
بسم الله الرحمن الرحيم

Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

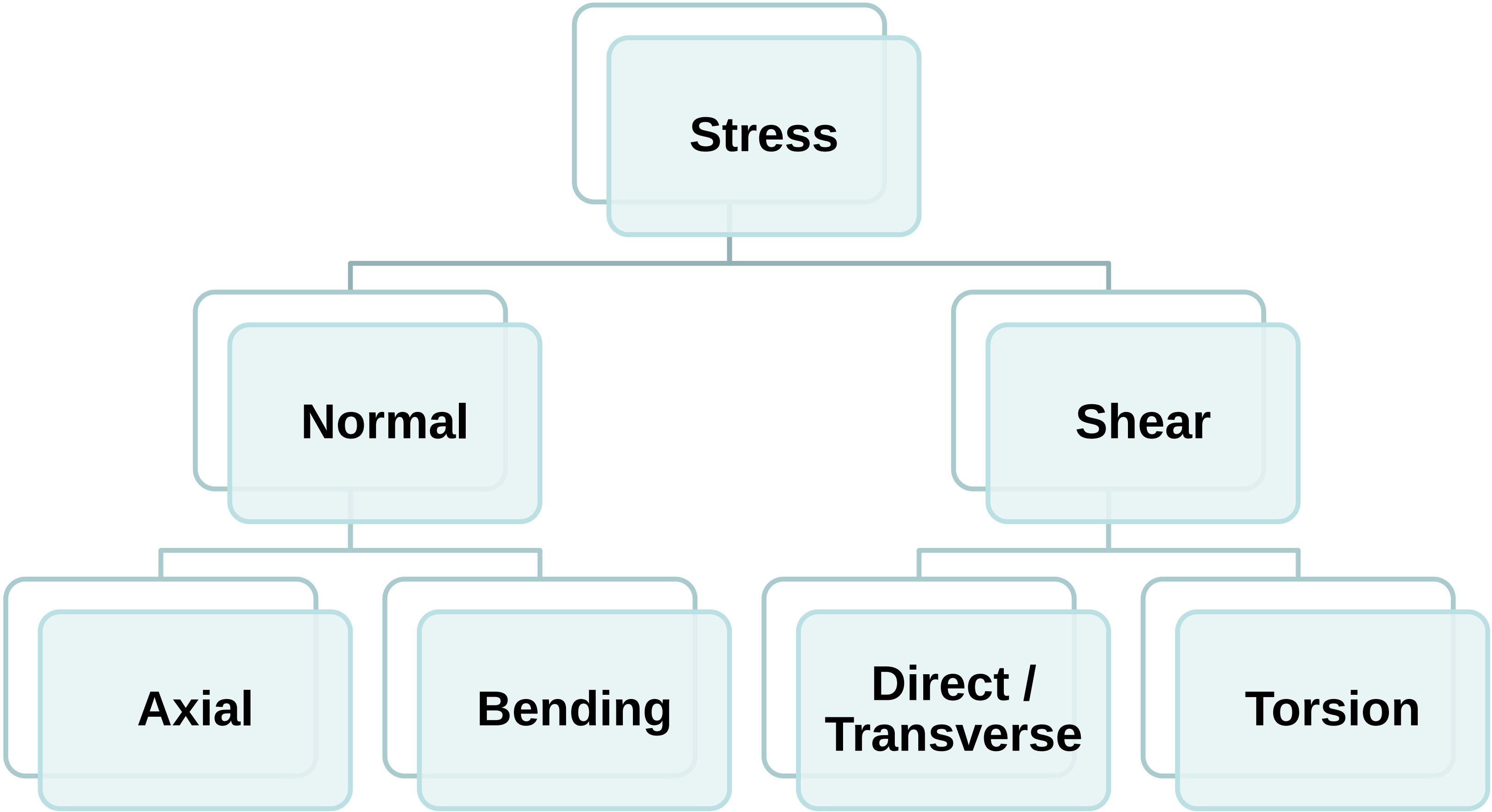
Transverse, torsion & hardness testing

Dr. Mahmoud Khedr

Outline

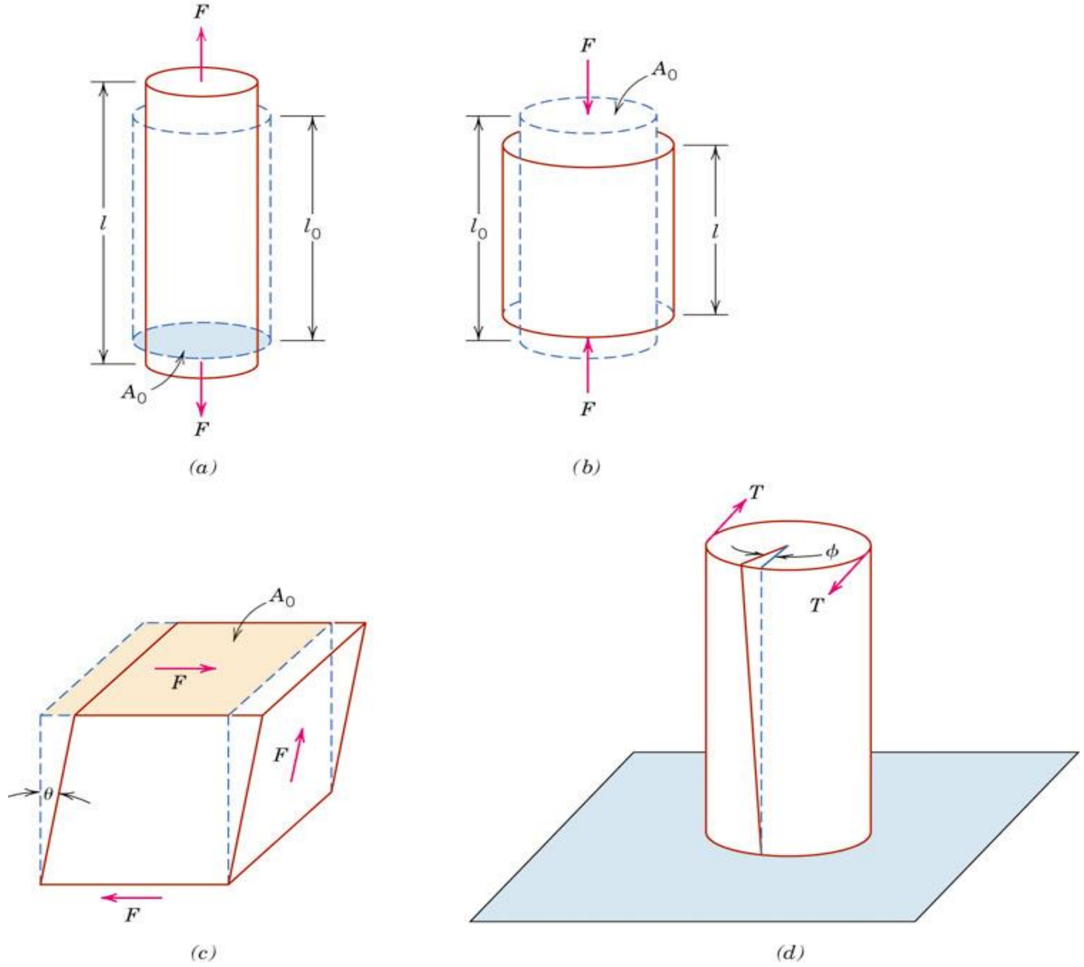
- Transverse stress.
- Direct & Punching Shear stresses.
- Torsion test.
- Stress distribution & mode of failure.
- The mechanical properties after torsion.
- Hardness testing machine.
- Brinell Hardness.
- Vickers Hardness.
- Rockwell Hardness.

Stresses types



- Stress
  - Normal
    - Axial
    - Bending
  - Shear
    - Direct / Transverse
    - Torsion

Loading types



Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1^{st} year

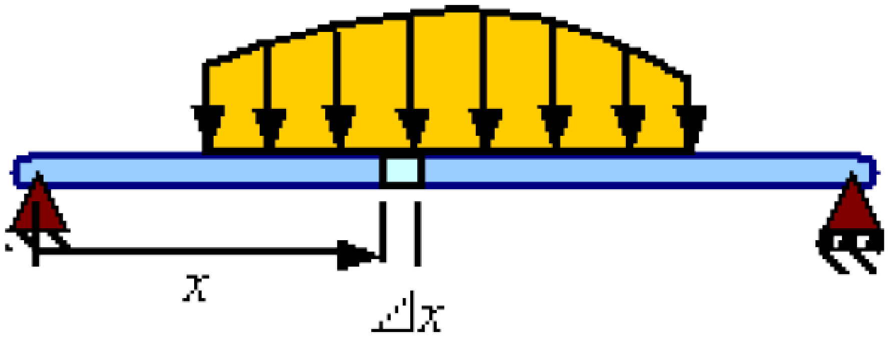
20.04.2019 – Week 11

Transverse shear Stress

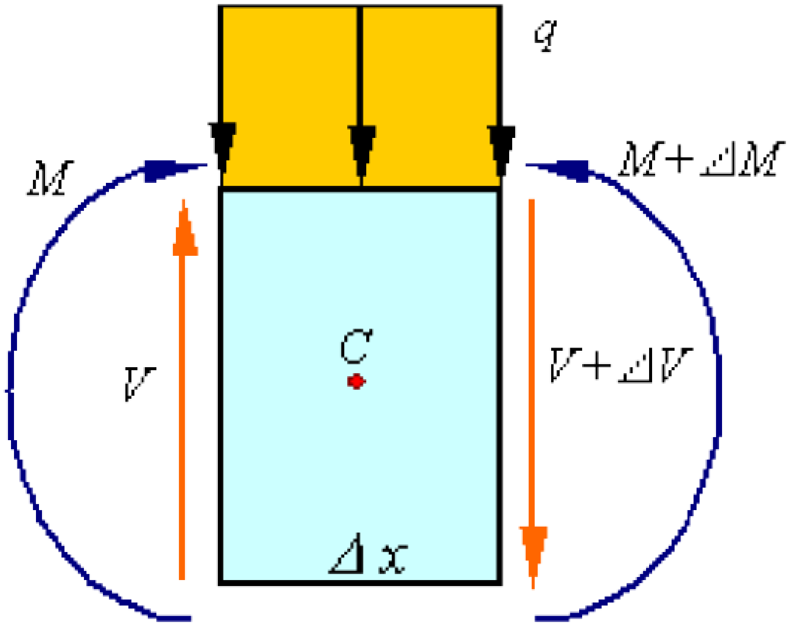
Dr. Mahmoud Khedr

Flexure Shear

Flexure shear is produced due to the action of shearing force accompanying the bending of the beams under transverse loads.

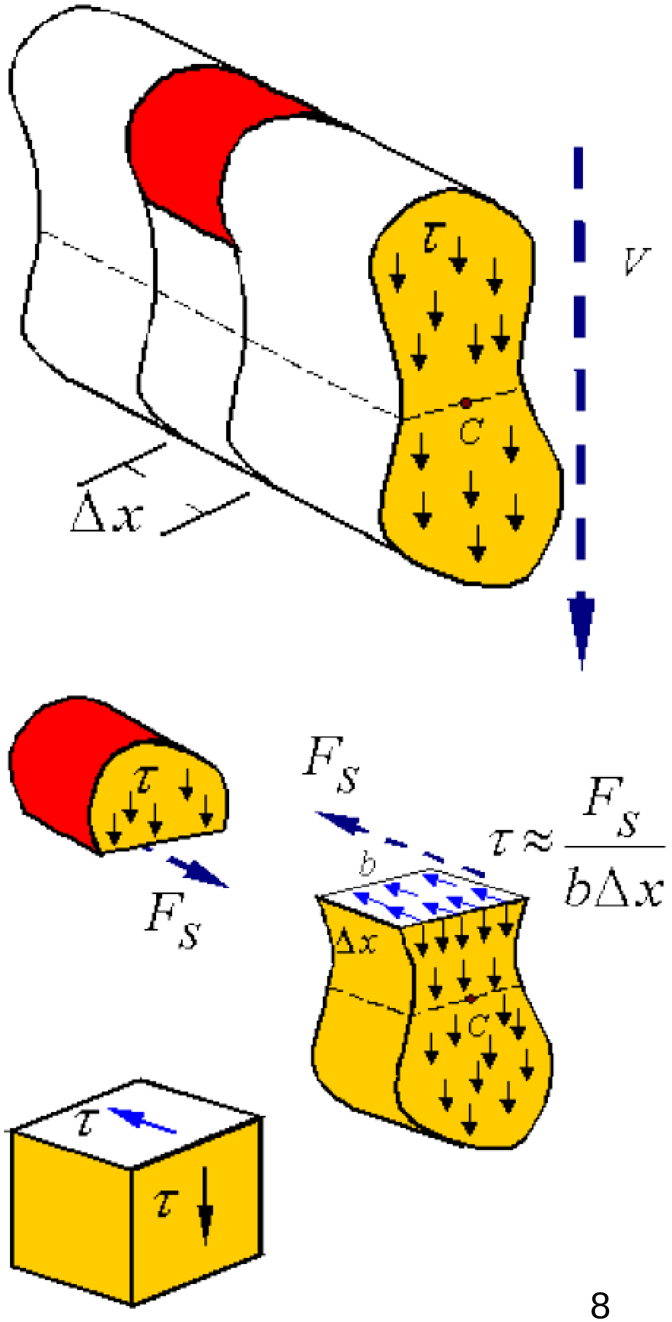


Consider a segment of the beam shown. The shear load on the vertical surfaces are generated by shear stress that can be calculated by the following process.



Flexure Shear Stresses

To calculate the shear stress τ generated from the shear load V consider removing the segment of the beam shown in red.



By symmetry of stress, shear stresses on the cross section results in equal shear stresses on the plane perpendicular to the cross section as shown. This shear stress results in a shear load F_s.

Flexure Shear Stresses

Therefore, equilibrium in the axial direction for this segment is written as:

$$F_s + \int_{A^*} [-\frac{(M + \Delta M)y}{I}]dA - \int_{A^*} [-\frac{My}{I}]dA = 0$$

$$\Rightarrow \quad F_s = \frac{\Delta M}{I} \int_{A^*} y dA$$

The integral in this expression is the first moment of the area A^* about the neutral axis. This first moment will be denoted by Q so that:

$$Q = \int_{A^*} y dA$$

Flexure Shear Stresses

The shear stress can now be calculated from the shear load by dividing it by the area it is applied on to get

$$\tau = \frac{F_s}{b\Delta x} = \frac{\Delta M}{\Delta x}\frac{Q}{Ib}$$

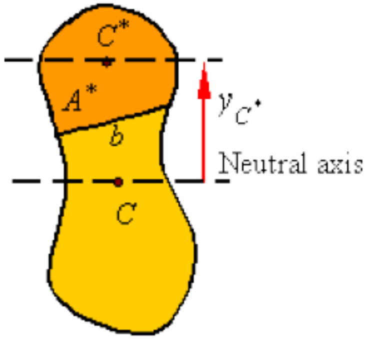
Taking the limit as $\Delta x \to 0$ gives $\tau = \frac{VQ}{Ib}$

where we note that $\frac{dM}{dx} = V$

Calculating the first moment of the area Q

The first moment of the area can be calculated from the relation

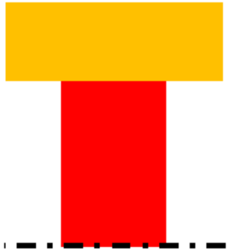
$$Q = A^{*} y_{C^{*}}$$



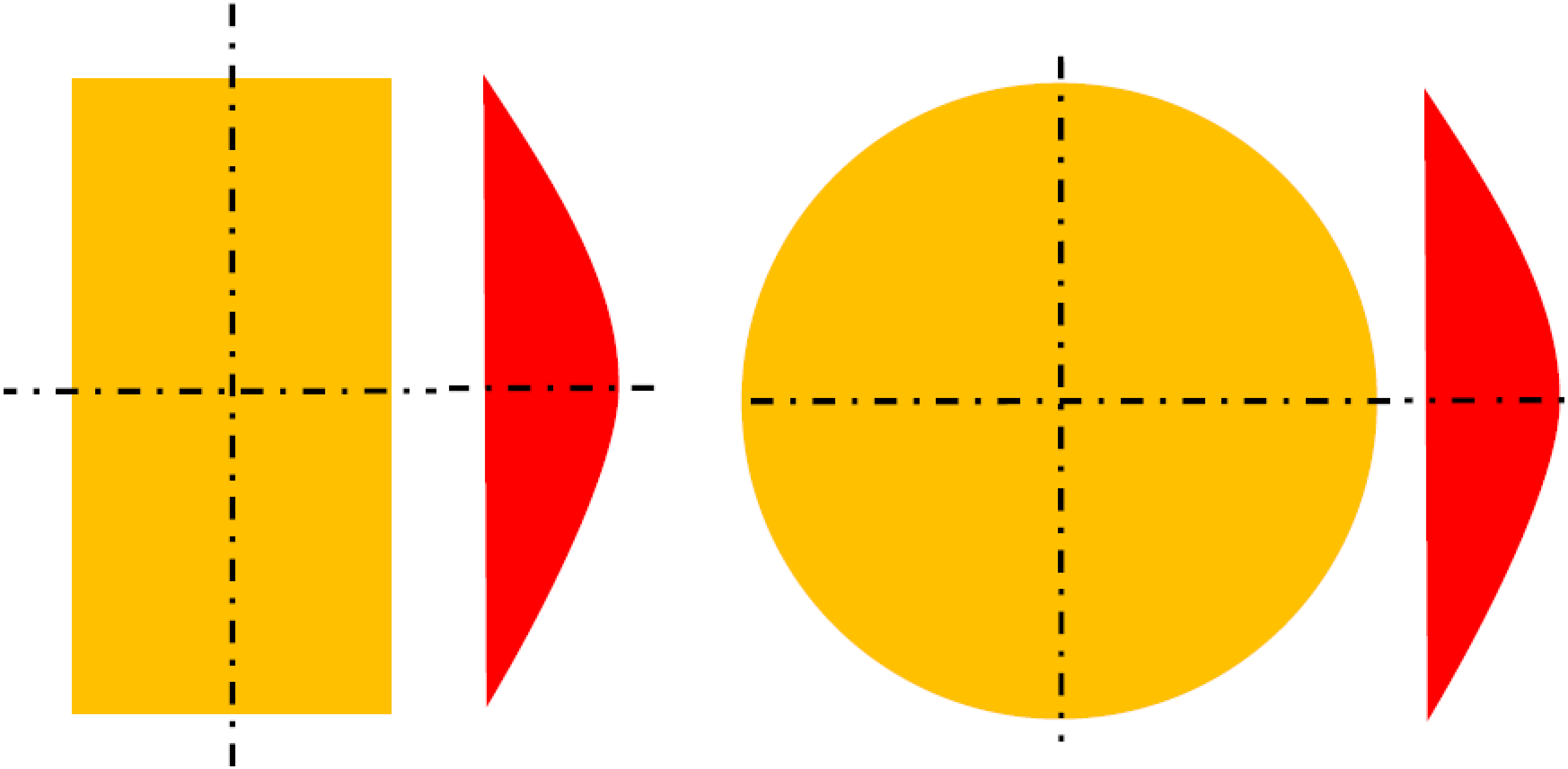
where A^{*} is the area of the part of the cross section that is considered, is the vertical distance from the centroid of the cross section y_c to the centroid of A^{*}.

For composite areas, the first moment of area can be calculated for each part and then added together. The equation for Q in this case is

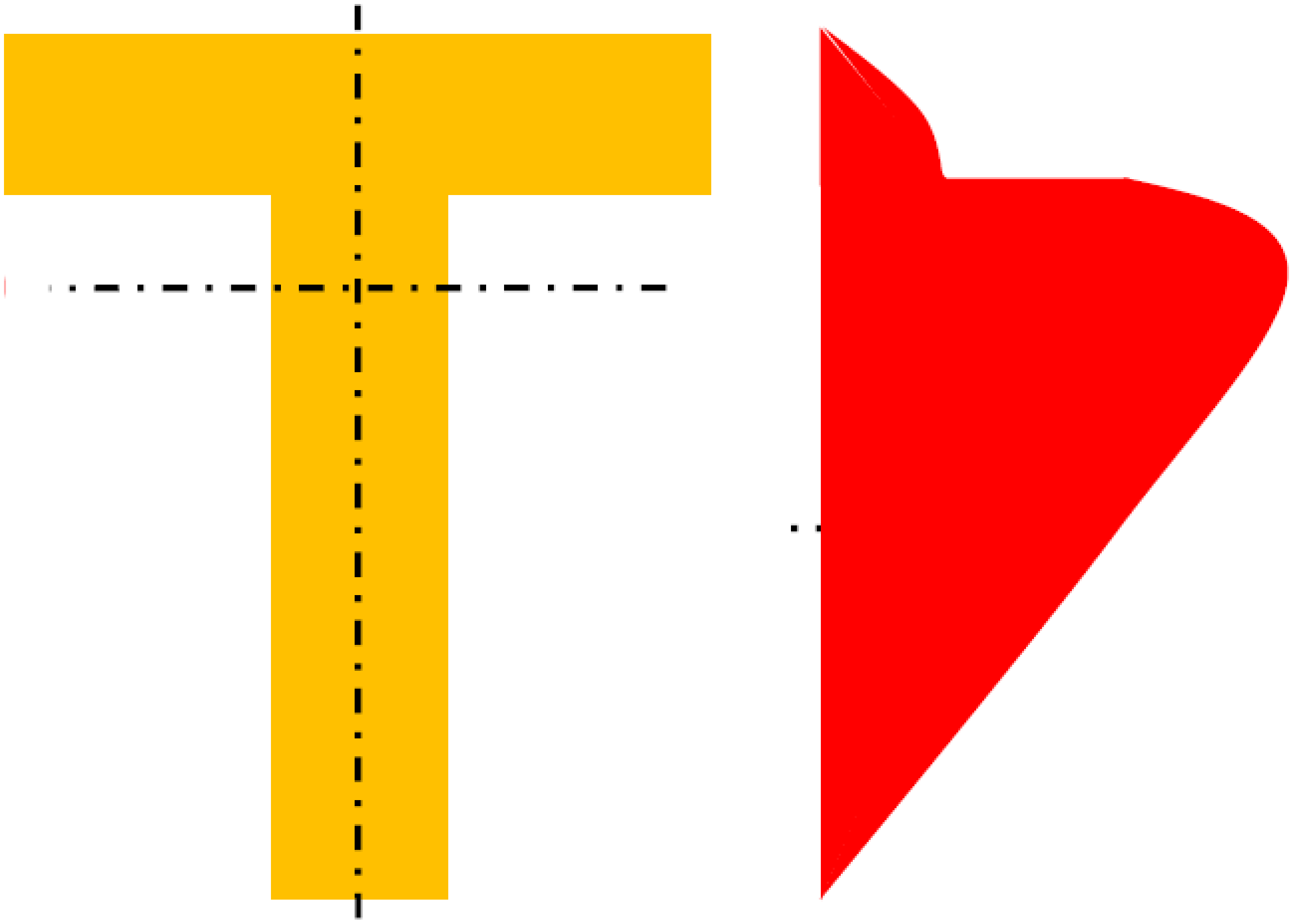
$$Q = \sum_{i=1}^{n} A_i^{*} y_{c_i^{*}}$$



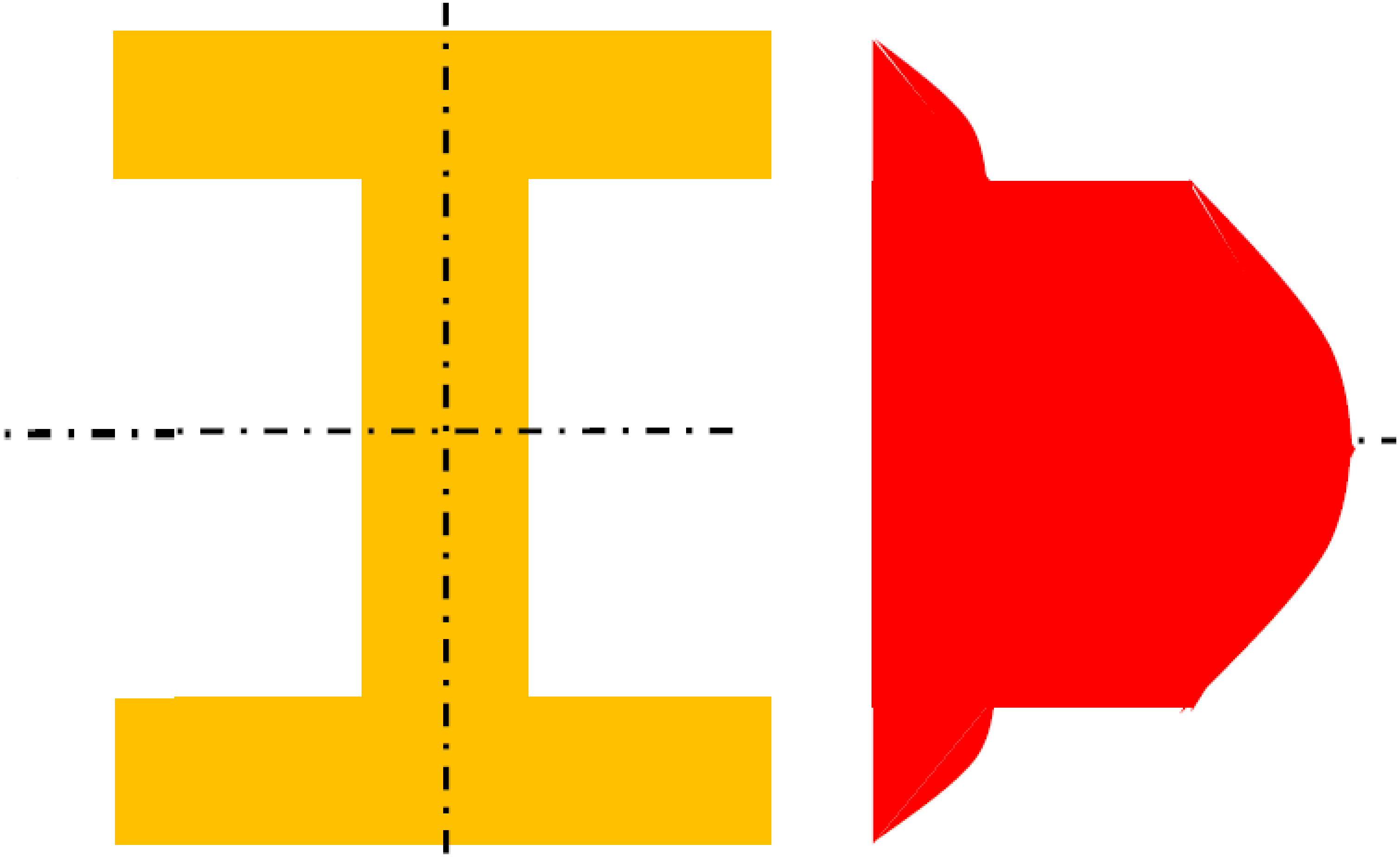
Distribution of flexure shear stresses in standard sections



Distribution of flexure shear stresses in standard sections



Distribution of flexure shear stresses in standard sections



Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

Single, Double & Punching shear

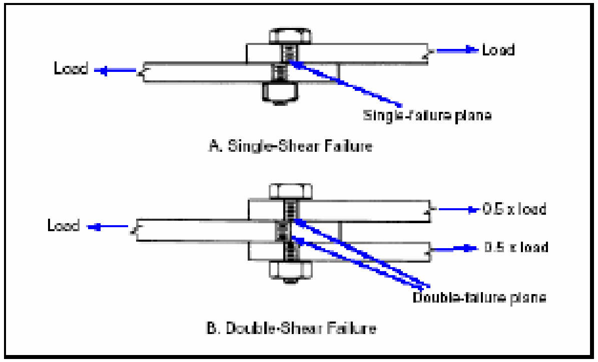
Dr. Mahmoud Khedr

Direct Shear stress

Types of Direct Shear

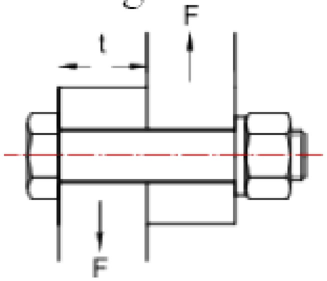
Direct Shear is called single shear if one critical single cross section is subjected to shearing force.

Direct Shear is called double shear if two critical cross sections are subjected to shearing force.



Single Shear

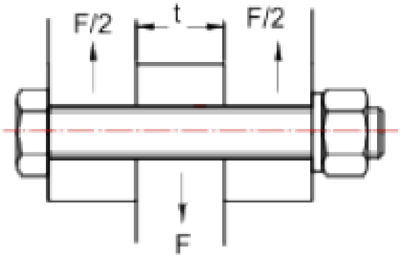
$\textit{Shear Stress} = 4\ .\ F / \pi .\ d^2$



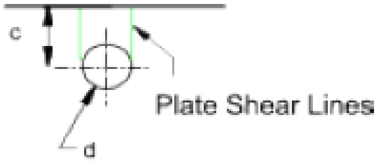
Single Shear

Double Shear

$\textit{Shear Stress} = 2\ .\ F / \pi .\ d^2$



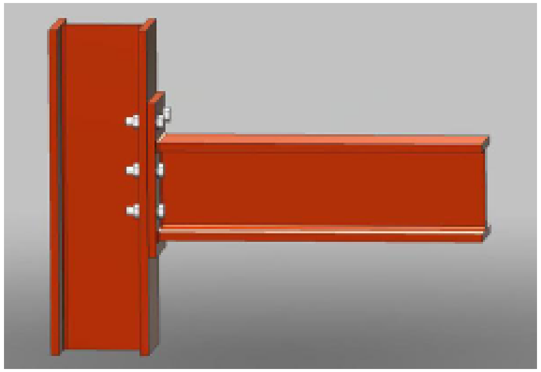
Double Shear



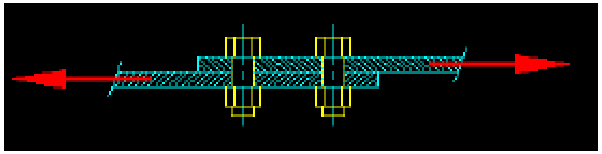
Direct Shear stress

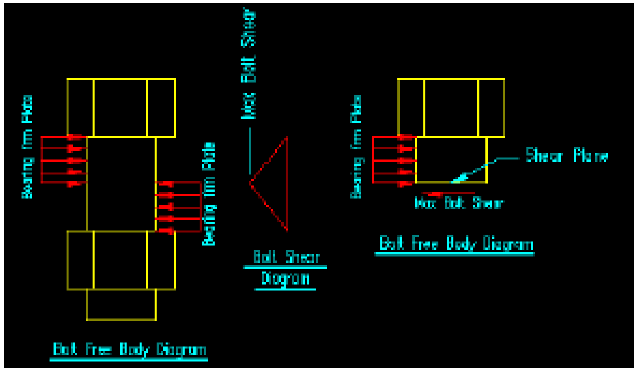
Bolted Connections

Bolted connections are made with nuts and bolts. They can are either be single or double shear connections.



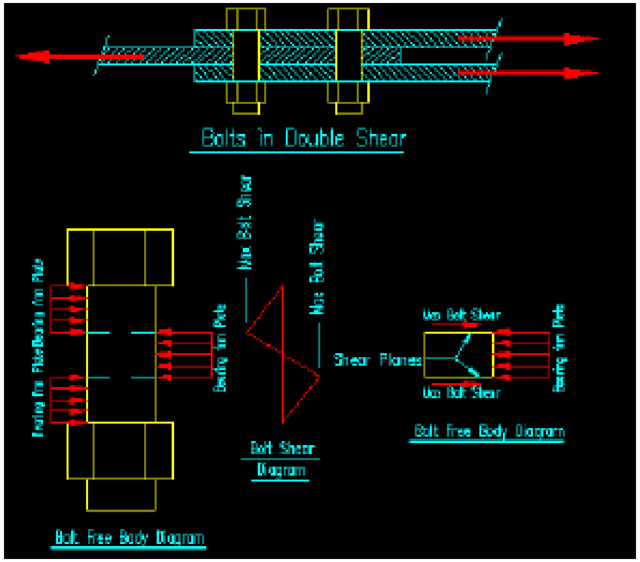
Single shear





Shear Stress $= 4 \,.\, F / \pi .\, d^{2}$

Double shear



Shear Stress $= 2 \,.\, F / \pi .\, d^{2}$

Direct Shear stress

Mode of Failure for Direct Shear

Direct shear tests are carried out on metals used in making nuts and bolts where the bolts are going to be subjected to direct shear during the normal use.

Failure mode consists of two portions:

The first portion has a ***smooth surface*** due to the sliding of planes due to the shearing force.

The second portion is rough due to the ***sudden failure*** of the cross section under the action of the concentrated stresses.

Punching Shear

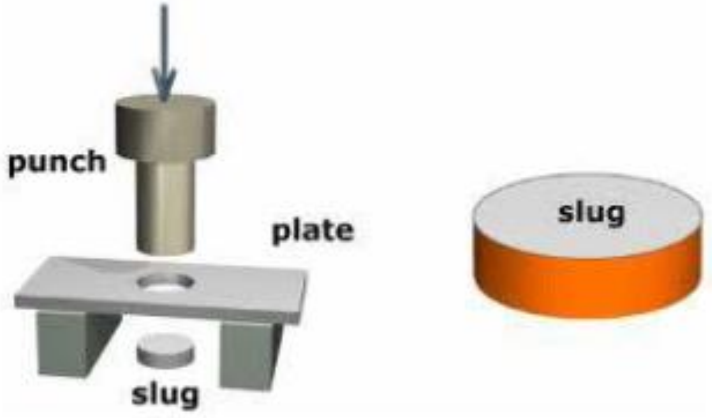
Punching Shear occurs when a hole is punched under static load in a thin plate producing a hole of diameter Φ and a metal slug.

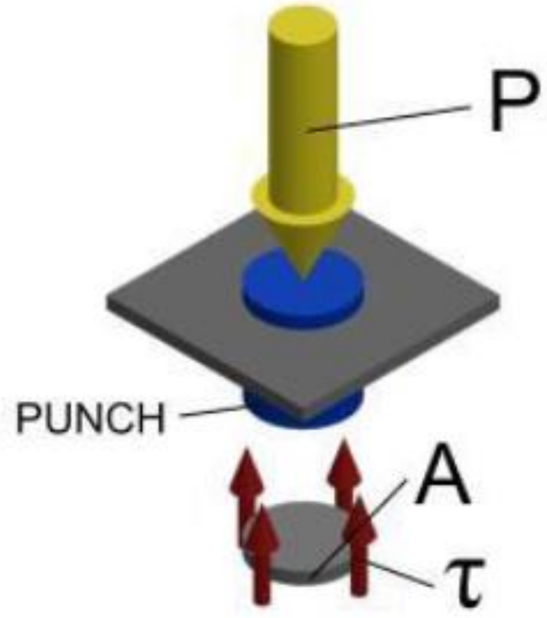
Punching shear stress is calculated as

$$\tau = P / (\pi . \Phi . t)$$

where;
τ = punching shear stress
Φ = hole diameter
t = plate thickness

Punching shear is used in the steel structures industry for plates thinner than 12mm.





Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

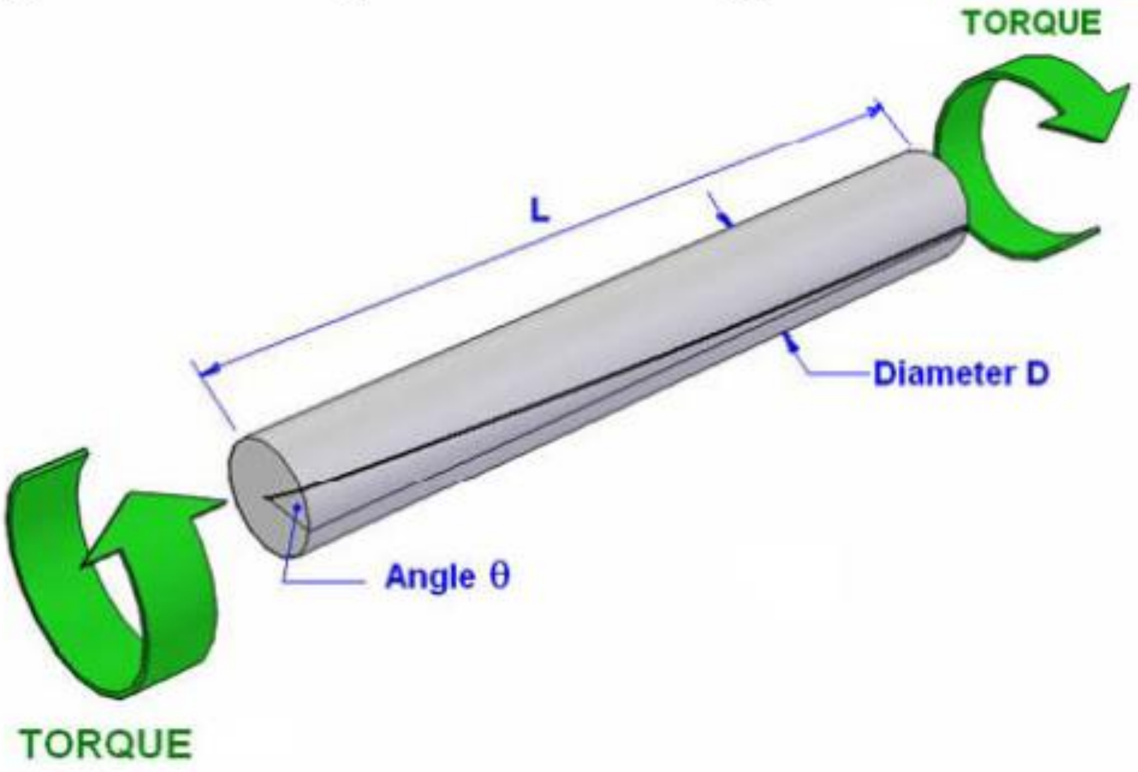
Torsion test

Dr. Mahmoud Khedr

Introduction

Torsion is an important type of loading that can produce pure shear stresses in engineering applications. Under only torsion moment, pure shear stresses are produced while the stiffness under shear stress is called the Modulus of rigidity G.(MPa) It is also called Shear Modulus.

Torsion may produce a sliding state due to the application of ***twisting moment (Torque)***

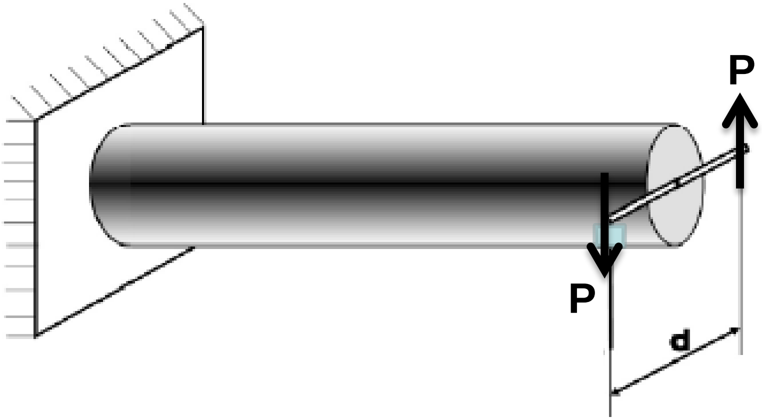


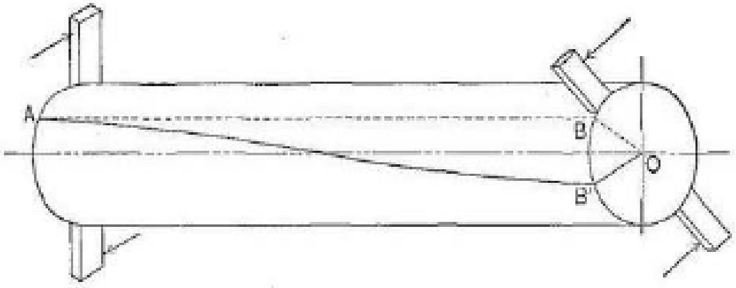
Basic Theory of Torsion

1. *We will derive the theory of torsion of circular shafts.*
2. *An example of torsion loading is shown here. In this example we load the shaft by two equal and opposite forces acting on a bar perpendicular to the shaft axis.*
3. *The moment generated by these forces is called a* ***twisting moment*** *. The magnitude of the moment due to this couple is given by*

$$T = P * d$$

*where, P is the applied force and d is the distance between the lines of action of the forces. This twisting moment is also called the '****Torque****'.*



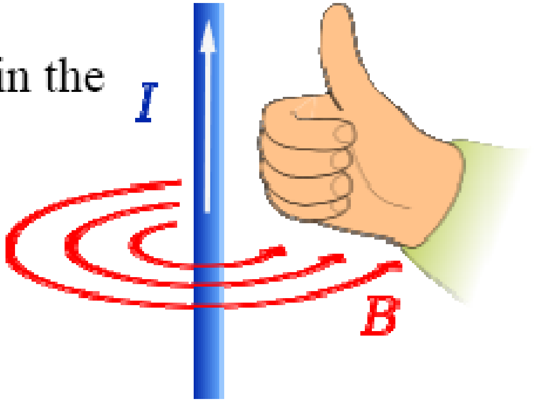


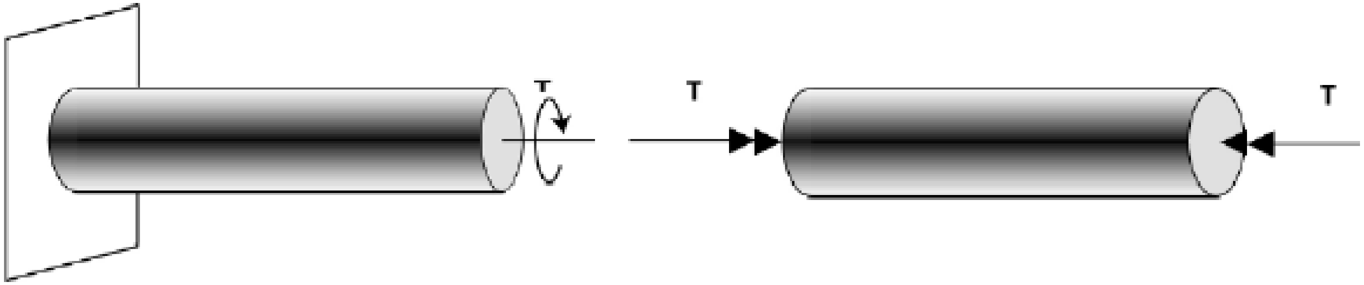
Alternate representations of torque

Two alternate ways of depicting torque are shown here.

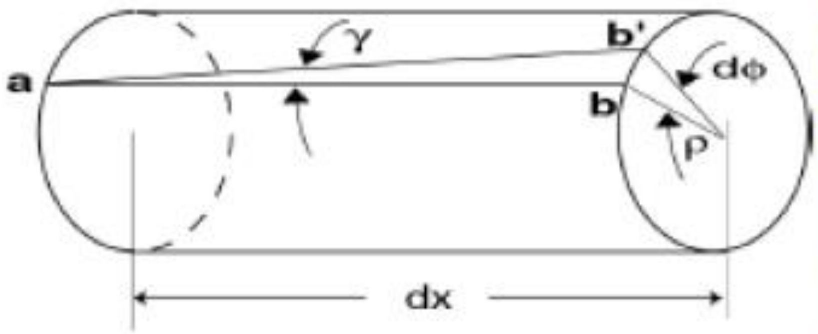
1. In the left-hand figure the torque is shown as a loop with an arrow depicting its direction.
2. In the right-hand figure the torque is shown as a vector moment. The direction of the moment is parallel to the shaft. The sign of the moment, can be understood using the right hand rule.

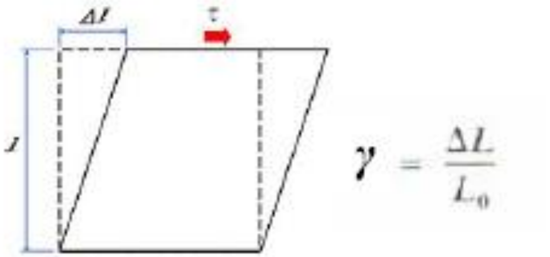
The ***right hand rule*** is that "if you rotate your right hand in the direction of the applied torque, then your thumb points in the direction of the vector indicated by two arrowheads in the right-hand figure.





Deformation due to torsion





$$\gamma = \frac{\Delta L}{L_0}$$

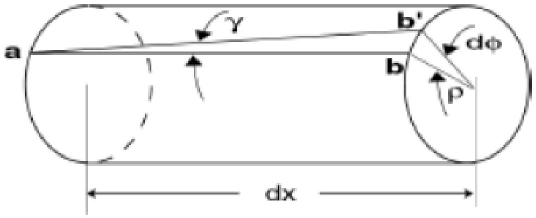
- ρ is the radial distance to any point.
- ϕ is the angle of twist in radians
- γ is the shear strain.
- The horizontal line ab moves to ab'
- The shear strain is $\gamma = \dfrac{bb'}{ab}$
- From geometry $\gamma dx = \rho d\phi$
- So the strain $\gamma = \rho \dfrac{d\phi}{dx}$

- Hence twist and strain are related as

$$\gamma = \frac{\rho\phi}{L}$$

Note: Relations here are based solely on geometry and so they are valid for circular shaft of any material, linear or non-linear, elastic or non-elastic.

Deformation due to torsion



The theory of torsion of circular shafts.

Look at a small section of length dx of a circular shaft under torsion. During twisting, one end of the shaft will rotate about the longitudinal axis with respect to the other end. The magnitude of this rotation is measured in terms of the angle (in radians) by which one end rotates relative to the other. This is called the *'Angle of Twist'.*

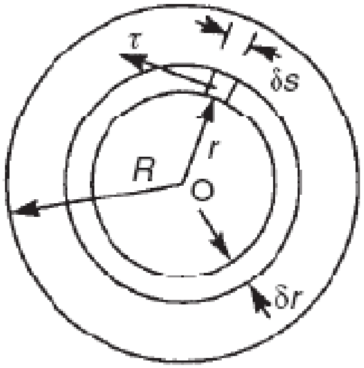
It can be seen that the line AB, which was initially horizontal, rotates through an angle γ, and moves to the line AB'. Here d φ is the "*angle of twist*".

The "*shear strain*", gamma is the angle between AB and AB'. It is found by the distance BB' divided by the distance AB. Using geometry, the arc length: $\gamma = \rho\, d\phi / dx$.

Let's assume that we are dealing with a shaft of uniform cross section and materials, thus the total twist, φ *over a length L is simply* $\gamma = \rho\, \phi / L$. This is the relation of shear strain γ to twist angle (φ), radial distance (ρ), and shaft length (L).

All the relations here, are based solely on the geometry of the circular shaft. Hence they are valid for any type of material. This is not so in what follows, the calculation of stresses based on linear elastic material behavior.

Stresses in Torsion



For a linear elastic material, using Hooke's law, we can write the shear stress using Hooke's law for a linear elastic material as

$$\tau = G * \gamma$$

where, G is the Shear Modulus.

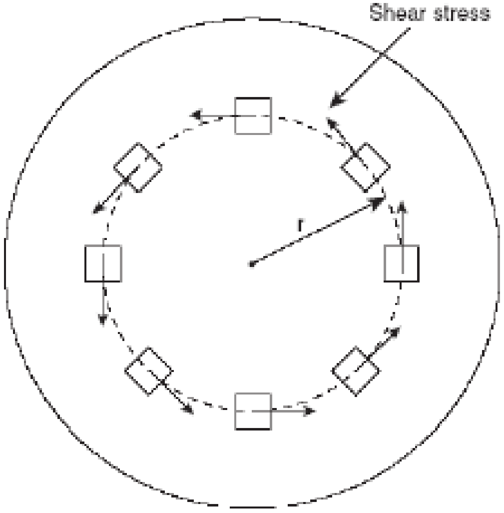
The shear strain on a small area of material situated at a distance ρ from the center, the shear strain is

$$\gamma = \rho\, \phi / L$$

and the shear stress is

$$\tau = G\, \rho\, \phi / L$$

*The torque, T, is calculated by integrating over the cross section the product of shear stress, τ, and the distance, ρ, from the center of the shaft. The torque, T, is found by integrating the shear stress along any ring "donut" of radius ρ * distance over the cross section, S, of the shaft*



$$T = \int_S \tau \rho \, dA$$

Relation of torque & angle of twist

Using stress from previous relations and substituting the stress from previous expressions, we find that torque is the integral of shear stresses over the cross section of the shaft.

$$T = \int_S \tau \rho \, dA$$

$$T = \int_S G\frac{\phi}{L}\rho^2 dA = G\frac{\phi}{L}\int_S \rho^2 dA = G\frac{\phi}{L}J$$

where J is the polar moment of inertia "will discuss polar moment of inertia, J, on the next slide".

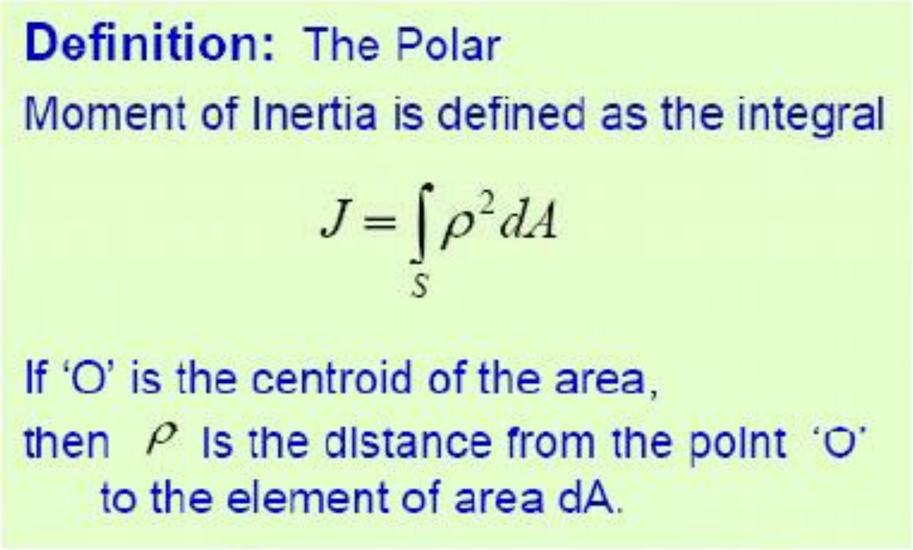
Using the above we find the relation between the angle of angle of twist and the torque as:

$$\phi = \frac{TL}{GJ}$$

And the we can write the shear stress as: $\tau = G\frac{\rho\phi}{L} = G\frac{\rho}{L}\frac{TL}{JG} = \frac{T\rho}{J}$

The theory of torsion compatibility may be rearranged as follows; $\frac{T}{J} = \frac{G\theta}{L} = \frac{\tau}{R}$

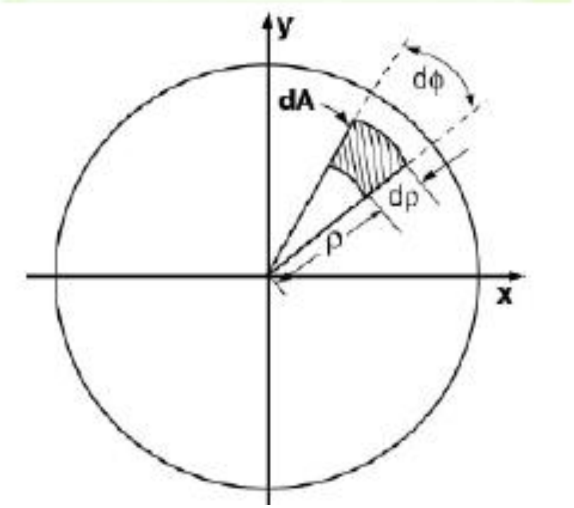
Polar moment of Inertia

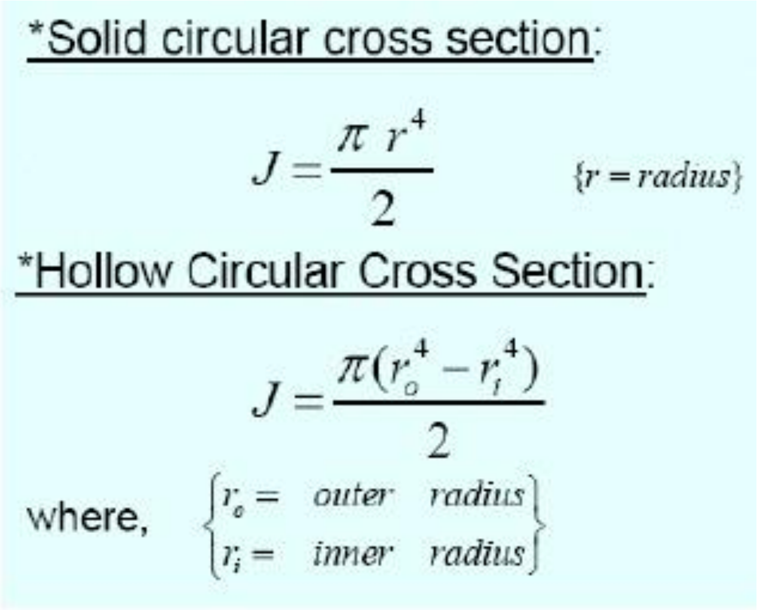


Definition: The Polar Moment of Inertia is defined as the integral

$$J = \int_S \rho^2 dA$$

If 'O' is the centroid of the area, then ρ Is the dIstance from the poInt 'O' to the element of area dA.





*Solid circular cross section:

$$J = \frac{\pi\ r^4}{2} \qquad \{r = radius\}$$

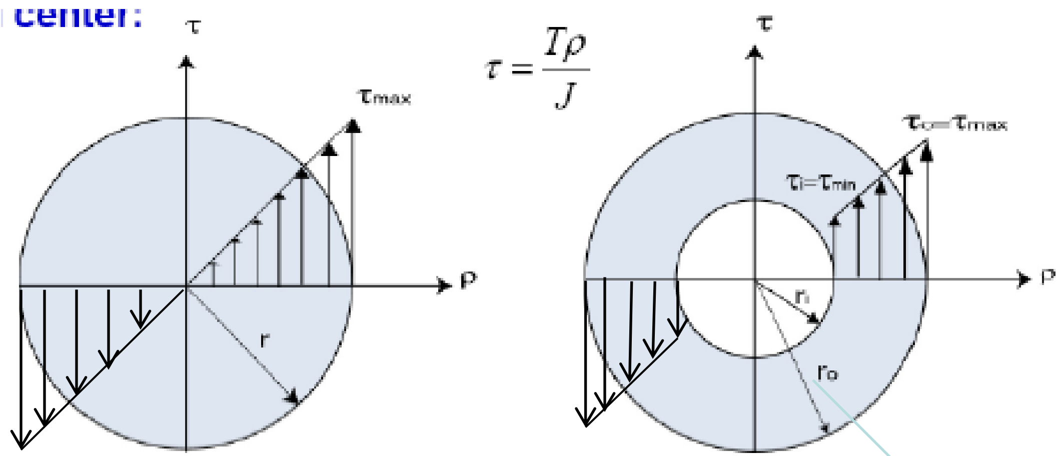
*Hollow Circular Cross Section:

$$J = \frac{\pi(r_o^4 - r_i^4)}{2}$$

where, $\begin{Bmatrix} r_o = & outer & radius \\ r_i = & inner & radius \end{Bmatrix}$

Torsion stress distribution in a circular cross section

In a circular shaft shear stress varies linearly from center:
The shear stress distribution on a circular cross section under torsion loading.
The shear stresses are directly proportional to the distance from the center. For a circular shaft, the shear stress would be maximum for an element which is farthest from the center.

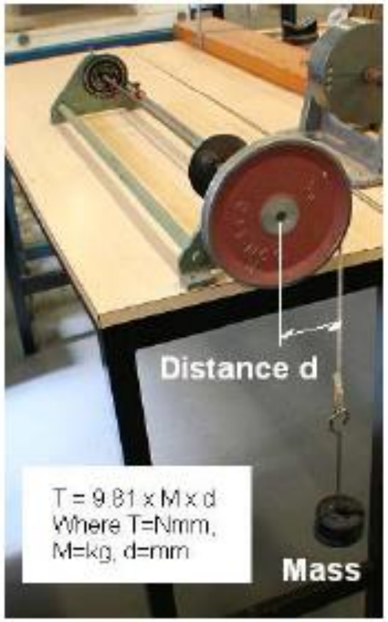


$$\tau = \frac{T\rho}{J}$$

The shear stress is zero at the center while it is the maximum at the surface. For a hollow shaft the shear stress is minimum for on the inside surface and maximum on the outer surface.

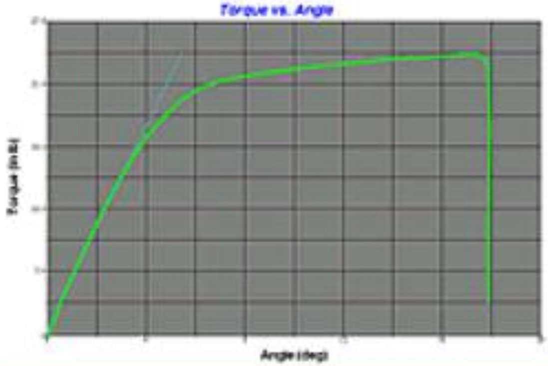
Note: The shear stress is maximum for the outermost element where the radii is maximum.

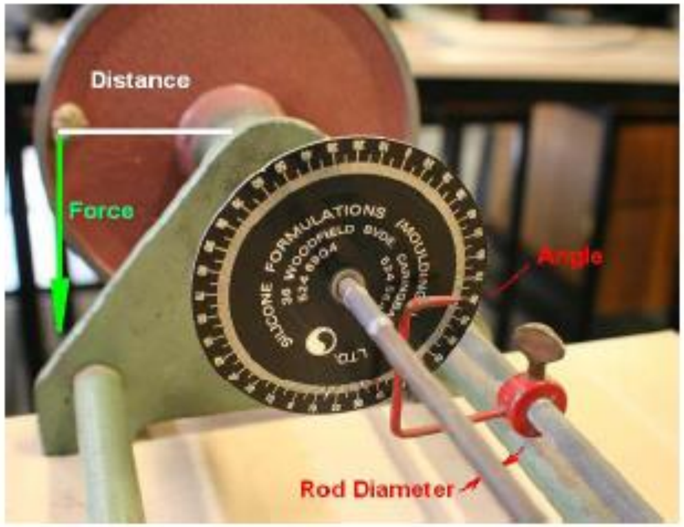
Performing of a torsion test



T = 9.81 x M x d
Where T=Nmm,
M=kg, d=mm

1. Torsion test is carried out by applying a twisting moment and measuring the corresponding twisting angle.
2. The specimen used is a solid pipe of diameter D and length L fixed from one end and attached to a pulley from the other end.
3. A mass "M" is hanged at a distance "d = D/2" producing a twisting moment "T = Mg * d"
4. The twisting angle θ is measured using a proctor attached to the specimen as shown.
5. The twisting moment, twisting angle relation is drawn.





Mode of Failure

Figure 16.6 Failure in torsion of a circular bar of brittle cast iron, showing a tendency to tensile fracture across a helix on the surface of the specimen.

1- Brittle Metals

The torsional failure of ductile materials occurs when the shearing stresses attain the yield stress of the material. The greatest shearing stresses in a circular shaft occur in a cross-section and along the length of the shaft. A circular bar of a ductile material usually fails by breaking off over a normal cross-section, as shown in Figure 16.7.

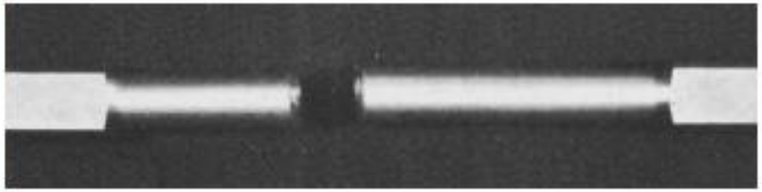


Figure 16.7 Failure of torsion of a circular bar of ductile cast iron, showing a shearing failure over a normal cross-section of the bar.

2- Ductile Metals

Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

Watching a torsion testing practice.

1

2

Dr. Mahmoud Khedr

Benha University
Shoubra Faculty of Engineering

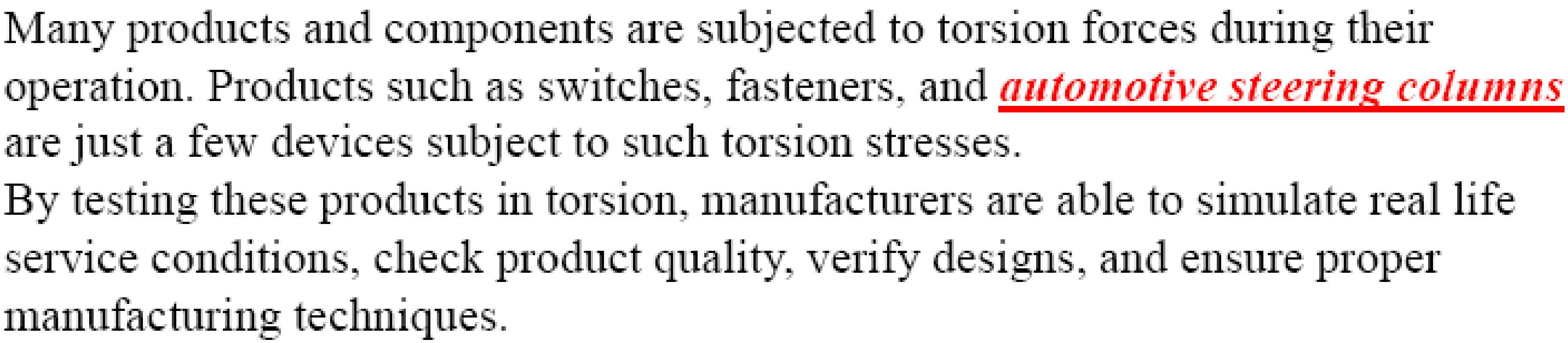
Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

The mechanical properties after torsion test.

Dr. Mahmoud Khedr

Why do we perform a torsion test?

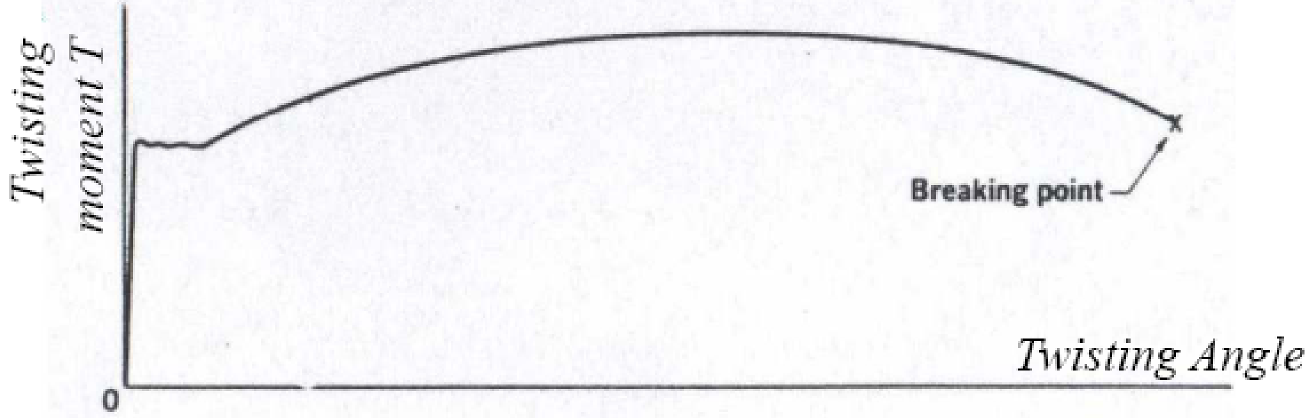


Many products and components are subjected to torsion forces during their operation. Products such as switches, fasteners, and ***automotive steering columns*** are just a few devices subject to such torsion stresses.

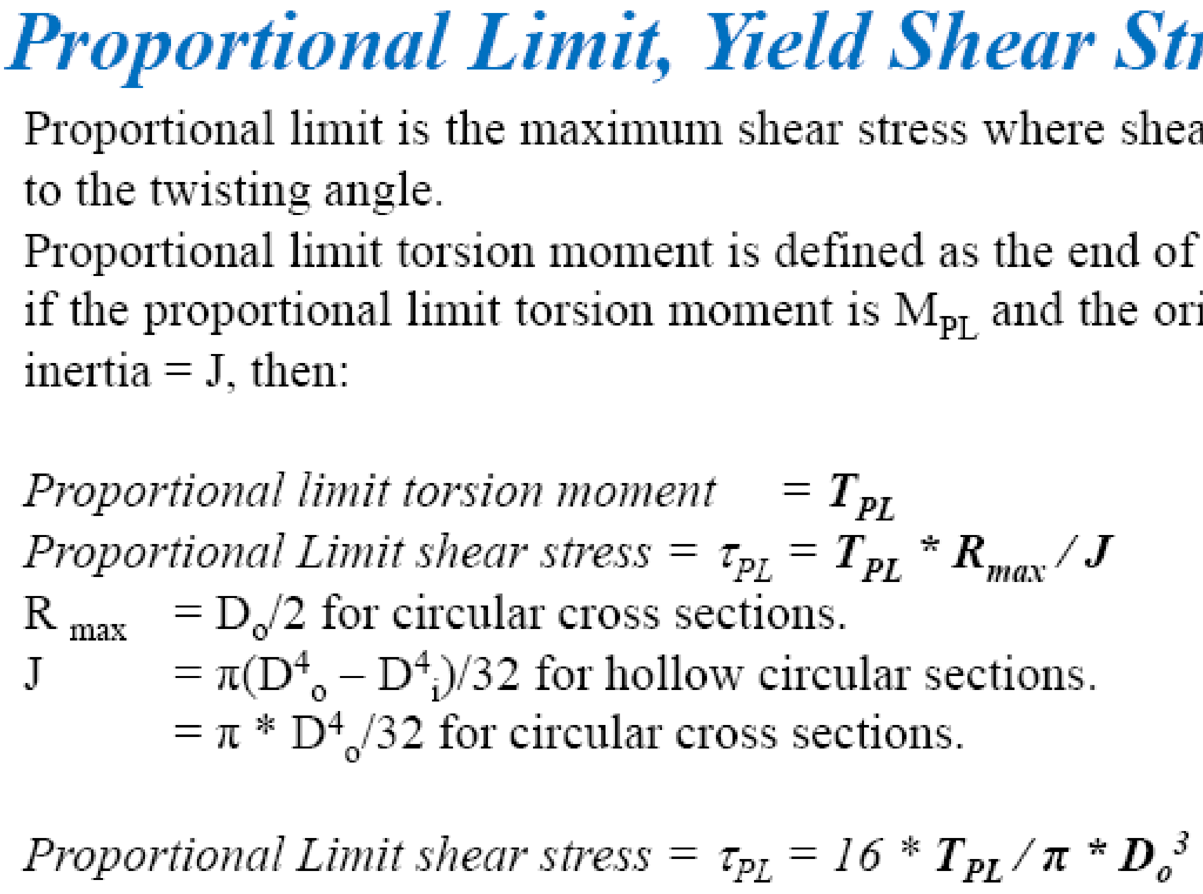
By testing these products in torsion, manufacturers are able to simulate real life service conditions, check product quality, verify designs, and ensure proper manufacturing techniques.

The mechanical properties after torsion test.

- A torsion test can be conducted on most materials to determine the torsion properties of the material. These properties include but are not limited to:
- Modulus of elasticity in shear
- Yield shear strength
- Modulus of rupture in shear
- Modulus of resilience in shear
- Modulus of toughness in shear
- Ductility
- While they are not the same, they are analogous to properties that can be determined during a torsion test. In fact, the "torque versus angle" diagram looks very similar to a “load v elongation" curve that might be generated by a tensile test.



The mechanical properties after torsion test.



Proportional Limit, Yield Shear Strength

Proportional limit is the maximum shear stress where shear stress is proportional to the twisting angle.

Proportional limit torsion moment is defined as the end of the straight line. Thus, if the proportional limit torsion moment is M_{PL} and the original polar moment of inertia = J, then:

Proportional limit torsion moment $= T_{PL}$

Proportional Limit shear stress $= \tau_{PL} = T_{PL} * R_{max} / J$

R_{max} $= D_o/2$ for circular cross sections.

J $= \pi(D^4_o - D^4_i)/32$ for hollow circular sections.

$= \pi * D^4_o/32$ for circular cross sections.

Proportional Limit shear stress $= \tau_{PL} = 16 * T_{PL} / \pi * D_o^3$

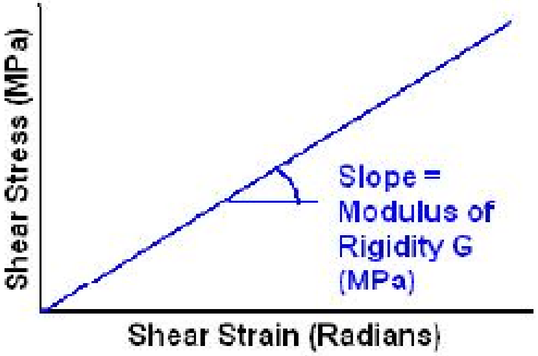
The mechanical properties after torsion test.

Shear Modulus, Modulus of Rigidity

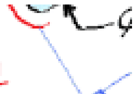
The torsion moment – twisting angle “load-deformation” diagram for most engineering materials exhibit a linear relationship between the applied twisting moment and twisting angle within the elastic region. Consequently, an increase in stress causes a proportionate increase in strain.

The relation between *the shear modulus*, applied twisting moment, measured twisting angle and the specimen property is given as follows;

$$\frac{G\,\theta}{L} = \frac{T_{PL}}{J} = \frac{\tau_R}{R} = \frac{\tau_r}{r}$$



$$G = \frac{T_{PL}\,L}{\theta_{PL} * J}$$



E = Modulus of Elaslicity
" " Stiffners
Young's Modulus

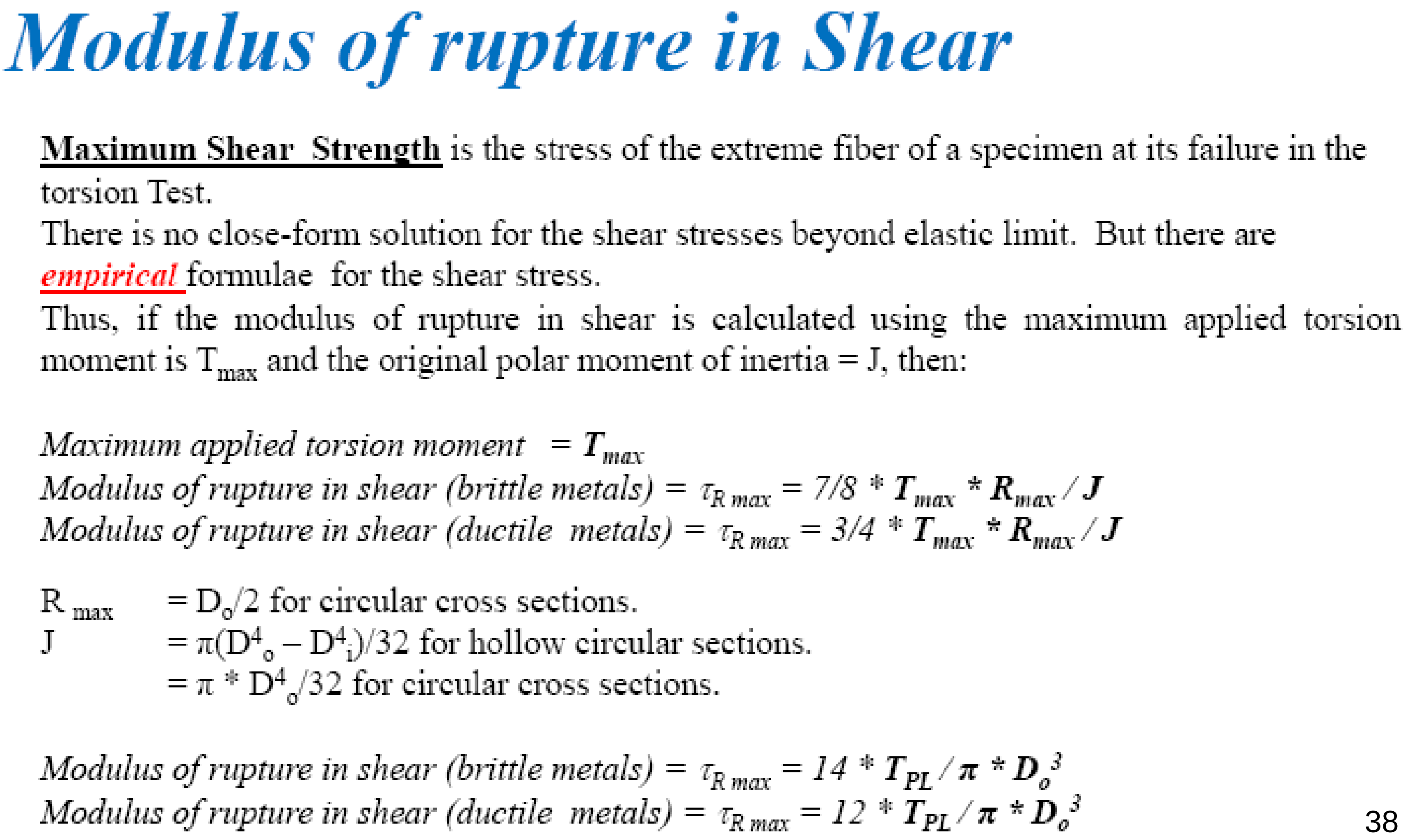
AXIAL
Steel 200GPa

G = Modulus of Rigidity

SHEAR
Steel 80 GPa

$G \approx 0{\cdot}4E$ For metals especially

The mechanical properties after torsion test.



Modulus of rupture in Shear

Maximum Shear Strength is the stress of the extreme fiber of a specimen at its failure in the torsion Test.

There is no close-form solution for the shear stresses beyond elastic limit. But there are *empirical* formulae for the shear stress.

Thus, if the modulus of rupture in shear is calculated using the maximum applied torsion moment is T_{max} and the original polar moment of inertia = J, then:

Maximum applied torsion moment $= T_{max}$

Modulus of rupture in shear (brittle metals) $= \tau_{R\,max} = 7/8 * T_{max} * R_{max} / J$

Modulus of rupture in shear (ductile metals) $= \tau_{R\,max} = 3/4 * T_{max} * R_{max} / J$

R_{max} $= D_o/2$ for circular cross sections.

J $= \pi(D^4_o - D^4_i)/32$ for hollow circular sections.

$= \pi * D^4_o/32$ for circular cross sections.

Modulus of rupture in shear (brittle metals) $= \tau_{R\,max} = 14 * T_{PL} / \pi * D_o^3$

Modulus of rupture in shear (ductile metals) $= \tau_{R\,max} = 12 * T_{PL} / \pi * D_o^3$

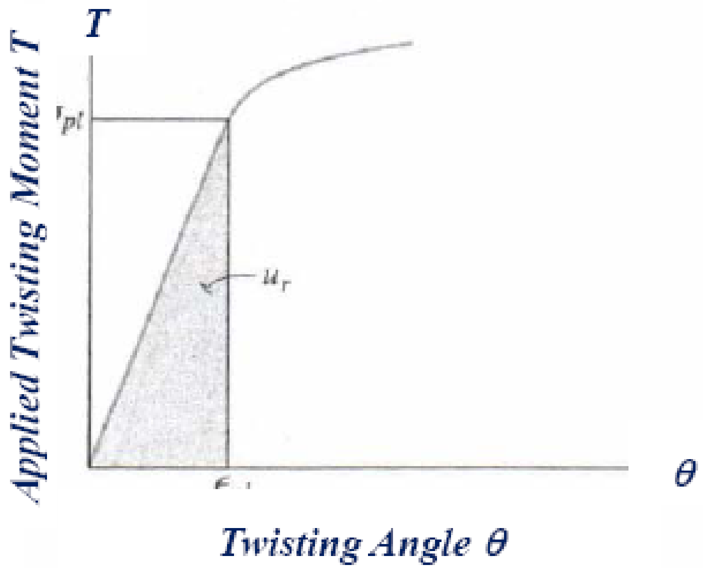
The mechanical properties after torsion test.

Modulus of Resilience

A material's resilience represents the ability of the material to absorb energy without any permanent damage to the material. In particular, when the load a reaches the proportional limit, the strain-energy density, is calculated by and is referred to as the *modulus of resilience Ur.* Mathematically it is the area under the straight line “elastic region” of the load-deformation curve per unit volume.

$$U_r = \frac{T_{PL} * \theta_{PL}}{2 * A * L}$$

θ_{PL} is in radians NOT degrees.



(a)

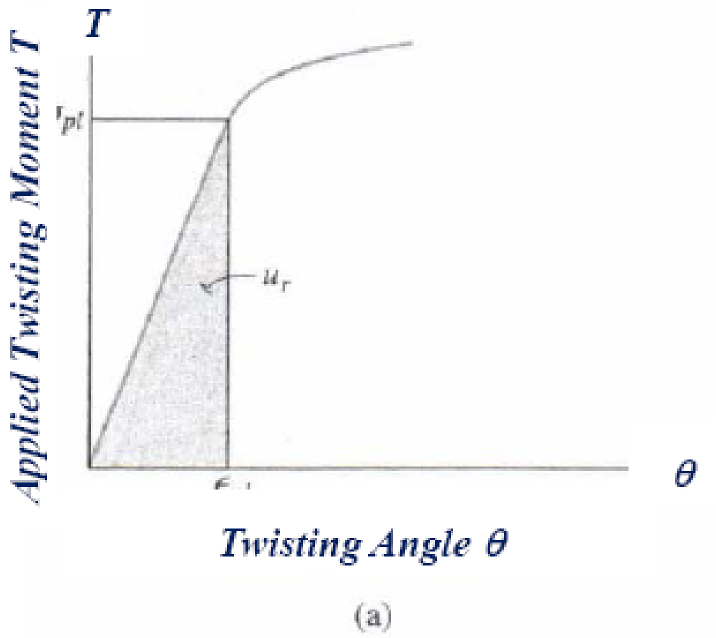
The mechanical properties after torsion test.

Modulus of Resilience

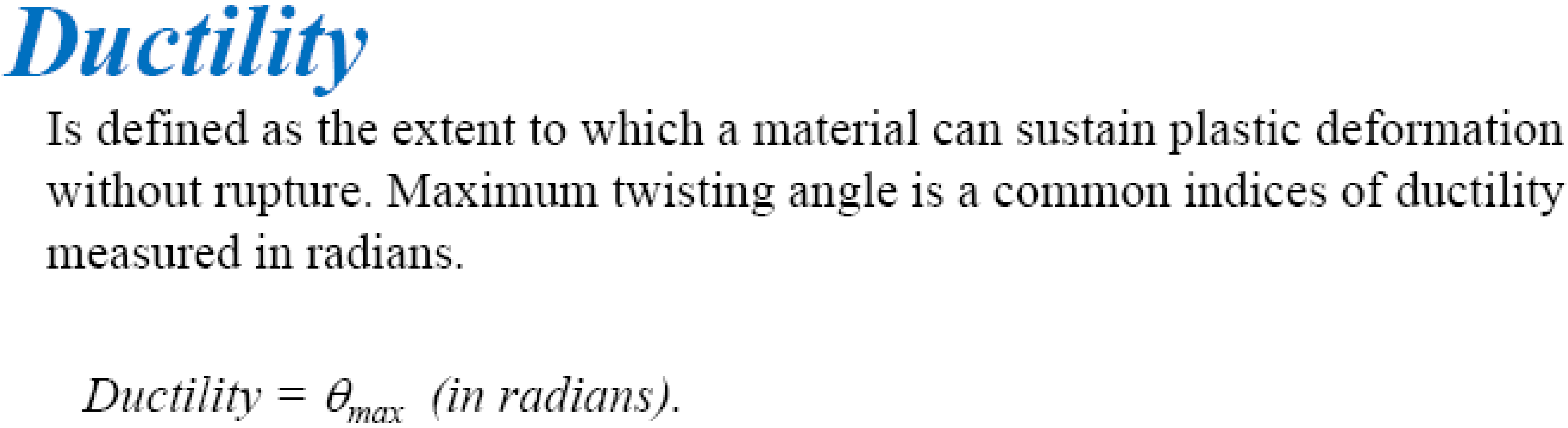
A material's resilience represents the ability of the material to absorb energy without any permanent damage to the material. In particular, when the load a reaches the proportional limit, the strain-energy density, is calculated by and is referred to as the *modulus of resilience Ur.* Mathematically it is the area under the straight line “elastic region” of the load-deformation curve per unit volume.

$$U_r = \frac{T_{PL} * \theta_{PL}}{2 * A * L}$$

θ_{PL} is in radians NOT degrees.



The mechanical properties after torsion test.



Ductility

Is defined as the extent to which a material can sustain plastic deformation without rupture. Maximum twisting angle is a common indices of ductility measured in radians.

$$\text{Ductility} = \theta_{max} \ \text{(in radians)}.$$

Benha University
Shoubra Faculty of Engineering

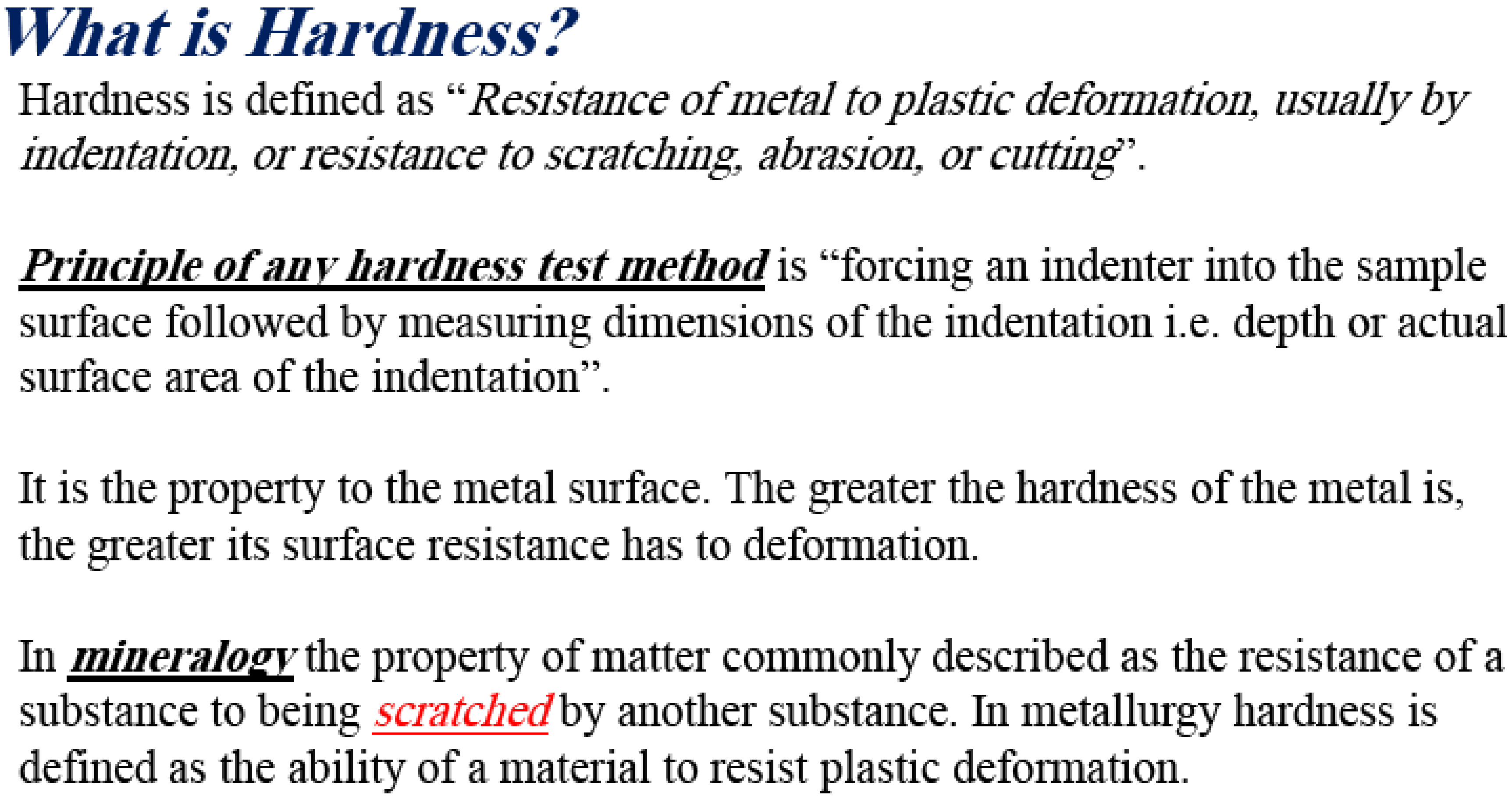
Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

Introduction to indentation hardness

Dr. Mahmoud Khedr

Introduction



What is Hardness?

Hardness is defined as "*Resistance of metal to plastic deformation, usually by indentation, or resistance to scratching, abrasion, or cutting*".

Principle of any hardness test method is "forcing an indenter into the sample surface followed by measuring dimensions of the indentation i.e. depth or actual surface area of the indentation".

It is the property to the metal surface. The greater the hardness of the metal is, the greater its surface resistance has to deformation.

In ***mineralogy*** the property of matter commonly described as the resistance of a substance to being *scratched* by another substance. In metallurgy hardness is defined as the ability of a material to resist plastic deformation.

Introduction

Indentation Hardness

Indentation hardness as the resistance of a material surface to indentation. This is the usual type of hardness test, in which a pointed or rounded ***indenter*** is pressed into a surface under a substantially ***static load***.

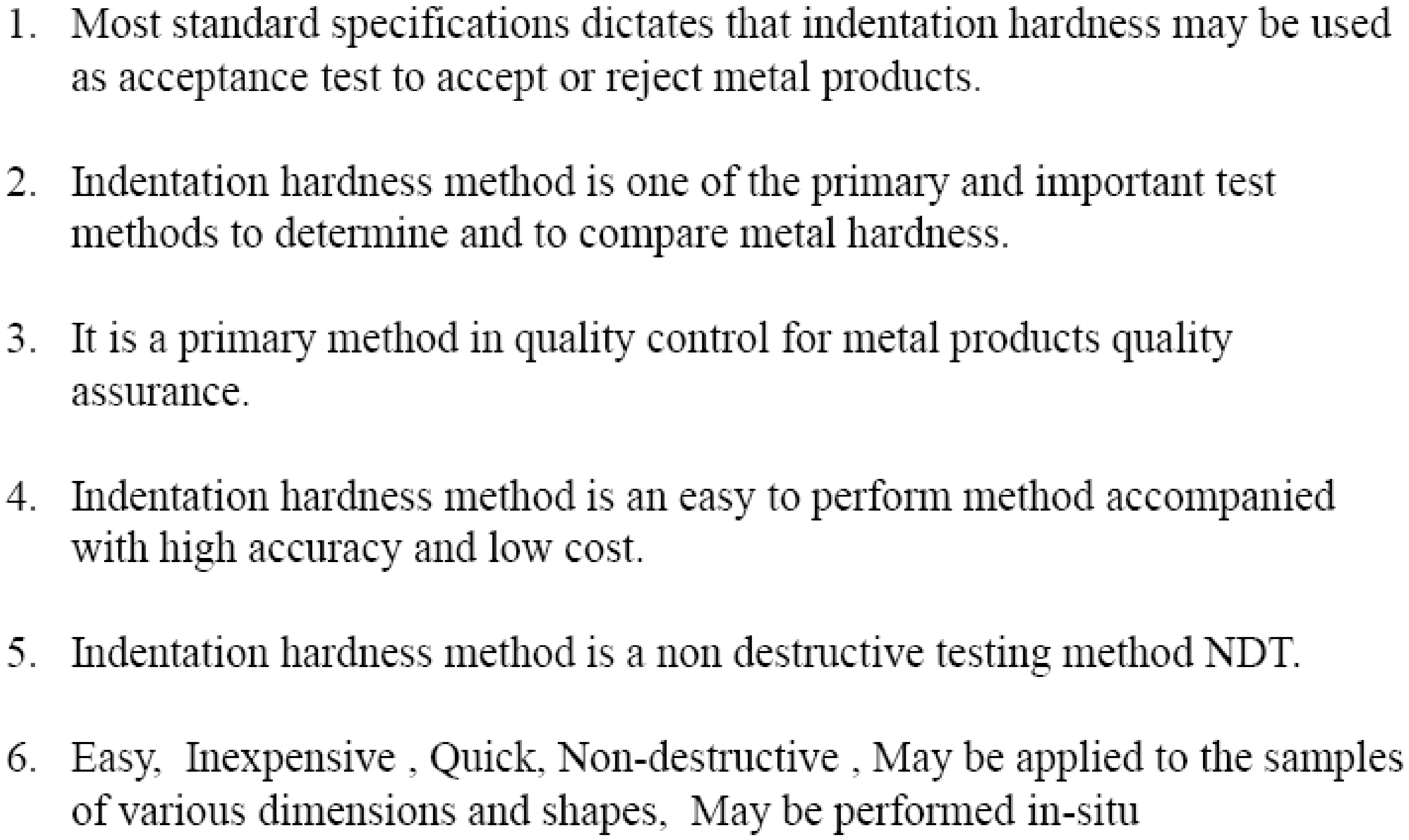
There are three types of tests used with accuracy by the metals industry;

The ***Brinell*** *hardness test,*
The ***Vickers*** *hardness test, and*
The ***Rockwell*** *hardness test.*

It can generally be assumed that a ***strong metal*** is also a ***hard metal***.

The way the three of these hardness tests measure a metal's hardness is to determine the metal's resistance to the ***penetration*** of a non-deformable ***ball or cone***. The tests determine the ***depth*** which such a ball or cone will sink into the metal, under a given load, within a specific period of time.

Advantages of Indentation Hardness



1. Most standard specifications dictates that indentation hardness may be used as acceptance test to accept or reject metal products.

2. Indentation hardness method is one of the primary and important test methods to determine and to compare metal hardness.

3. It is a primary method in quality control for metal products quality assurance.

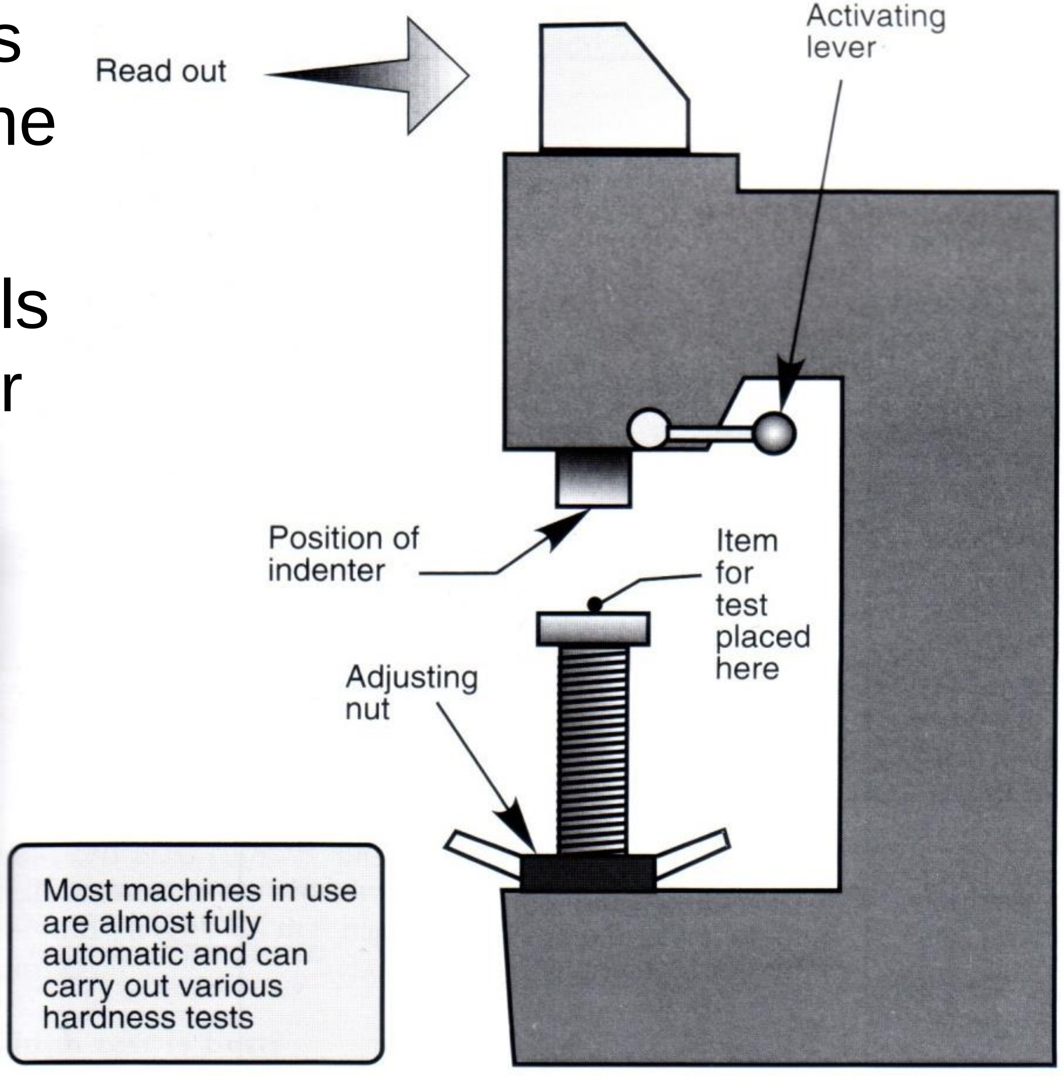
4. Indentation hardness method is an easy to perform method accompanied with high accuracy and low cost.

5. Indentation hardness method is a non destructive testing method NDT.

6. Easy, Inexpensive , Quick, Non-destructive , May be applied to the samples of various dimensions and shapes, May be performed in-situ

Hardness testing machine

- The indenter is pressed into the metal
- Softer materials leave a deeper indentation



Most machines in use are almost fully automatic and can carry out various hardness tests

Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

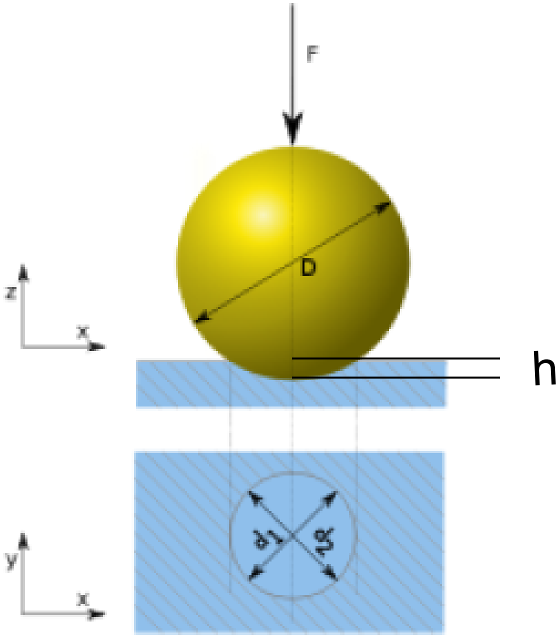
Brinell Hardness

Dr. Mahmoud Khedr

Brinell Hardness

A hardened steel ball of 1, 2.5, 5 or 10 mm in diameter *hardened steel* or *tungsten carbide* is used as indenter. The loading force is in the range of :

- 30 kg for testing lead alloys,
- 500 kg for testing aluminum alloys,
- 1000 kg for copper alloys, and
- 3000 kg for testing steels



The indentation is measured and the Brinell Hardness Number (HB) is calculated by the formula:

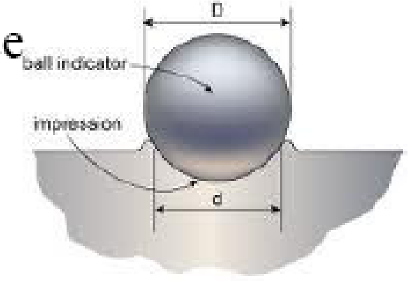
BHN = F/ (π * D* h) $$\mathrm{BHN} = \frac{2P}{\pi D(D - \sqrt{(D^2 - d^2)})}$$

where:
P = applied force (kg),
h = depth of indentation (mm),
D = diameter of indenter (mm), and
d = diameter of indentation (mm).

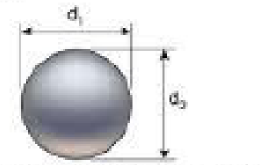
Brinell Hardness

Precautions for Brinell Hardness tests:

1. The indentation diameter should be measured in two perpendicular directions.
2. The large size of indentation and possible damage to test-piece limits its usefulness.
3. Plastic deformations are not allowed around the indentation.
4. The ratio between d/D = (1/4 – ½) $\underline{=}$ 3/8 where D is the diameter of indenter (mm) and d is the diameter of indentation (mm).
5. Brinell hardness test may not be performed on thin plates where t < 10 h where: t is the plate thicness and h is the indentation depth.
6. Test piece may be leveled, smooth, free of loose particles, debris, oil or grease.
7. Test piece may not suffer any bulging or indentation on the opposite side.
8. Min edge distance is *2.5 d*



(a) Brinell indentation



(b) measurement of impression diameter

Brinell Hardness

Brinell Hardness Testing Machines

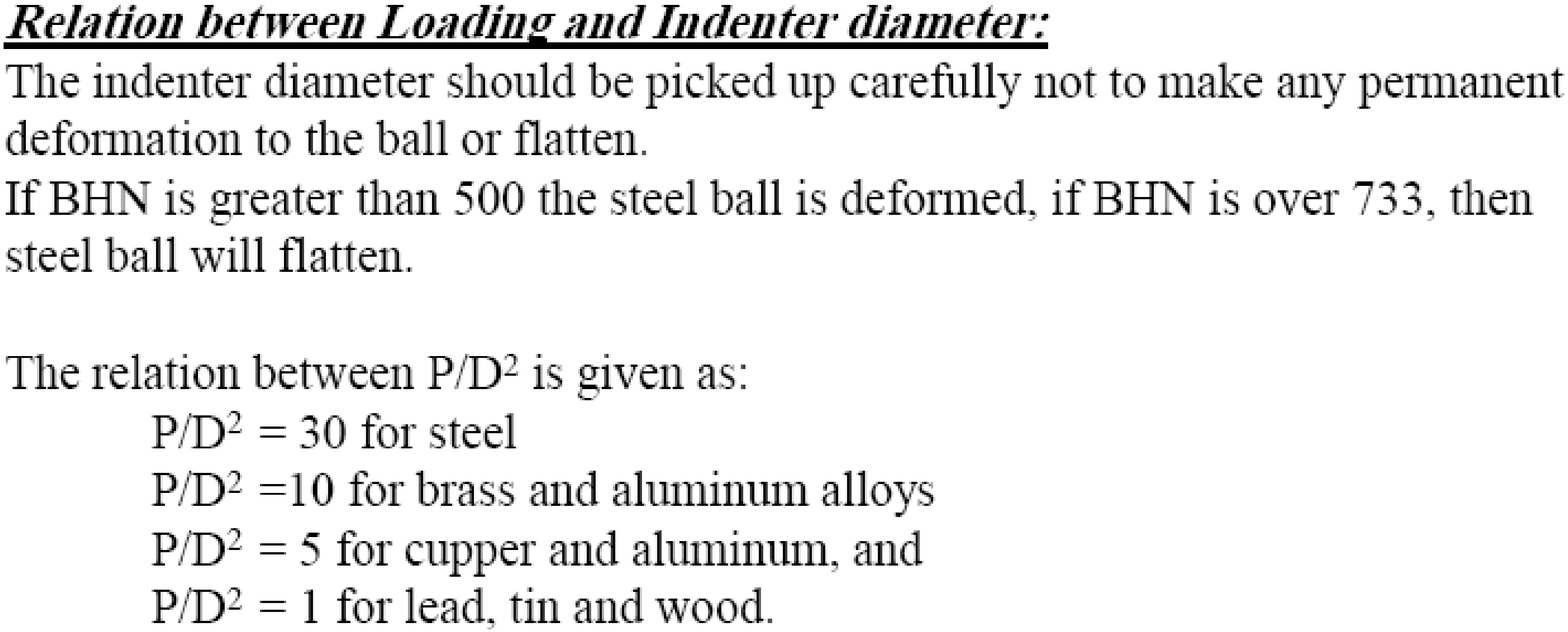
Brinell Hardness Manual C-Clamp tester

Optics Digital Brinell hardness tester

Portable Brinell hardness tester

Automatic Brinell Hardness Tester

Brinell Hardness



Relation between Loading and Indenter diameter:

The indenter diameter should be picked up carefully not to make any permanent deformation to the ball or flatten.

If BHN is greater than 500 the steel ball is deformed, if BHN is over 733, then steel ball will flatten.

The relation between P/D^2 is given as:

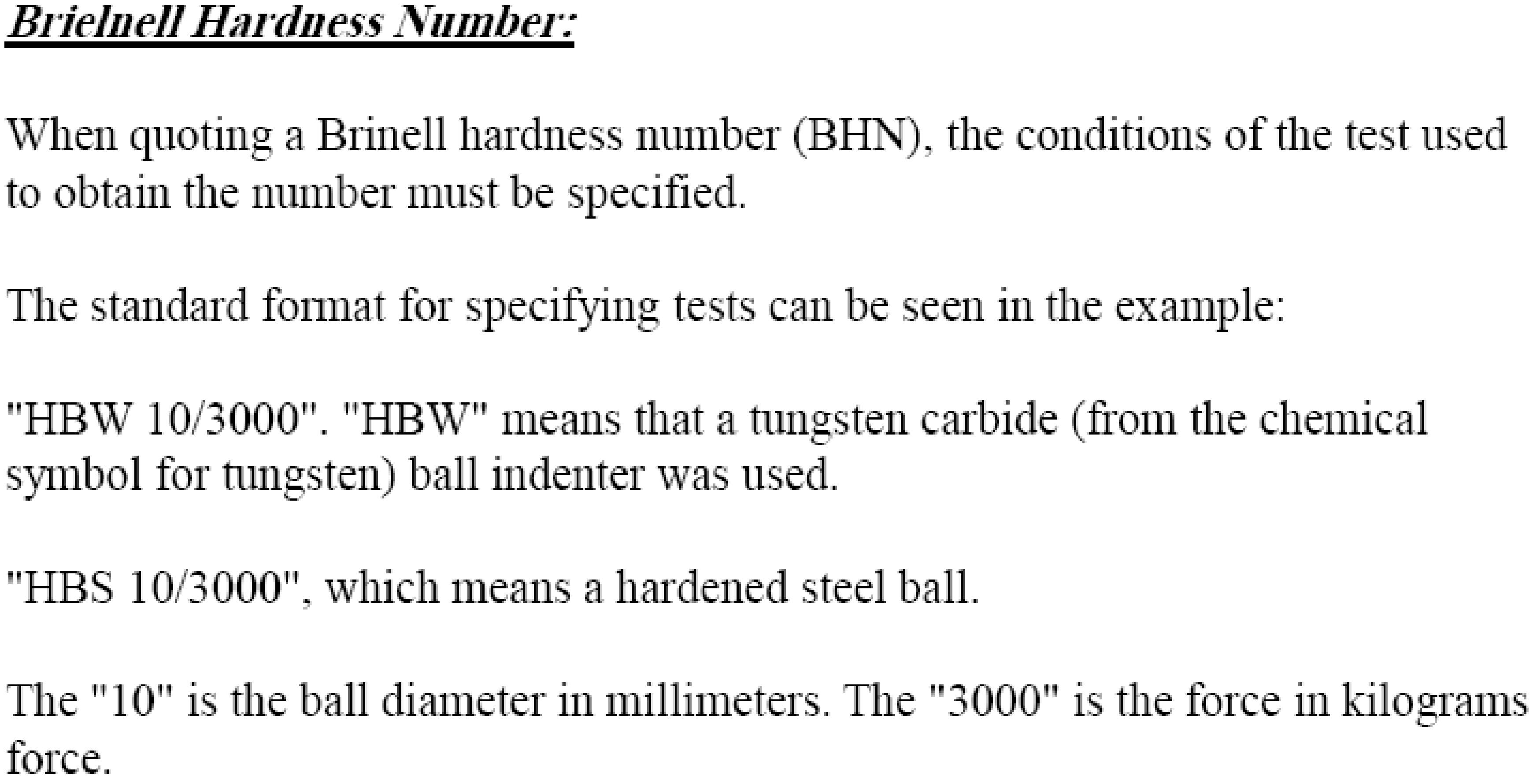
$P/D^2 = 30$ for steel

$P/D^2 =10$ for brass and aluminum alloys

$P/D^2 = 5$ for cupper and aluminum, and

$P/D^2 = 1$ for lead, tin and wood.

Brinell Hardness



Brielnell Hardness Number:

When quoting a Brinell hardness number (BHN), the conditions of the test used to obtain the number must be specified.

The standard format for specifying tests can be seen in the example:

"HBW 10/3000". "HBW" means that a tungsten carbide (from the chemical symbol for tungsten) ball indenter was used.

"HBS 10/3000", which means a hardened steel ball.

The "10" is the ball diameter in millimeters. The "3000" is the force in kilograms force.

Brinell Hardness

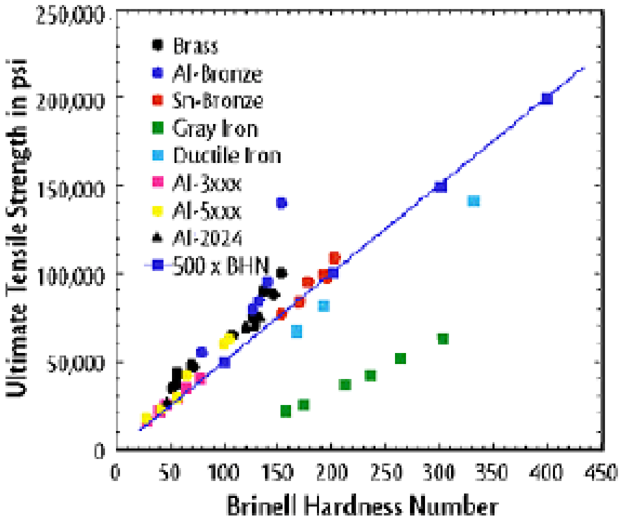
BHN & UTS

There is no definite relationship between BHN and UTS for the metal. BHN can NOT be used instead of “static tensile test”.

Yet, for ferrous metals, there is an approximate “imperical” relation beteen BHN and UTS .

This relation is useful in determining an approximate value for the insitu UTS if the portable Brinell Hardness tester is used.

UTS = 36% BHN.



Brinell Hardness

The Brinell Hardness Test

Brinell hardness testing: Surface preparation

This image shows sample preparation for Brinell hardness testing experiment. Using a small hand grinder with a 600 mesh abrasive disc a flat area in the centre of the raised boss is lightly polished. A great care has to be taken by using light pressure to ensure that the surface is not deformed or overheated. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness testing: Calibration block

This image shows how to do calibration during Brinell hardness testing. The check that the machine is giving accurate results is done by making a hardness test on a standard block. The hardness value measured is compared against the certified hardness of the standard block. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell Hardness

The Brinell Hardness Test

Brinell hardness test: Ready for the test

This image shows the casting located on the support anvil, ready to commence the Brinell hardnes test. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness test: Load limits

This image shows how to apply load during Brinell hardness testing. By winding the hand wheel we raise the test piece up until the indenter just touches the casting surface. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell Hardness

The Brinell Hardness Test

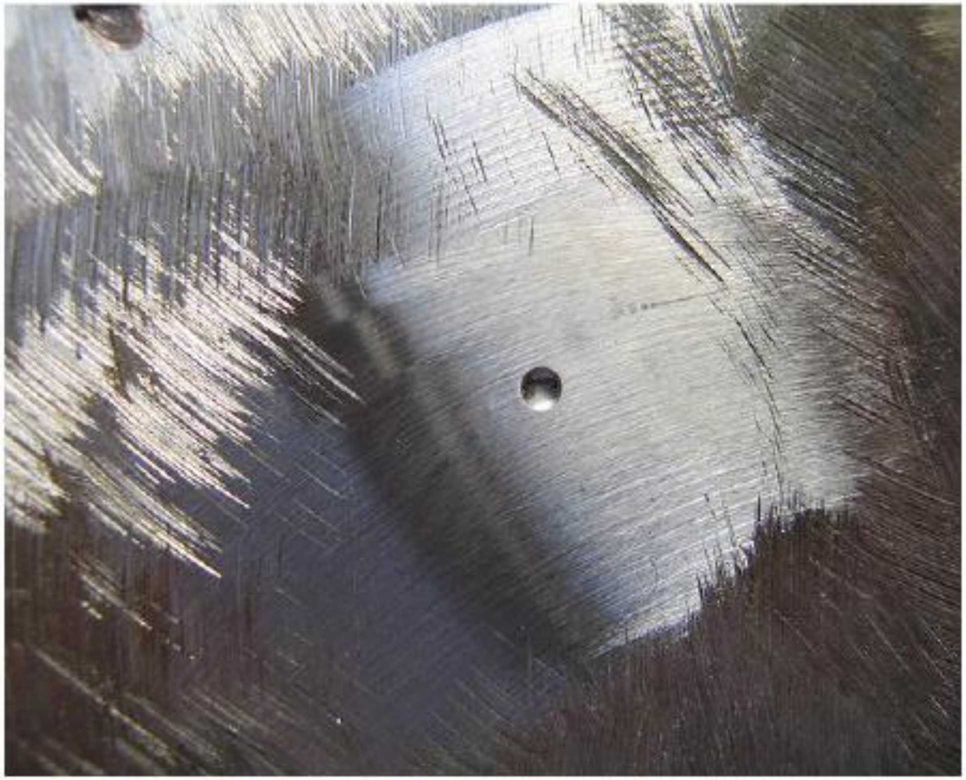
Brinell hardness test: Set position

This image shows a set position for Brinell hardness testing. As the indenter touches the metal surface the display window of the machine indicates that the start position is "SET". Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness test: Applying load

This image shows how to apply load during Brinell hardness testing by depressing the actuating lever. The display screen indicates when the load application is complete. A standard test is of 15 seconds duration. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell Hardness



Brinell hardness test: Ball impression

This image shows the impression on the prepared area of the casting in Brinell hardness testing. You can see that it is circular and the edges are sharply defined. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness test: Reading ball impression

This image shows how to read ball impression during Brinell hardness testing. A hand held microscope is used to measure the diameter of the impression in two directions at right angles. Courtesy of Roger White and Derrick Hurley, Bradford College.

Benha University
Shoubra Faculty of Engineering

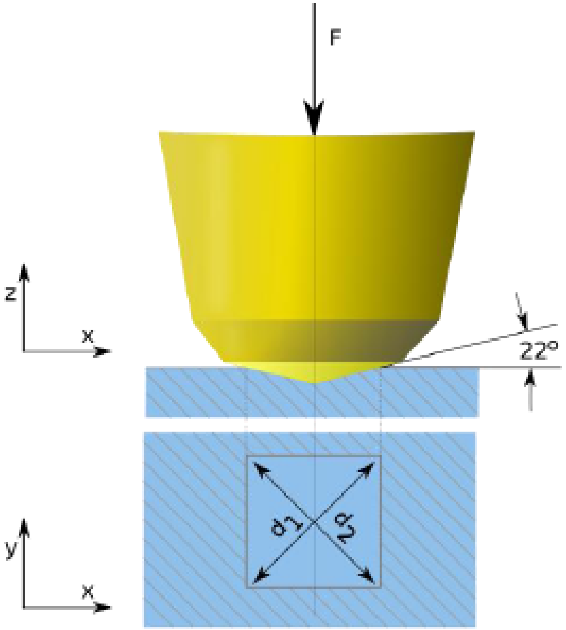
Energy & sustainable energy Dep.
1^{st} year

20.04.2019 – Week 11

Vickers Hardness

Dr. Mahmoud Khedr

Vickers Hardness



The **Vickers hardness test** was developed as an alternative to the Brinell method to measure the hardness of materials.

The Vickers test is often easier to use than other hardness tests as the indenter can be used for all materials irrespective of hardness.

The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the **Vickers Pyramid Number** (HV) or **Diamond Pyramid Hardness** (DPH).

The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force.

Vickers Hardness

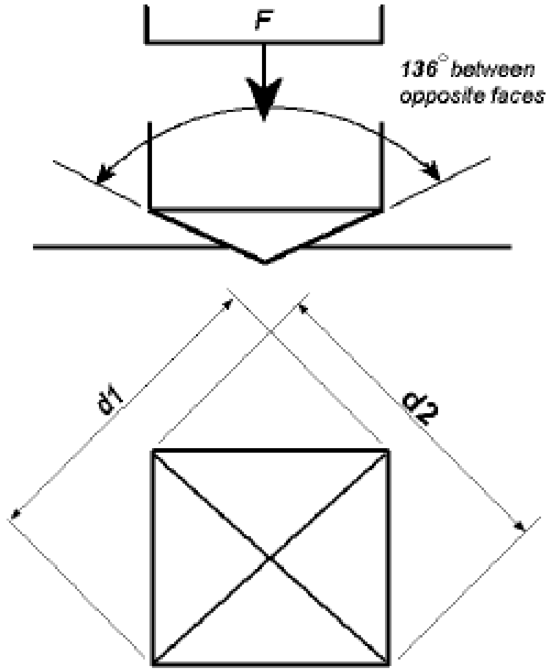
Advantages of VHT: Irrespective of specimen size;

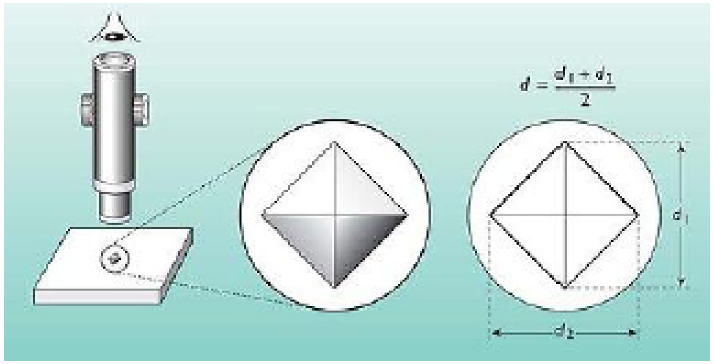
- The indenter shape is capable of producing geometrically similar impressions.
- The impression have well-defined points of measurement;
- The indenter have high resistance to self-deformation.

A diamond in the form of a square-based pyramid is used.

It had been established that the ideal size of a ***Brinell*** *impression was 3/8 of the ball diameter. As two tangents to the circle at the ends of a chord 3d/8 long intersect at 136°, it was decided to use this as the included angle of the indenter.*

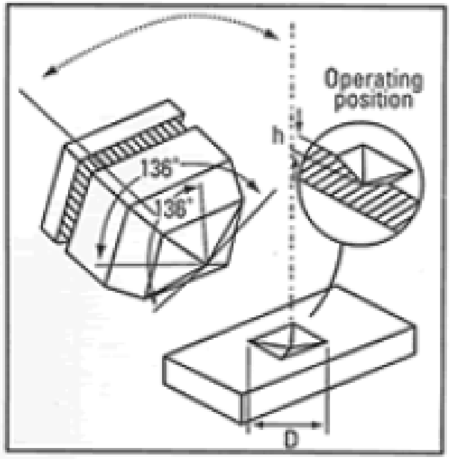
The hardness value obtained on a homogeneous piece of material remained constant, irrespective of load.





Vickers Hardness

1. The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for ***10 to 15 seconds***
2. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated.
3. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.



4. Accordingly, loads of various magnitudes are applied to a flat surface, depending on the hardness of the material to be measured. The HV number is then determined by the ratio F/A where

F is the force applied to the diamond in kilograms-force and
A is the surface area of the resulting indentation in mm^2.
The area A can be determined by the formula

$$A = \frac{d^2}{2\sin(136^\circ/2)}$$

Vickers Hardness

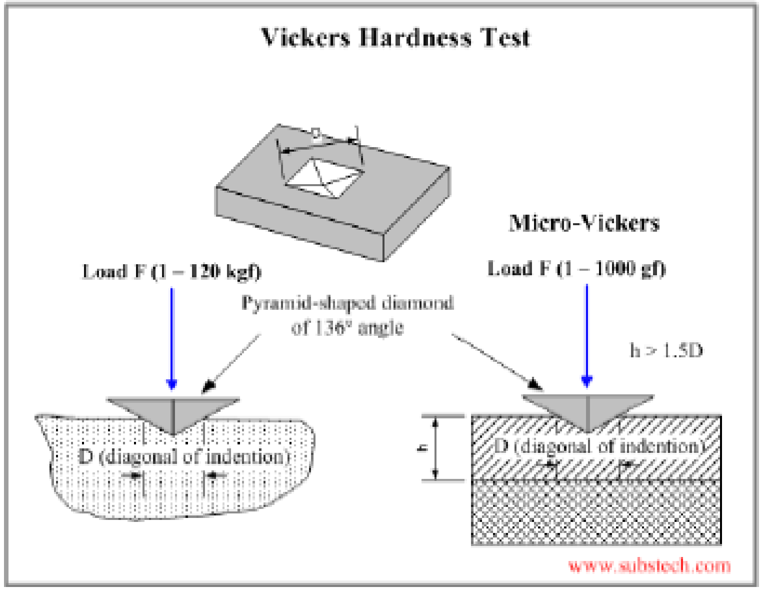
$$HV = \frac{F}{A} \approx \frac{1.8544F}{d^2}$$

HV = Vickers hardness

F= Load in kgf

d= Arithmetic mean of the two diagonals, d_1 and d_2 (mm)

Vickers hardness numbers are reported as **xxxHVyy**, e.g. **440HV30**, or **xxxHVyy/zz** if duration of force differs from 10 s to 15 s, e.g. 440Hv30/20, where: **440** is the hardness number, **HV** gives the hardness scale (Vickers), **30** indicates the load used in kg, **20** indicates the loading time if it differs from 10 s to 15 s. Vickers values are generally independent of the test force.



www.substech.com

Examples of HV values for various materials

Material	Value
316L stainless steel	140HV30
347L stainless steel	180HV30
Carbon steel	55–120HV5
Iron	30–80HV5

Vickers Hardness

The Vickers hardness test

Vickers diamond indentor: the end

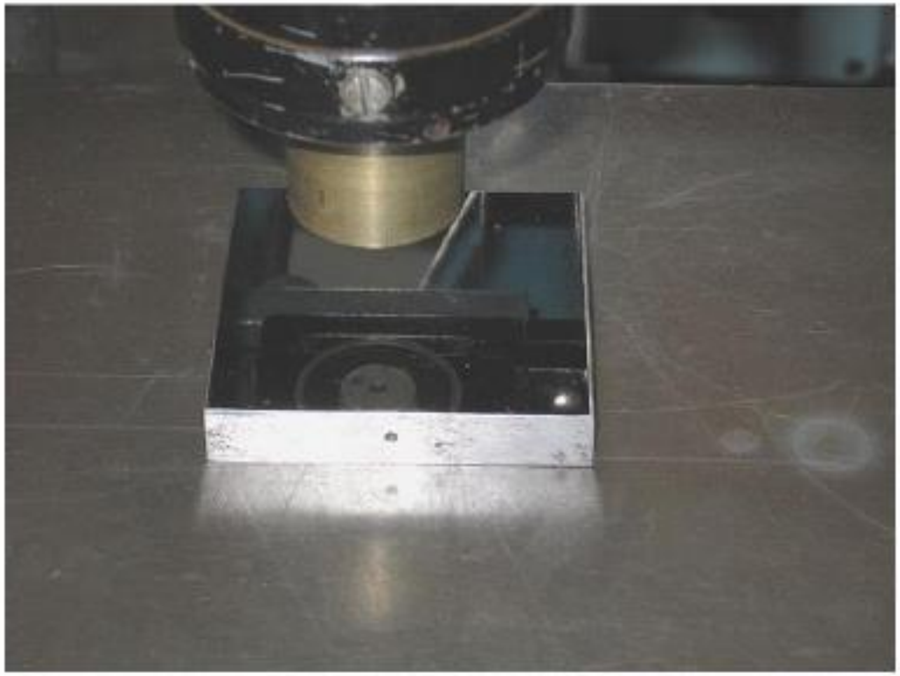
This image shows the end on view of the Vickers diamond indenter. The condition of the diamond indenter is extremely important to ensure that the test result is accurate. Courtesy of Roger White and Derrick Hurley, Bradford College.

Vickers diamond indentor: the mount

This image shows the mount of a Vickers diamond indenter. The condition of the diamond indenter is extremely important to ensure that the test result is accurate. Courtesy of Roger White and Derrick Hurley, Bradford College.

Vickers Hardness

The calibration



Vickers hardness test: Calibration block

This image shows the beginning of the calibration of the measuring device during Vickers hardness test. In order to check that the measuring device is calibrated an impression on a standard test block is made. It then checked that the measured result lies within the acceptance range of the block. Courtesy of Roger White and Derrick Hurley, Bradford College.

Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

20.04.2019 – Week 11

Rockwell Hardness

Dr. Mahmoud Khedr

Rockwell Hardness

- Gives direct reading.
- Rockwell B (ball) used for soft materials.
- Rockwell C (cone) uses diamond cone for hard materials.
- Flexible, quick and easy to use.

Two most common indenters are
Ball – B and
Cone – C

Rockwell Hardness

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter.

The indenter is forced into the test material under a preliminary minor load *F0* (Fig. 1A) usually 10 kg.

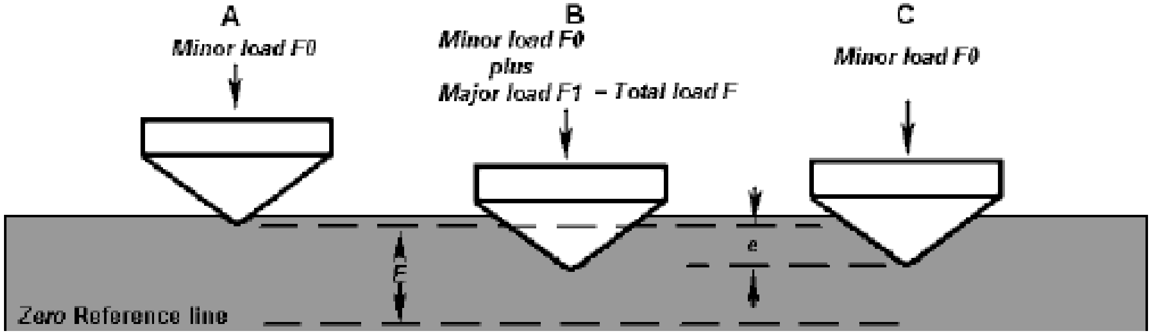
When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position.

While the preliminary minor load is still applied an additional major load (50 or 90 or 150 kg) is applied with resulting increase in penetration (Fig. 1B).

When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained.

Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig. 1C).

The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number: HR = $E - e$



Rockwell Hardness

Rockwell hardness tester

Rockwell hardness tester
Close up

Digital
Rockwell hardness tester

Rockwell Hardness

F0 = preliminary minor load in kgf

F1 = additional major load in kgf

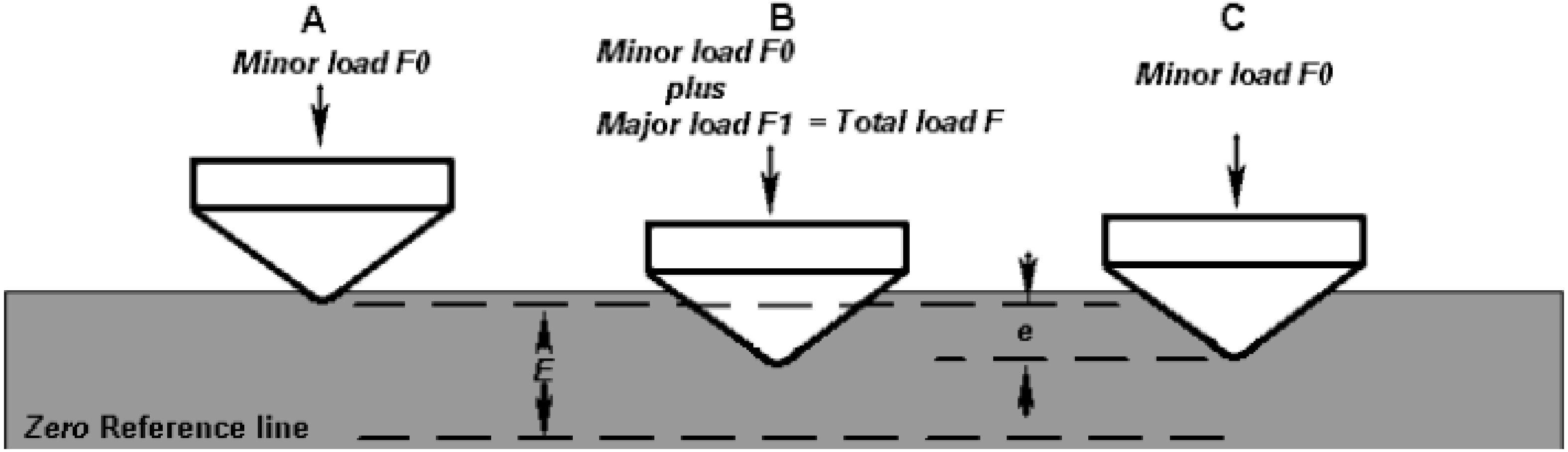
F = total load in kgf

e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm

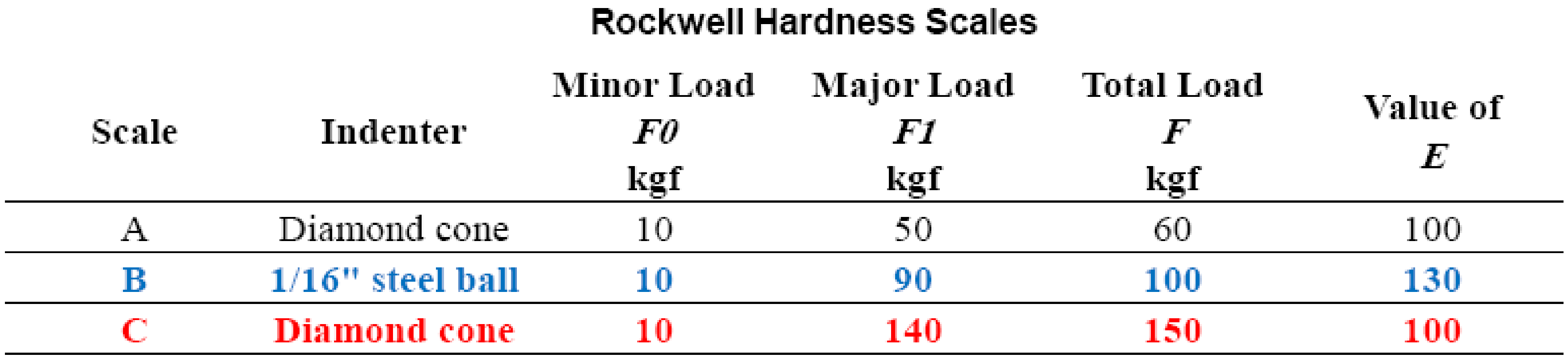
E = a constant depending on form of indenter:

100 units for diamond indenter,	$HRC = 100 - e / 0.002$
130 units for steel ball indenter	$HRB = 130 - e / 0.002$

HR = Rockwell hardness number, that is inversely proportional to the distance e i.e. as e increases HR decreases.



Rockwell Hardness



Rockwell Hardness Scales

Scale	Indenter	Minor Load *F0* kgf	Major Load *F1* kgf	Total Load *F* kgf	Value of *E*
A	Diamond cone	10	50	60	100
B	**1/16" steel ball**	**10**	**90**	**100**	**130**
C	**Diamond cone**	**10**	**140**	**150**	**100**

HRA	Cemented carbides, thin steel and shallow case hardened steel.
HRB	Copper alloys, soft steels, aluminum alloys, malleable irons, etc.
HRC	Steel, hard cast irons, case hardened steel and other materials harder than 100 HRB.

Advantages of the Rockwell hardness method:

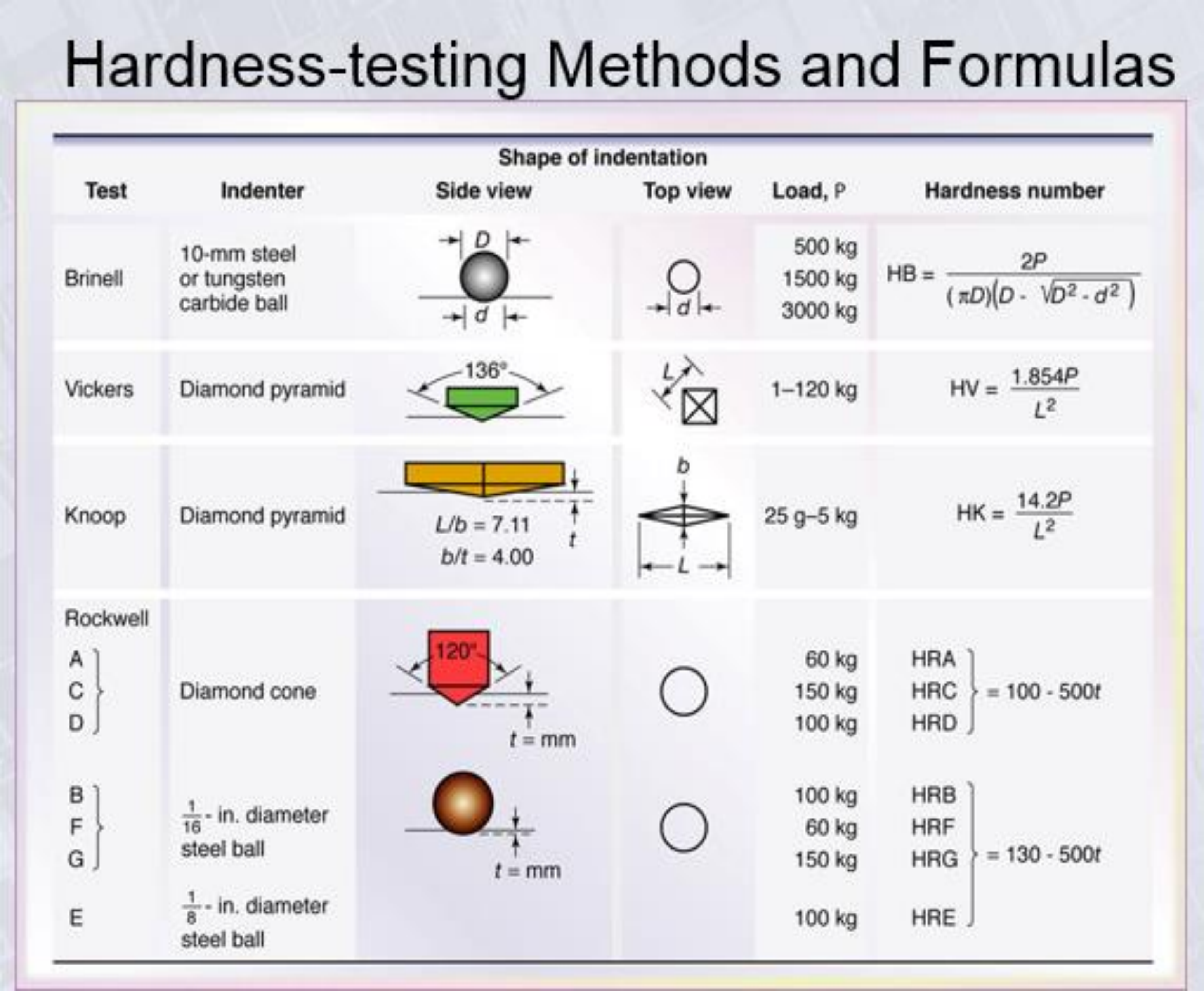
The direct Rockwell hardness number readout and rapid testing time.

The small amount or load required.

It gives the metal hardness and not only the surface hardness.

May be used for thin sheets.

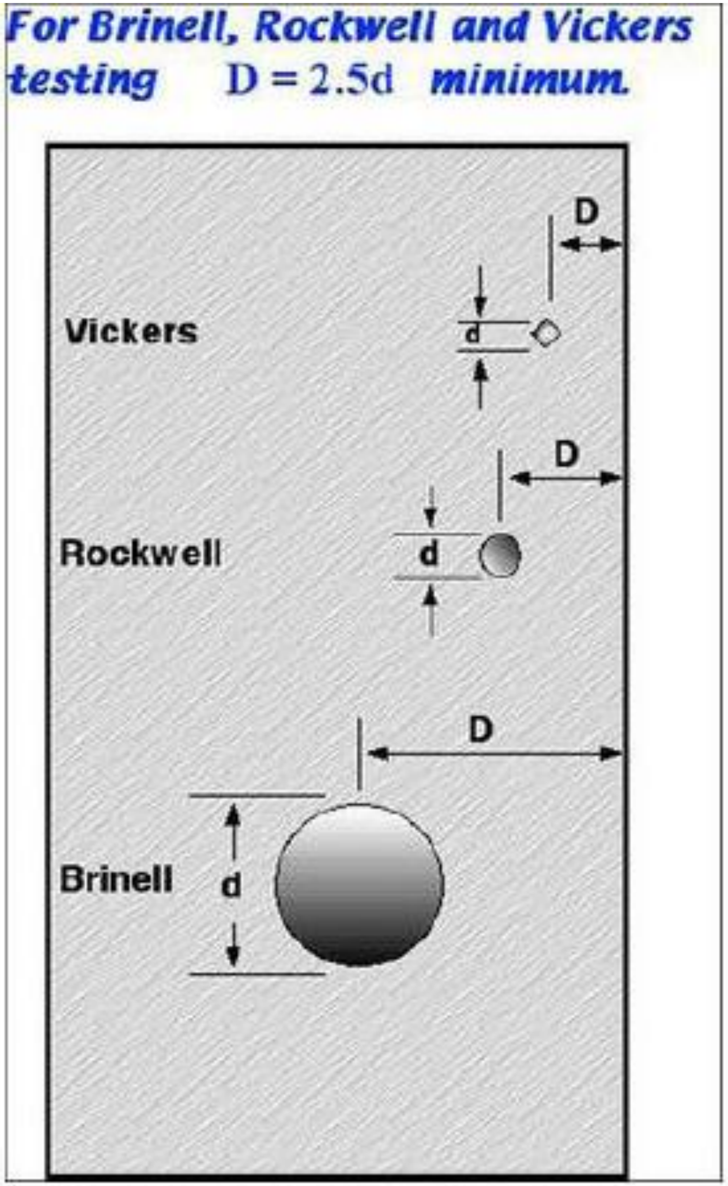
Comparison



Hardness-testing Methods and Formulas

		Shape of indentation			
Test	Indenter	Side view	Top view	Load, P	Hardness number
Brinell	10-mm steel or tungsten carbide ball	D d	d	500 kg 1500 kg 3000 kg	$HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid	136°	L	1–120 kg	$HV = \frac{1.854P}{L^2}$
Knoop	Diamond pyramid	$L/b = 7.11$ $b/t = 4.00$ t	b L	25 g–5 kg	$HK = \frac{14.2P}{L^2}$
Rockwell					
A C D	Diamond cone	120° t = mm		60 kg 150 kg 100 kg	HRA HRC HRD $= 100 - 500t$
B F G	$\frac{1}{16}$- in. diameter steel ball	t = mm		100 kg 60 kg 150 kg	HRB HRF HRG $= 130 - 500t$
E	$\frac{1}{8}$- in. diameter steel ball			100 kg	HRE

Minimum distance from edge



For Brinell, Rockwell and Vickers testing D = 2.5d *minimum.*

Watching of the testings

1Rockwell Hardness Test.mp4

2Brinell Hardness Test.mp4

3