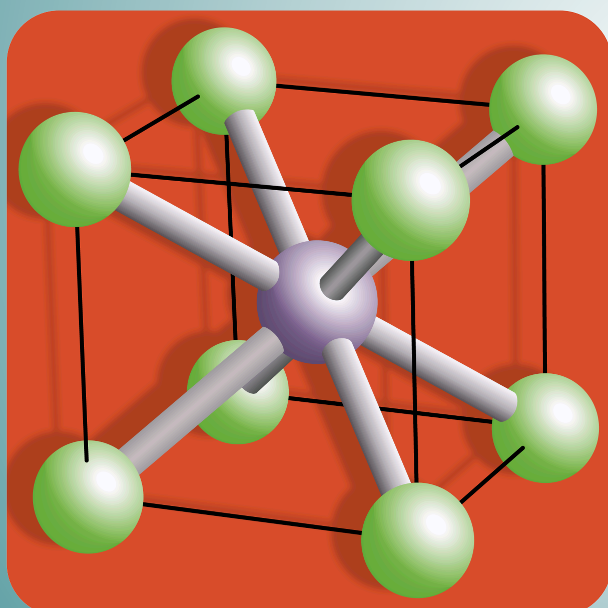
Materials

Topic 5. Other mechanical tests



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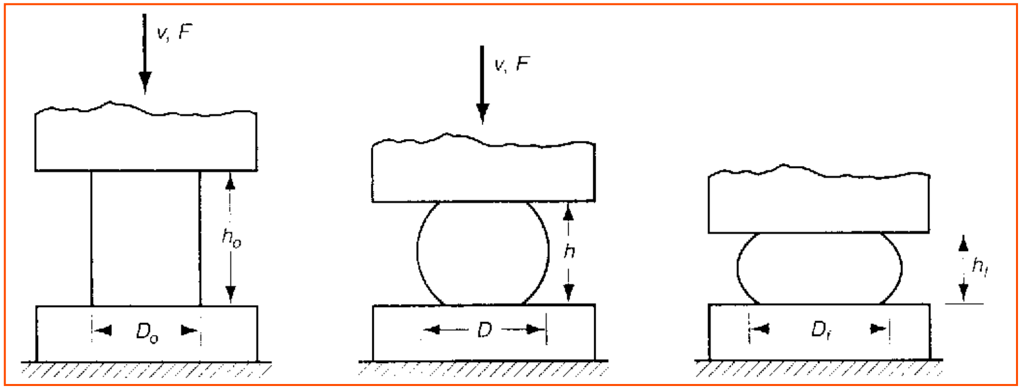
5.1. COMPRESSION TEST

- In compression tests, the shape of the specimen has great influence, so all of them are of geometries and normalized dimensions.

- The test is usually carried out by compressing a cylindrical or prismatic specimen between the two plates of a hydraulic press.

- Due to the friction between the specimen and the press plates, the lateral surface of the specimen is curved (barrel aspect), since the friction prevents the upper and lower surfaces of the specimen from expanding freely.



Compression strength

$$\sigma_C = \frac{F_{max}}{S_0}$$

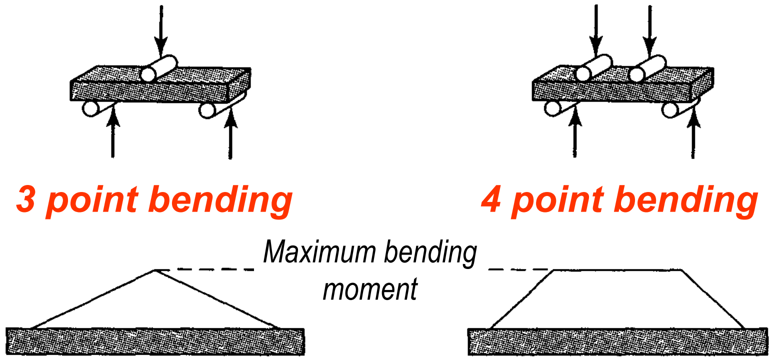
F_{max}: máximum compression force.

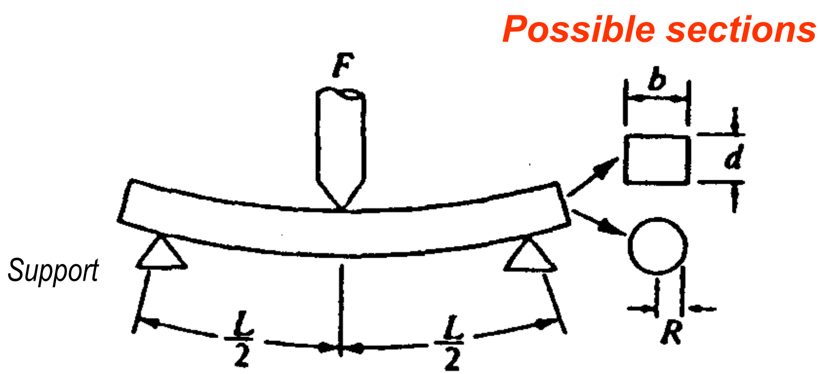
S_0: simple initial crosss section.

5.2. BENDING TEST

- **It is a test usually used in brittle materials (ceramics and glasses), although applicable to metallic materials. The load is applied vertically, in a point or two, giving rise to the in 3 or 4 point bending tests.**

- **The longitudinal stresses in the bending specimens are tensile in the lower support faces, and compression in the upper faces of the load application.**



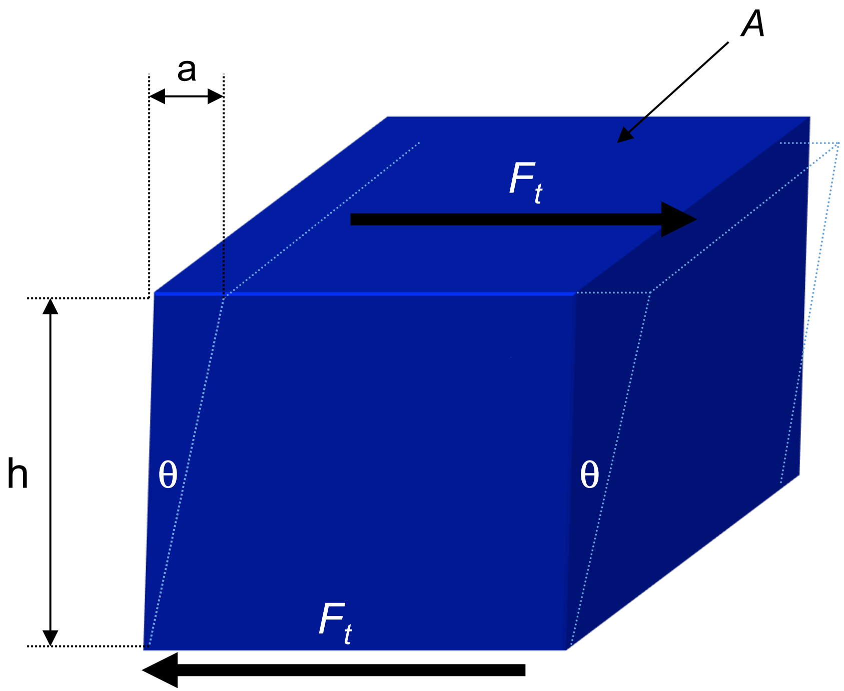


$$MOR = \frac{3 \cdot F \cdot L}{2 \cdot b \cdot d^2}$$

$$MOR = \frac{F \cdot L}{\pi \cdot R^3}$$

5.2. SHEAR TEST

- **A material can be subjected to tangential forces, also called shear forces, where the forces act parallel to a plane.**



$$\tau = \frac{F_t}{A}$$

τ: shear stress.

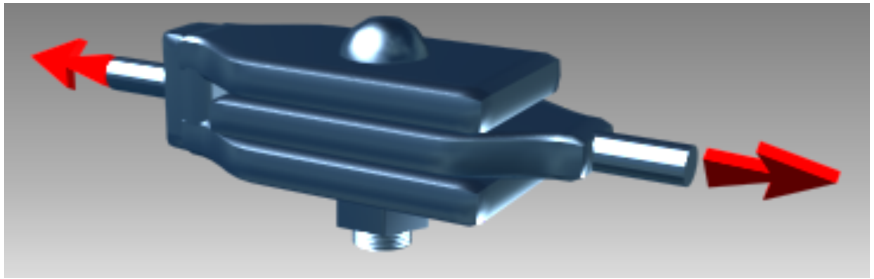
F_t: shear force.

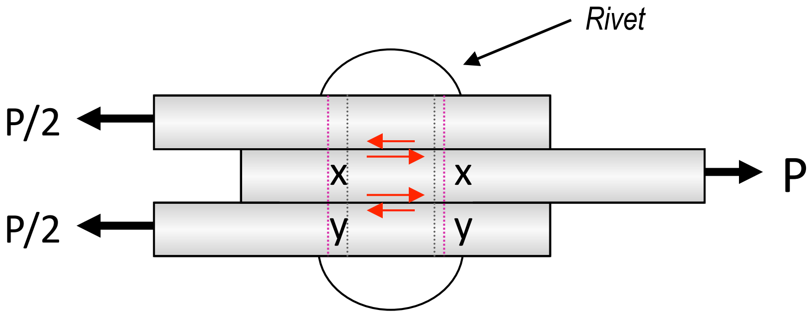
A: area over which the shear force acts.

$$\gamma = \frac{a}{h} = \tan\theta$$

γ: angular distortion by shear.

For small deformations: $\gamma \approx \theta$




Rivet
P/2
P/2
x
x
y
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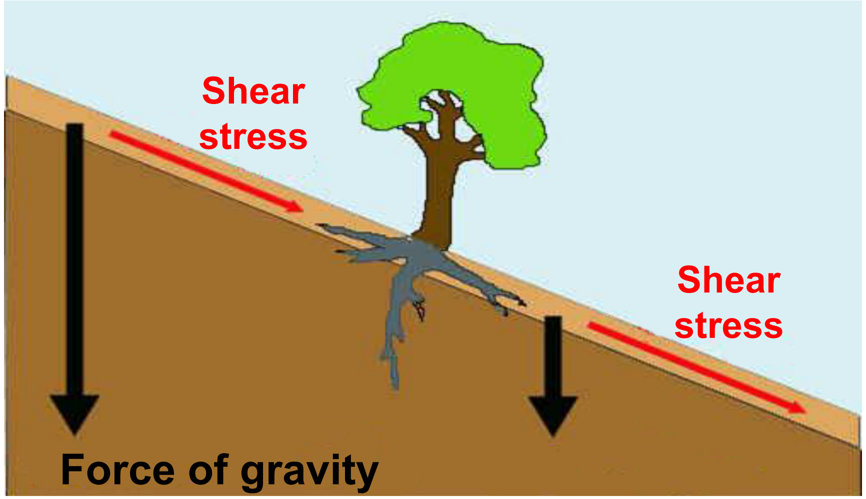
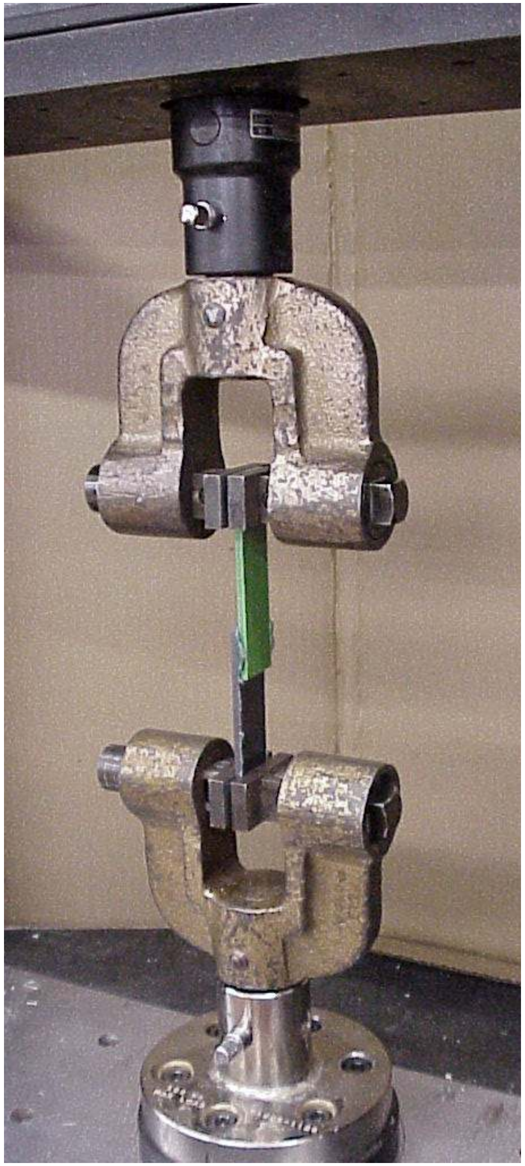

Shear
stress
Shear
stress
Force of gravity



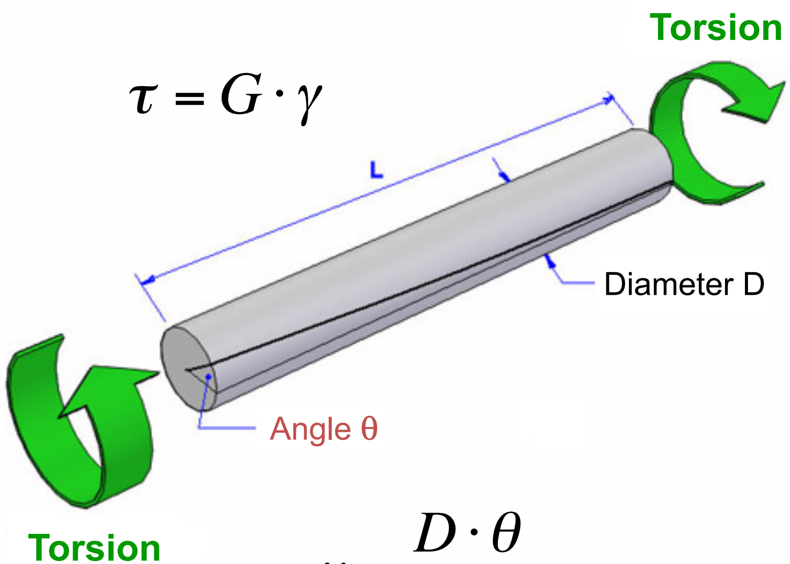
5.3. TORSION TEST

- **The test method used to determine the properties of materials against shear stresses is the torsion test.**

- **The ratio of the shear stress (τ) to the shear strain (γ) in the elastic range is known as the shear modulus (G).**

Hooke´s Law for shear

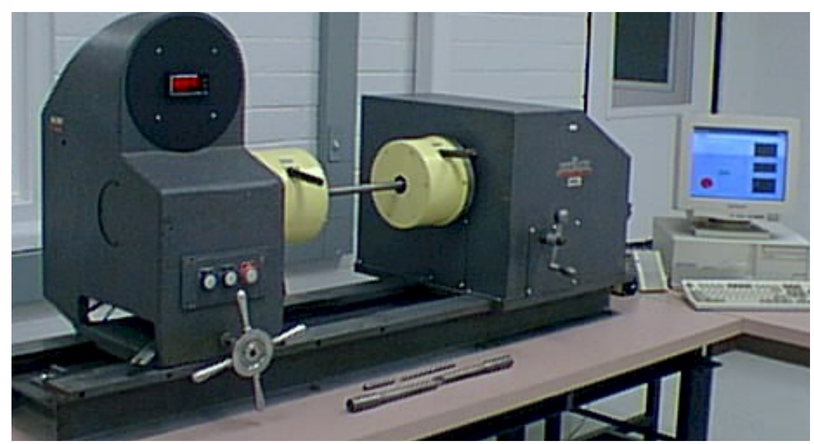
$$\tau = G \cdot \gamma$$



$$\tau = \frac{16 \cdot T}{\pi \cdot D^3}$$

T: torsión moment applied.

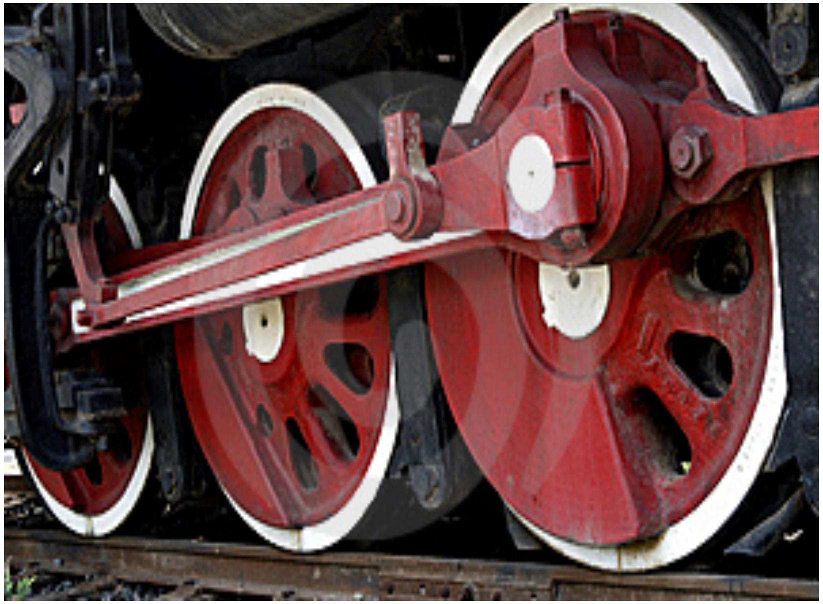
$$\gamma = \frac{D \cdot \theta}{2 \cdot L}$$



5.4. HARDNESS TEST

- **The hardness is the resistance of a material to be deformed on its surface against the dynamic action of another body. It is a measure of a material's resistance to localized plastic deformation (e.g., a small dent or a scratch).**

- **It is a property related to the resistant capacity of the material, also providing an indication of its resistance to scratching and wear or abrasion.**



- **Simple, fast, low cost and non-destructive test (ideal in quality control processes).**

- **It has different meanings depending on the applications:**

Resistance to indentation ➔ METALLURGY.
Elastic reaction of the material ➔ POLYMERS.
Scratch resistance ➔ MINERALOGY.
Cut resistance ➔ MACHINING.
Abrasion resistance ➔ LUBRICATION.
Mechanical resistance ➔ ING. DESIGN – CALCULATION.

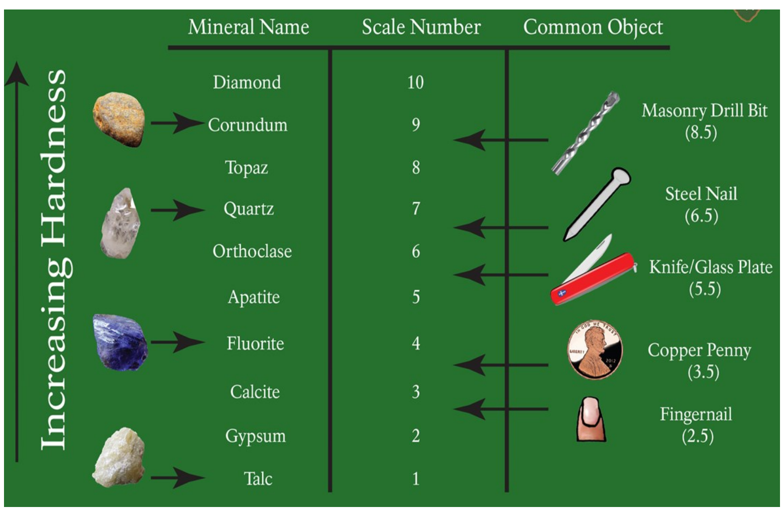
- **Several methods have been developed to determine this property.**

5.4.1. SCRATCH HARDNESS TESTING

- **They relate the hardness of a material and its resistance to being scratched.**

MOHS SCALE

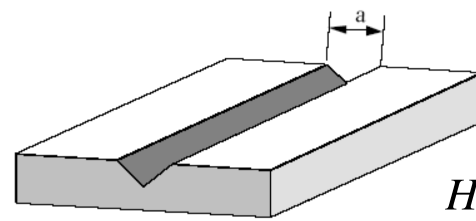
A qualitative hardness indexing scheme is the Mohs scale, which ranged from 1 on the soft end for talc to 10 for diamond. It is based on the fact that one body can be scratched by another that is harder. It is formed by 10 minerals arranged so that each of them is scratched by the one that follows.



Gray iron: 8 - 9 ; Steels: 6 - 8 ; Fe: 5

MARTENS TEST

The width (a) of the scratch (mm) produced in the material by a pyramidal diamond point (vertex angle of 90°) under constant load is measured.

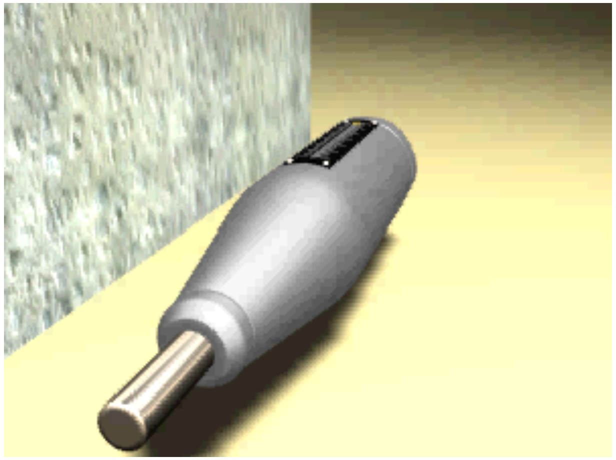


$$HM = \frac{10.000}{a^2}$$

Pb: 16.8 ; Cu: 37 ; Steel: 73 - 145

5.4.2. REBOUND HARDNESS TESTING

- It is measured with sclerometers that consist of a tube graduated from 0 to 100 (100 for maximum hardness). A projectile is propelled inside, whose shape depends on the sclerometer and the material to be tested, which impacts on the sample from a fixed position. The height of the rebound determines its hardness.

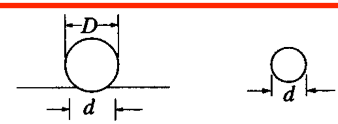
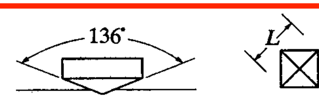
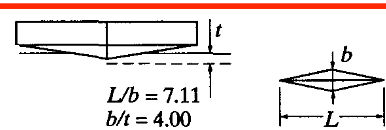
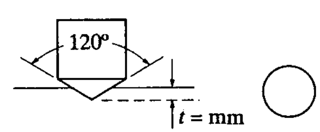
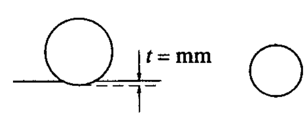


- A variety is the dynamic method that is based on the measurement of the drive (V_B) and rebound (V_A) speeds of the mobile body driven by a spring against the surface of the material to be tested.

$$HL = 1000\,\frac{V_B}{V_A}$$

5.4.3. INDENTATION HARDNESS TESTING

- In some quantitative hardness techniques a small indenter is forced into the surface of a material to be tested, under controlled conditions of load and rate of application. The depth or size of the resulting indentation is measured, which in turn is related to a hardness number; the softer the material, the larger and deeper is the indentation, and the lower the hardness index number.

Test	Indenter	Shape of Indentation: Side view	Shape of Indentation: Top view	Load	Formula for Hardness number
Brinell	10-mm sphere of steel or tungsten carbide			500 kg 1500 kg 3000 kg	$HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid			1-120 kg	$HV = \frac{1.854P}{L^2}$
Knoop	Diamond pyramid			25g-5kg	$HK = \frac{14.2P}{L^2}$
Rockwell				kg	
A C D	Diamond cone			60 150 100	HRA HRC HRD $= 100 - 500t$
B F G	Steel spheres 1/16” diameter			100 60 150	HRB HRF HRG $= 130 - 500t$
E	Steel spheres 1/8” diameter			100	HRE $= 130 - 500t$

Hardness tester

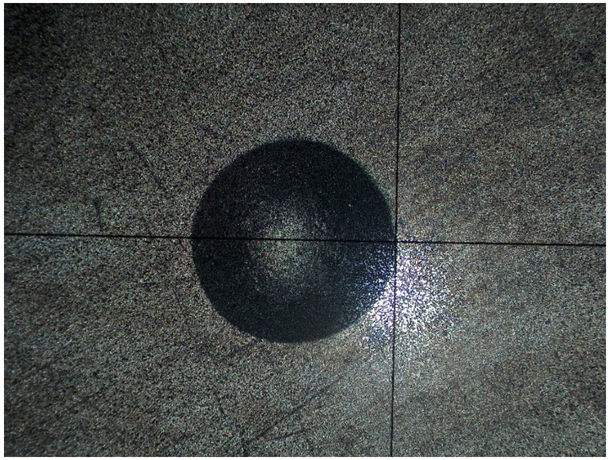
Indentators

Indentation

Printed footprints

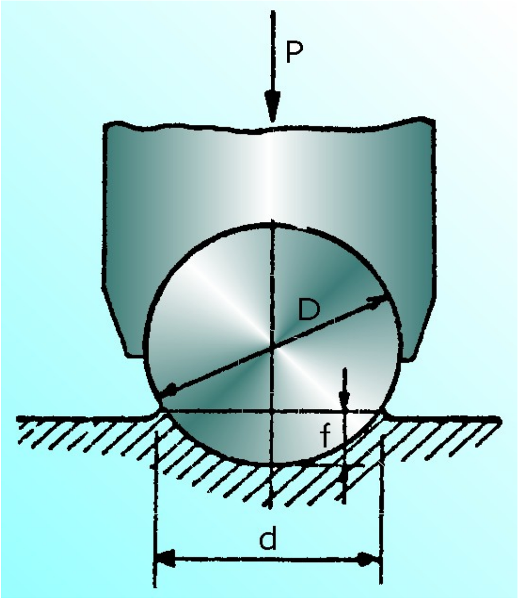
Profiles projector

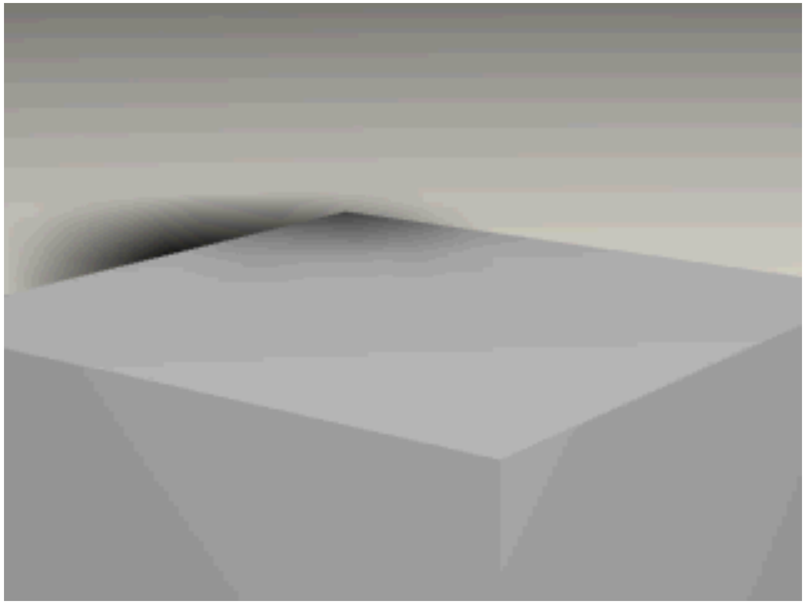
Footprint measurement



BRINELL METHOD

- The method consists of measuring the footprint of the spherical cap that produces a **hardened steel ball** compressed on a flat and smooth surface of the body to be tested until reaching the expected load and maintained for a certain time. The hardness is expressed as the quotient between the load applied in kg and the surface of the cap measured, in mm^2.

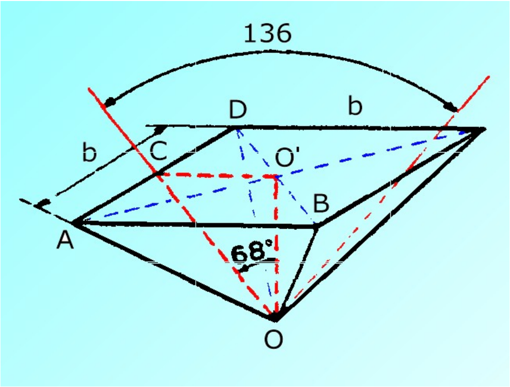


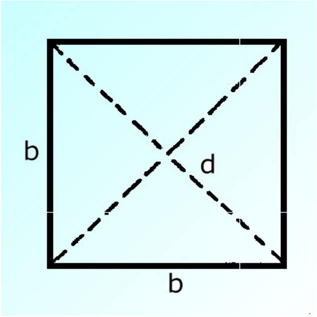


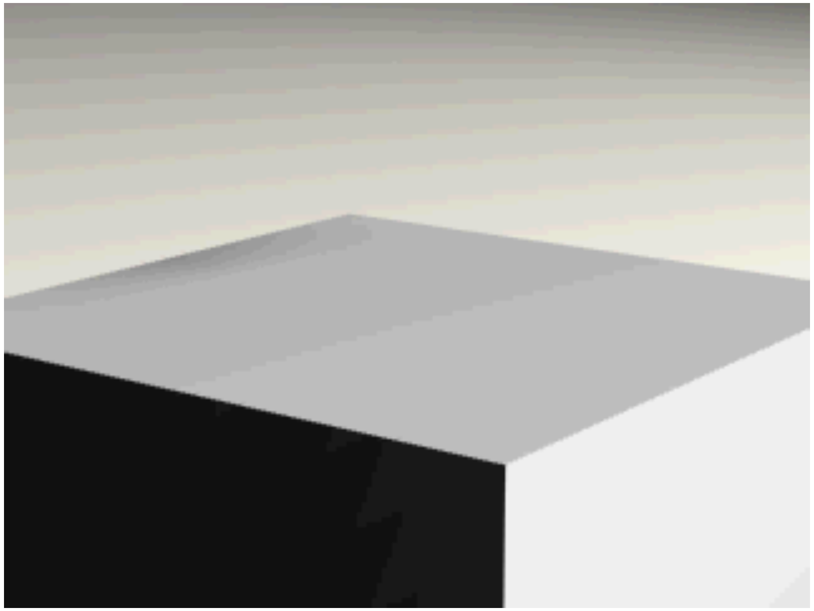
$$HB = \frac{P}{S} = \frac{2P}{\pi D\,(D - \sqrt{D^2 - d^2})}$$

VICKERS METHOD

- The indenter is a diamond pyramid with a square base, the opposite sides forming an angle of 136º at the vertex. The hardness is expressed as the quotient between the load, in kg and the surface of the projected fingerprint, in mm².





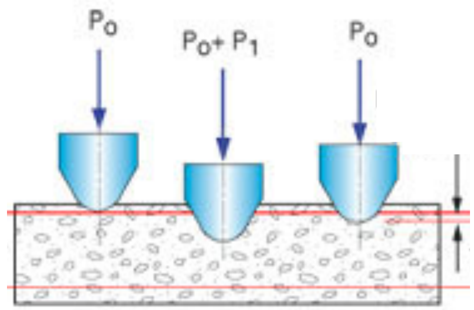


$$HV = \frac{P}{S} = \frac{1{,}854 \cdot P}{d^2}$$

ROCKWELL METHOD

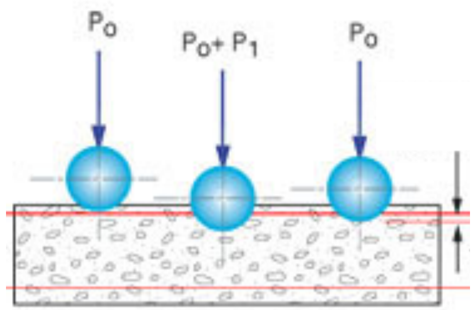
- The hardness is expressed according to the depth that the footprint reaches. There are 7 test variants, using cones and balls as indents.
- The indenter is pressed against the surface in three steps:
  - A preload (P_0) is applied, measuring the depth reached (e_0).
  - The test load is increased by a value P_1.
  - The load P_1 is removed, keeping P_0. The permanent depth (e_f) is measured.
- The difference in the depths ($t = e_f - e_0$) is a measure of the hardness of the material.

Rockwell C



$$HRC = 100 - 500 \cdot t$$

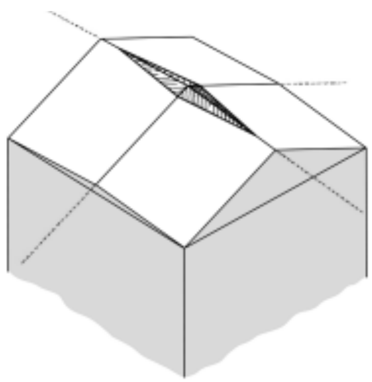
Rockwell B

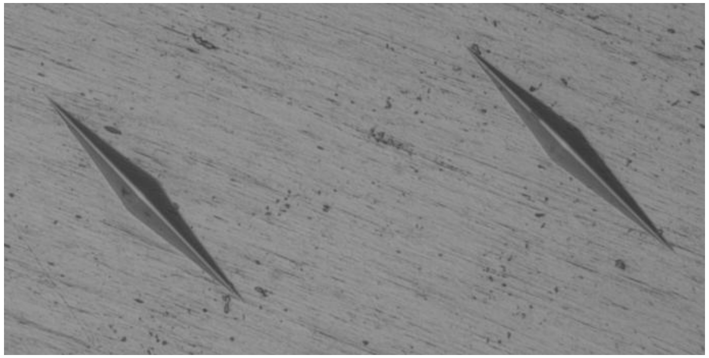


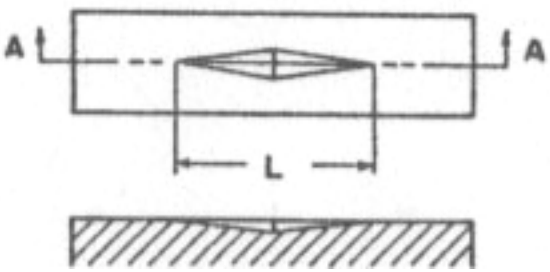
$$HRB = 130 - 500 \cdot t$$

KNOOP METHOD

- It is based on a diamond indenter in the shape of an elongated pyramid that presses a load P against the surface of the specimen and measures the greater diagonal (L) of the footprint after removing the load.
- It is suitable for small or thin specimens, and for brittle materials (ceramics and glass).
- It is also used in metal coatings, and even in grains and alloy phases.



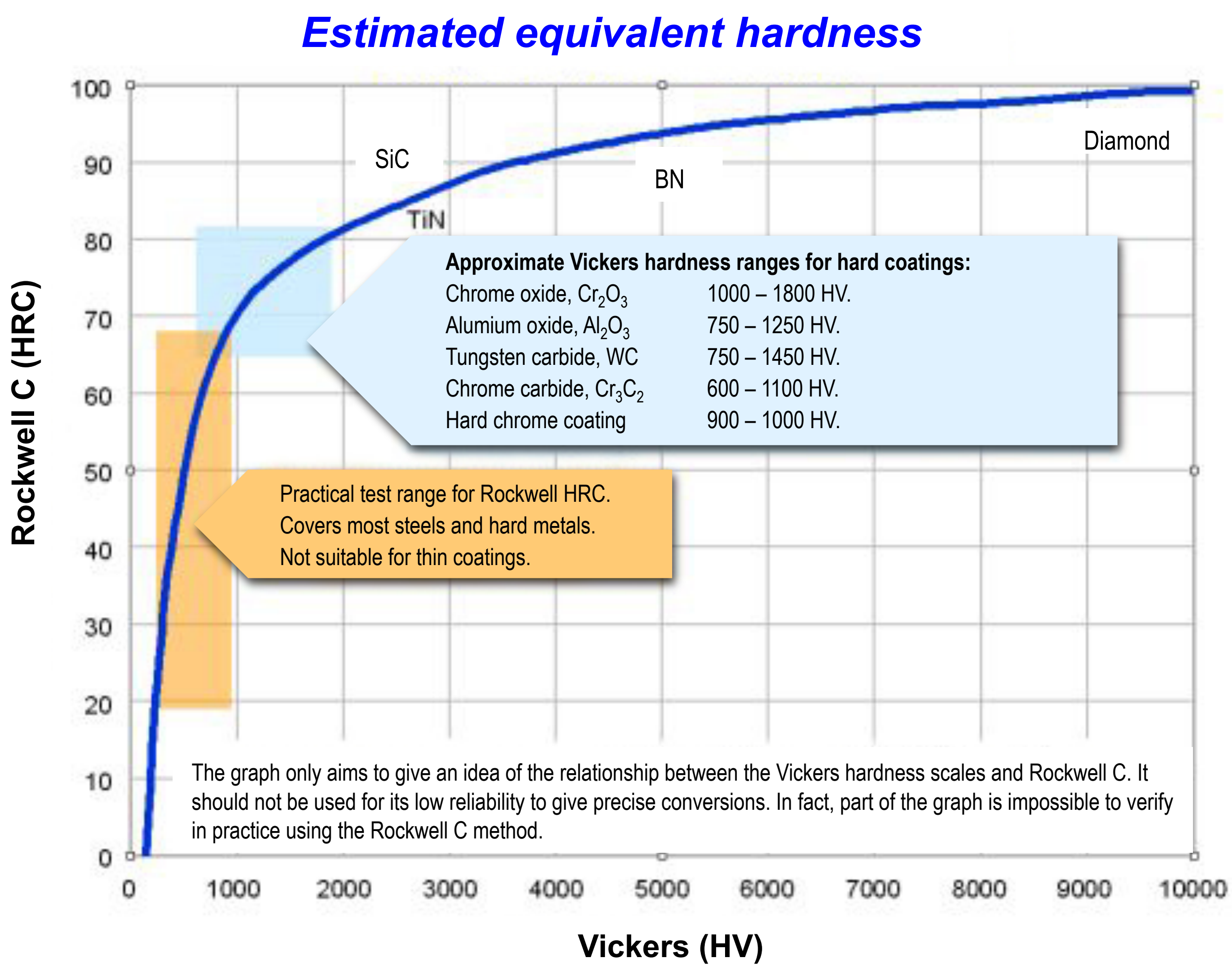


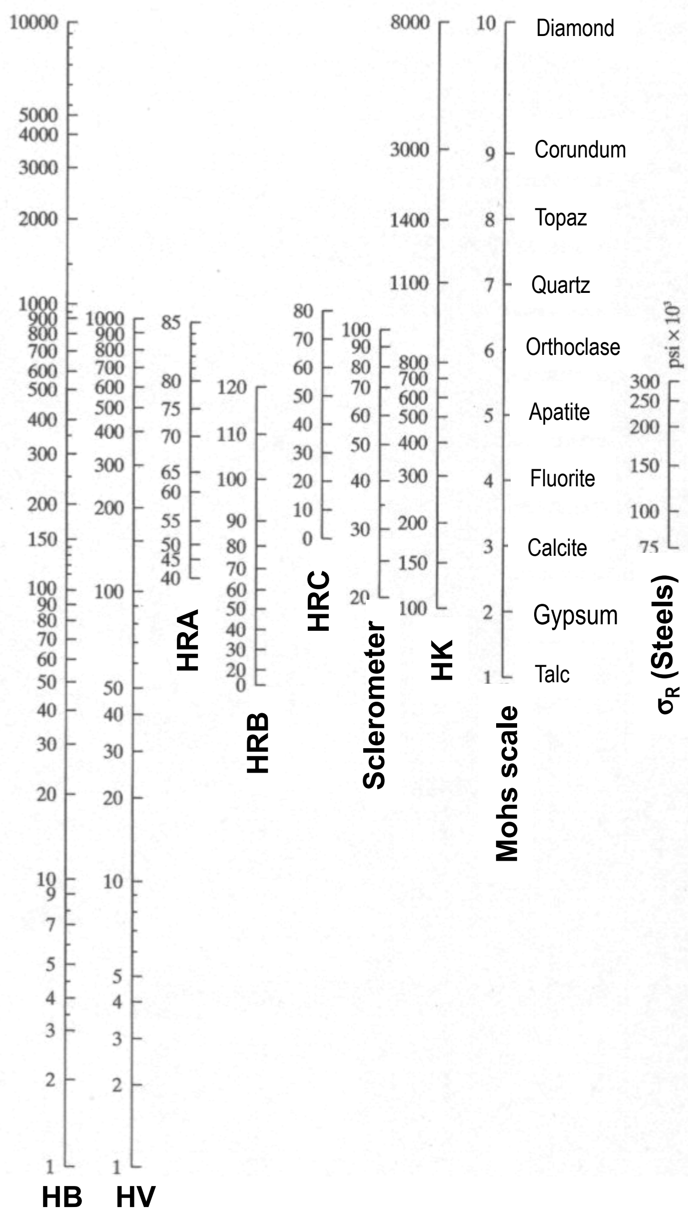


$$HK = 14{,}2 \cdot \frac{P}{L^2}$$

5.4.4. CONVERSION OF SCALES

- **The hardness values on different scales are interrelated approximately.**





Diamond

Boron nitride

Boron carbide

Titanium carbide

Tungsten carbide

Cementite
Hard Chrome
Martensite
Tool steels
Glass
0.5%%C Steel
Titanium
Gray iron
Ductile iron
Brass
Nickel
Iron

Bakelite
Zinc, Gold, Magnesium

Silver
Polystyrene
Aluminium
Vinyl resin
Graphite

Tin
Lead

5.4.5. HARDNESS – RESISTANCE RELATIONSHIP

- Relationship of the resistance with the methods for the measurement of the hardness.

- There is an empirical relationship between mechanical tensile strength (σ_R) and Brinell hardness (HB) for steels:

$$\boxed{\sigma_R = 500\ (HB)}$$

σ_R in psi, HB in kg/mm^2

(1 psi = 0.00689 MPa)