and the scales are set to read zero, then a major force is applied at the same indentation. The increased depth of indentation is shown on the scales of the machine as a direct reading of hardness without the need for calculation or conversion tables.
- The indenter used in this test is either a hardened steel ball or a carefully ground diamond cone.

- Low value of Rockwell Hardness Number shows a deep depth of indentation and higher value shows a shallow depth of indentation.



a) unloaded
b) first load applied
c) major load applied
d) load were released

d - the differentiate of indentation depth by $\mathbf{P_1}$ and $\mathbf{P_2}$

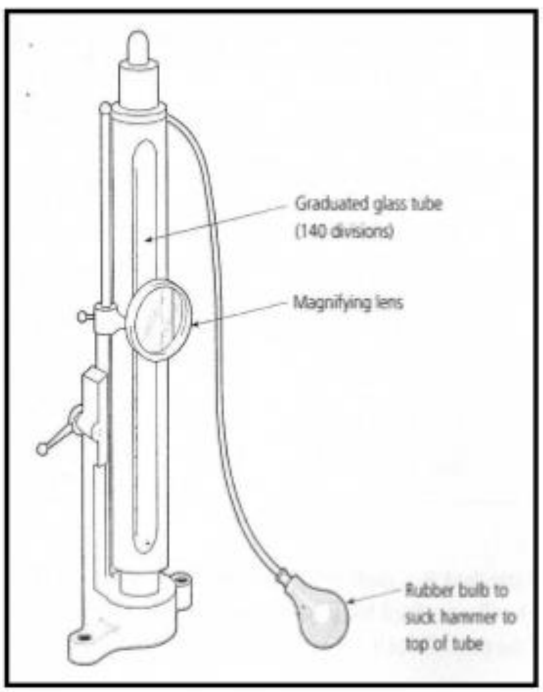
- The indenters most commonly used are :

i. diamond cone with an apex angle of 120°
ii. hard steel ball by varies of diameter

Scale	Indenter	Loads		
		First	Major	Total
B	Hard steel ball ∅ 1.6mm	10	90	100
C	Diamond cone with apex angle of 120°	10	140	150

4.3.4 Scleroscope Shore Hardness Test

- The Scleroscope Shore Hardness test is a rebound hardness test.
- This test measures the rebound of a weight that is dropped onto the specimen.
- A diamond-tipped hammer of mass 2.5g drops through a height of 250mm, the height of the first rebound indicates the hardness on a 140 division scale.
- This test suitable to measure a very hard metal. It is small and portable. Also suitable to measure the elasticity of rubbers.
- The Shore value for rubber and plastic determine by using a small equipment known as Durometer.
- Durometer is a hand appliance where the ball indenter or weight indented to the surface of the material under a spring expression and the meter scale displays will show the hardness of the material.



(a)

(b)

Figure 4.1 (a) Scleroscope Shore Test Equipment; (b) Analog Durometer

4.3.5 Knoop Hardness Test

- Principle :
  To determine the hardness over very small areas or the hardness of certain micro-constituents for identification purposes.
  Requires the use of extremely low loads, careful surface preparation of the specimen and measurement of indentation at higher magnification.
- The Knoop indenter is a diamond ground to a pyramidal form that produces a diamond-shaped indentation with the long and short diagonals by using 25g to 5kg of loads.
- It is suitable to test small and thinner specimen, brittle material such as gem stones, carbide and glass, and to measure grain hardness in metal.
- The indenter size is between 0.01 to 0.1mm, the length of the indent is seven times longer than its width and almost 30 times bigger than its depth.
- The Knoop Hardness Number (HK) given as the formula below :

$$HK = \frac{\text{Test load}}{\text{Area of spread indentation}}$$

$$= \frac{10\,F}{I^2 \times 7.028}$$

$$= \frac{1.42F}{I^2}$$

4.4 Impact Test / Toughness Test

- Toughness is a measurement of the amount of energy a material can absorb before fracturing.
- Principle :
  Striking a specimen with a controlled pendulum and measuring the energy absorbed in bending or breaking the specimen. The energy value indicates the toughness of the material.
- There are 2 types of impact test, namely the Charpy and the Izod.
- Both utilize the principle of swinging pendulum. The differences are in the standard design of the test piece with notch and the method of supporting and striking the specimen until its break/ fracture.
- The higher over swing of the pendulum after the impact, are the lower the toughness degree of the material, the value of the energy absorb are higher and the specimen are break easily.

Energy absorbed = energy before impact - energy after impact

Energy before impact
(i) gravity = $\frac{1}{2} mgh_1$
(ii) kinetic energy = $\frac{1}{2} mv_1^2$

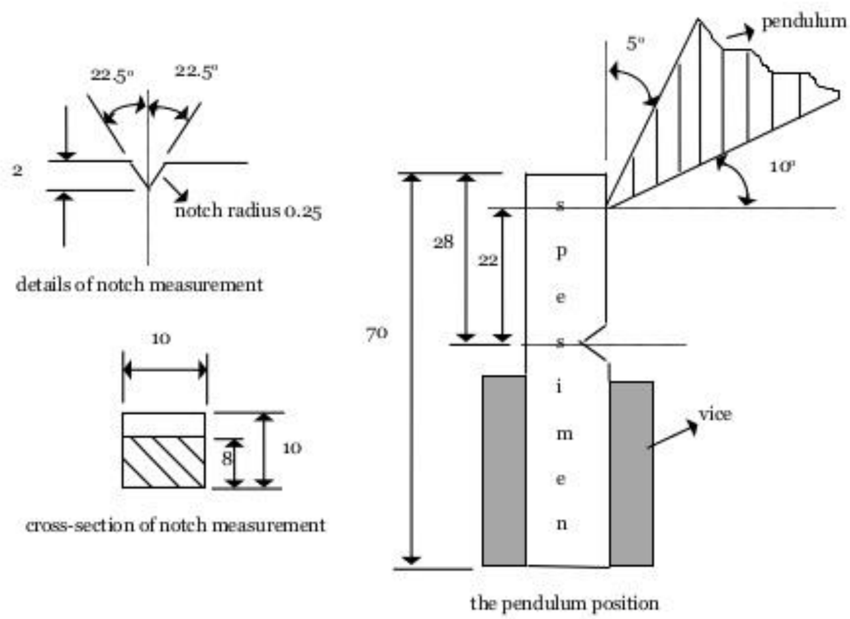
Energy after impact
(i) gravity = $\frac{1}{2} mgh_2$
(ii) kinetic energy = $\frac{1}{2} mv_2^2$

Energy absorb $= (\frac{1}{2} mgh_1 + \frac{1}{2} mv_1^2) - (\frac{1}{2} mgh_2 + \frac{1}{2} mv_2^2)$
$= \frac{1}{2} mh (h_1 - h_2) + \frac{1}{2} m (v_1^2 - v_2^2)$

4.4.1 Izod Impact Test

- The test consist of
    1. Breaking by one blow from a swinging hammer (with 162.72 J of the kinetic energy and 3.8m/s of velocity)
    2. A test piece gripped vertically at the bottom
    3. The notch in the same plane as the upper face of the grips
    4. The blow is struck at a fixed position facing the notch

- The pendulum is design in I shape.
- The shape and measurement of the notch as shown in the Figure 4.2 below :

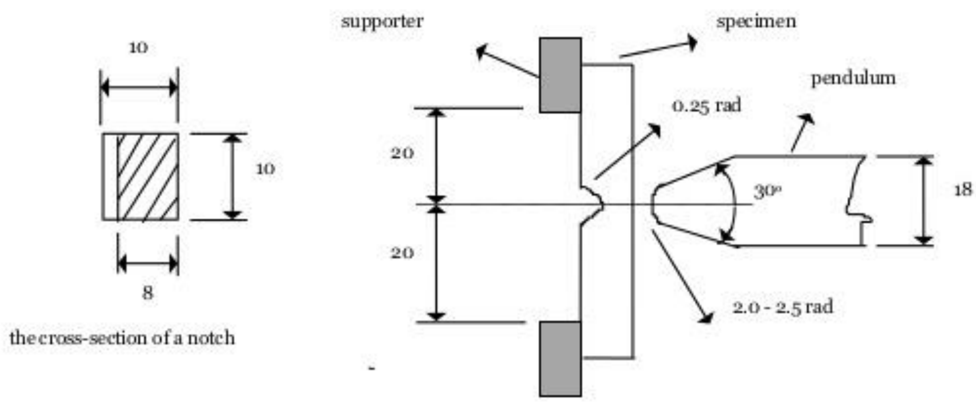


* all measurements are in mm

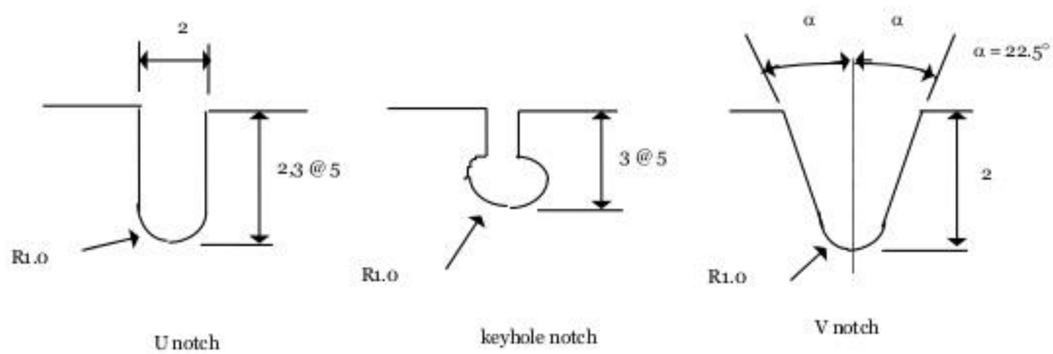
Figure 4.2 Izod Impact Test

4.4.2 Charpy Impact Test

- The test consists of :
    1. Breaking a standard test piece with one blow from a swinging hammer (with 298.3 J of kinetic energy and 5m/s of velocity)
    2. The test piece is notched in the middle
    3. The test piece is supported at each end as a beam
    4. The test piece should be in horizontal position, struck by the hammer in the plane of symmetry of the notch
- The pendulum designed in C shape.
- The figure below shows how the test conducted :



- In this test, there are others notching shapes as shown below :



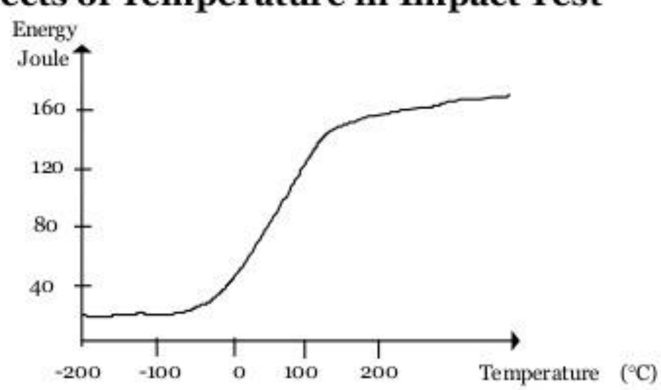
* all measurements are in mm

Figure 4.3 Charpy Impact Test / Standard Charpy Notch

4.5 The Interpretation of Impact Tests

- The notch impression :
  i. Causing stress concentration at the notching area
  ii. Notching lessen the material toughness
  iii. The impression of notch can be analyze by comparing the energy loss into the notched specimen and un-notched specimen
  iv. The energy loss are lower for notched specimen
- The shape of break or fracture of the specimen occurred provides the information below:
  1. Brittle metals
     - a clean break with little deformation and little reduction in cross-sectional area at the point of fracture
     - the fractured surfaces will show a granular structure ductile metals
     - the fracture will be rough and fibrous (uncompleted fracture)
  2. Brittle polymers
     - a clean break showing smooth, glassy, fractured surfaces with some splintering
  3. Ductile polymers
     - no distinctive appearance to the fracture except for a considerable reduction in cross-sectional area and some tearing of the notch

4.6 The Effects of Temperature in Impact Test



- As example the low carbon steel are tough and ductile at the temperature of 150°.