Engineering Materials & Metallurgy

(MEMEC02/MPMEC02)

UNIT-2

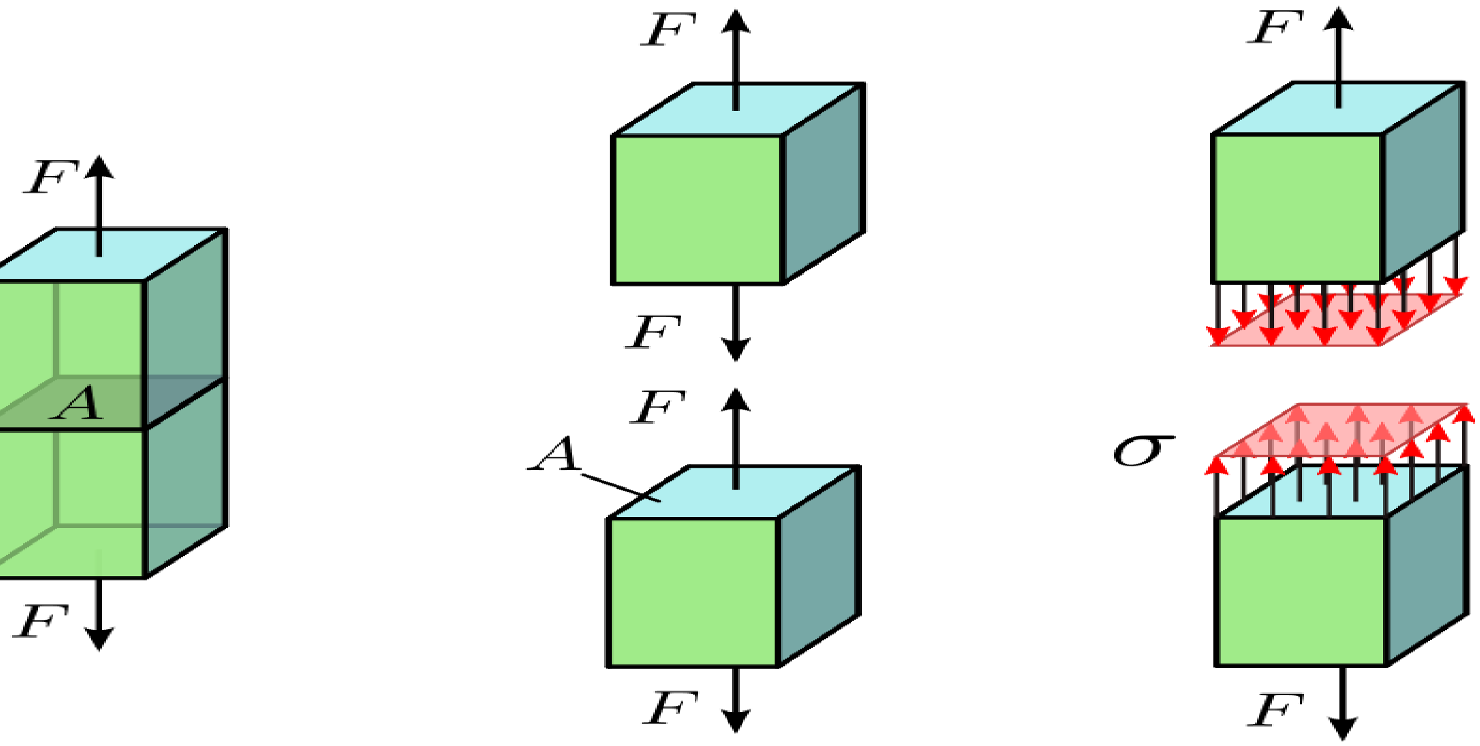
MECHANICAL PROPERTIES AND TESTING

Contents (Unit 2)

Lec. No.	Details of the Topics to be covered
1	Definition and classification of stress and strain
2	Stress-strain curve, Impact strength
3	Toughness, Hardness
4	Fracture and its classification (ductile vs brittle)
5	Fatigue
6	Creep
7	Non-destructive testing - I
8	Non-destructive testing - II

Stress/ Normal Stress/ Simple Stress

A material when subjected to an external force, an internal resisting force induced with in the material, this **internal resistive force is know as stress** or normal stress.



Normal stress

$$\sigma = \frac{P}{A}$$

σ – Normal Stress

P – Axial Force

A – Cross Sectional Area

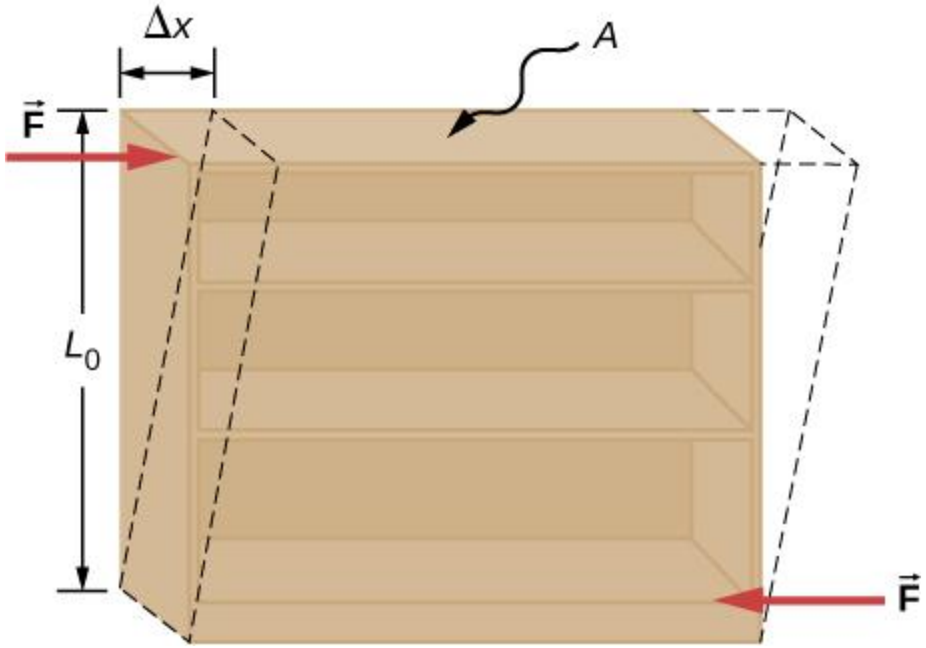
Unit of stress: In S.I.

N/m^2 (Pa)

Other units used in practice are **N/mm^2, kN/mm^2.**

Shear stress

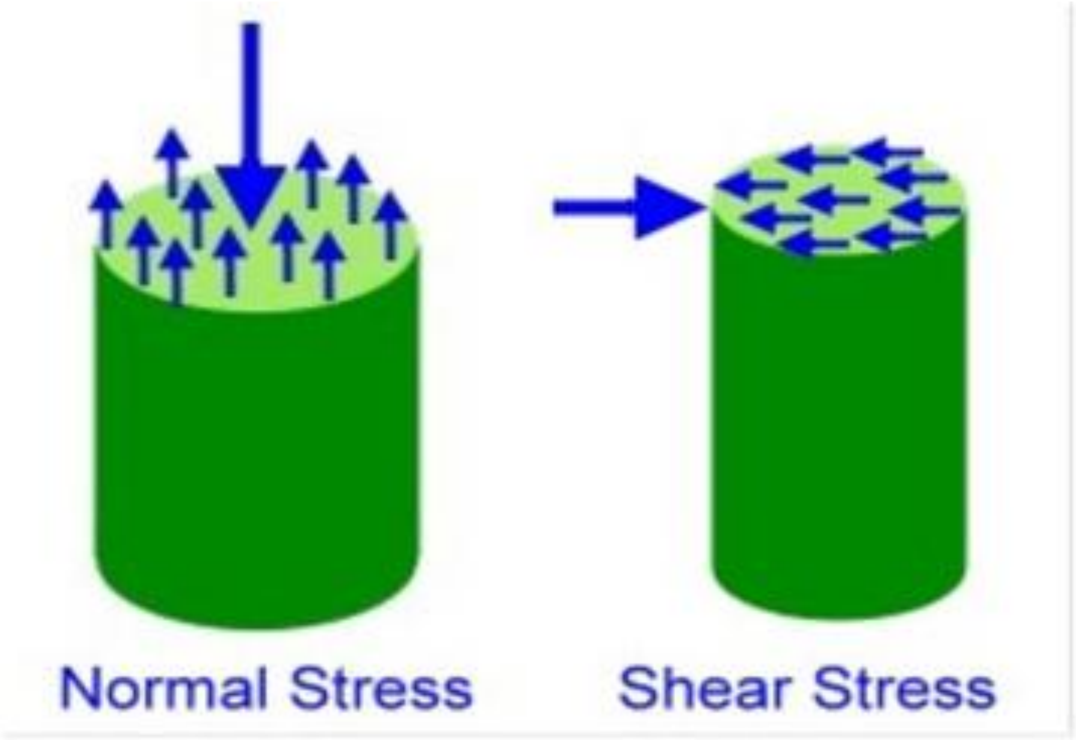
Shear stress is equal to shearing force per unit area.



The shear modulus is the proportionality constant , and is defined by the ratio of stress to strain. It is denoted by symbol S

$$S = \frac{\textbf{Shear stress}}{\textbf{\textit{Shear strain}}}$$

Difference between Normal stress and Shear stress



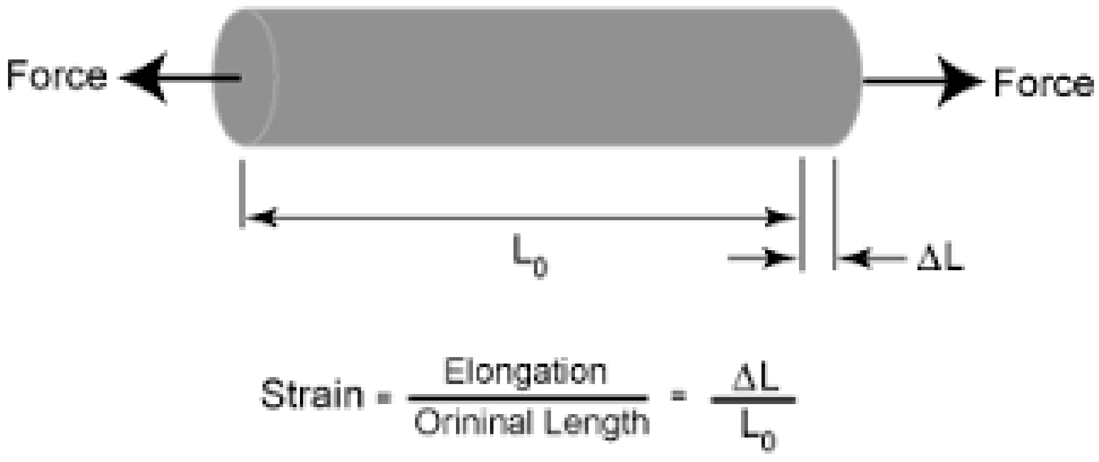
Strain

When an external force applied on a body, there is some change produced in dimensions of the body. ***The ration of change in dimensions of the body to the original dimension is known as strain.***

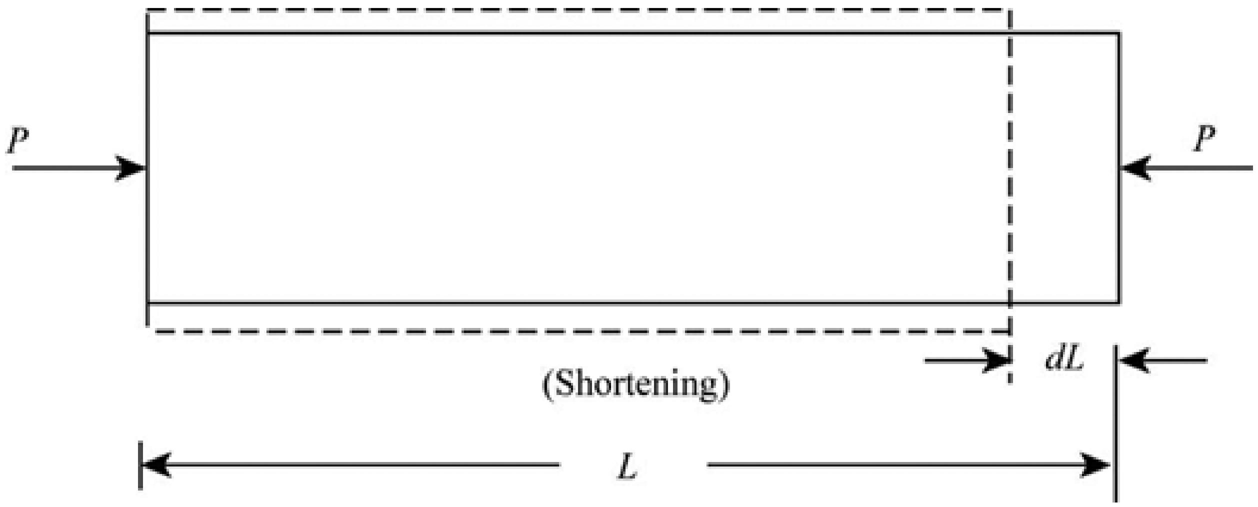
Stain is a **dimensionless quantity**

Types of strain:

- **Tensile strain:** It is the ratio of change in length to the original length of a body when subjected to a tensile force on it.



- **Compressive strain:** It is the ratio of change in length to the original length of a body when subjected to a compressive force on it.



- **Volumetric strain:** It is the ration of change in volume of the body to the original volume.
- **Shear Strain:** Stain induced due to shear stress.

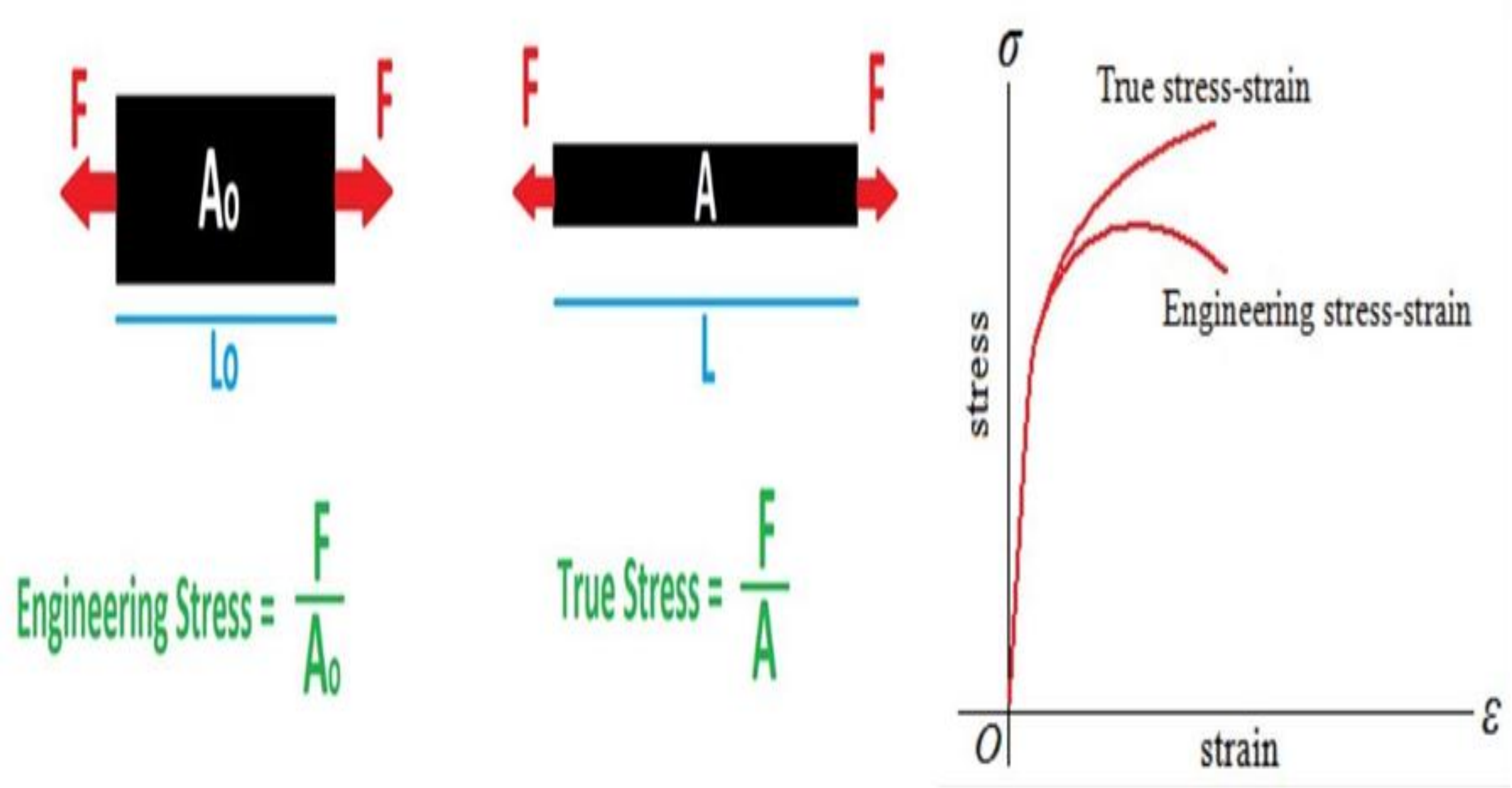
Engineering stress is the applied load divided by the original cross-sectional area of a material.

True stress is the applied load divided by the actual cross-sectional area (the changing area with respect to time) of the specimen at that load

Engineering strain is the amount that a material deforms per unit length in a tensile test. Also known as nominal strain.

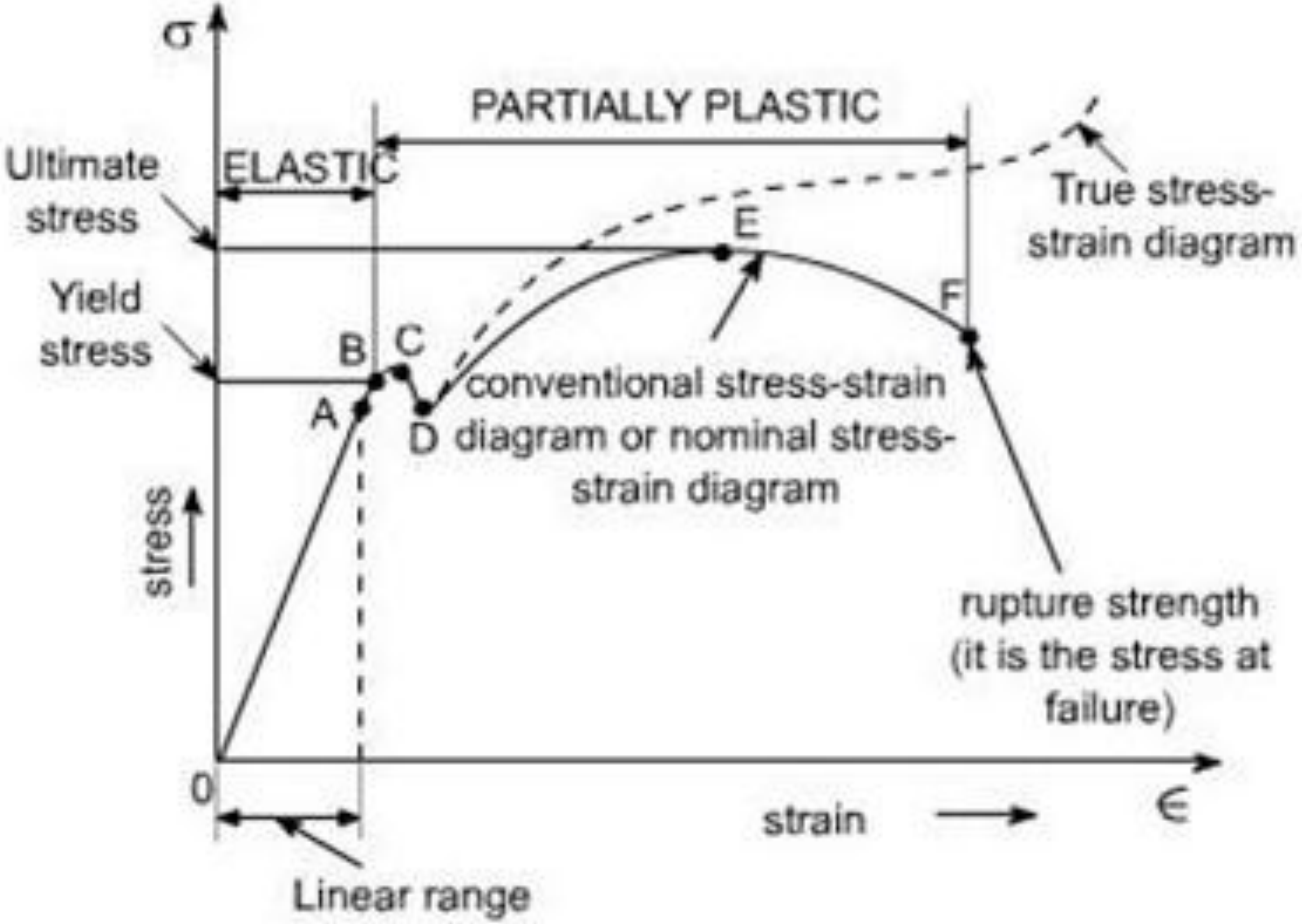
True strain is defined as the instantaneous elongation per unit length of the specimen.

True stress and true strain



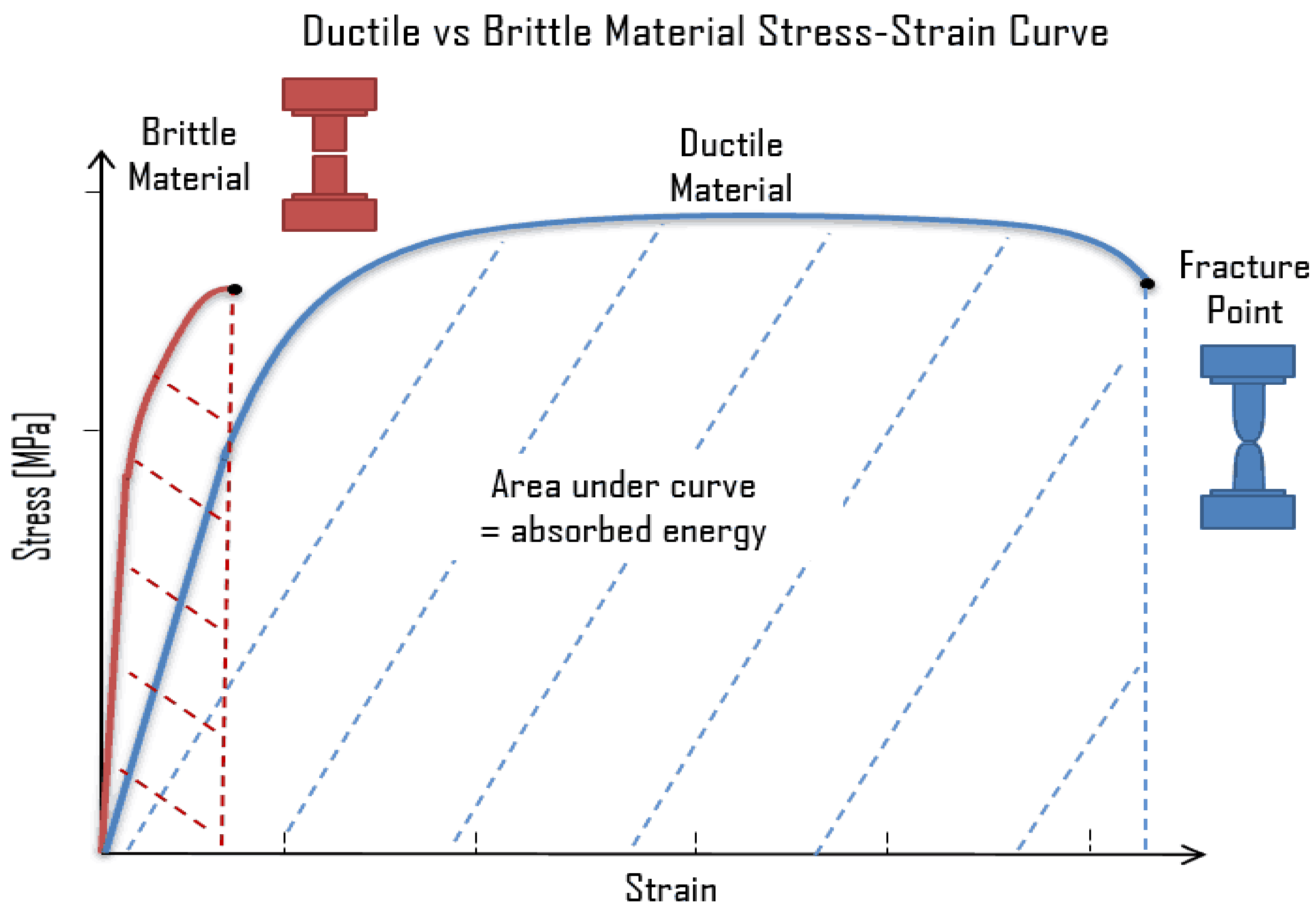
A	Proportional limit
B	Elastic limit
C	Upper yield point
D	Lower yield point
E	Ultimate stress
F	Fracture point

O-A	Linearly elastic
O-B	Elastic zone
B-F	Plastic zone
C-D	Yielding of material
D-E	Strain hardening
E-F	Necking



Stress strain graph for mild steel

Stress strain diagram for ductile and brittle materials



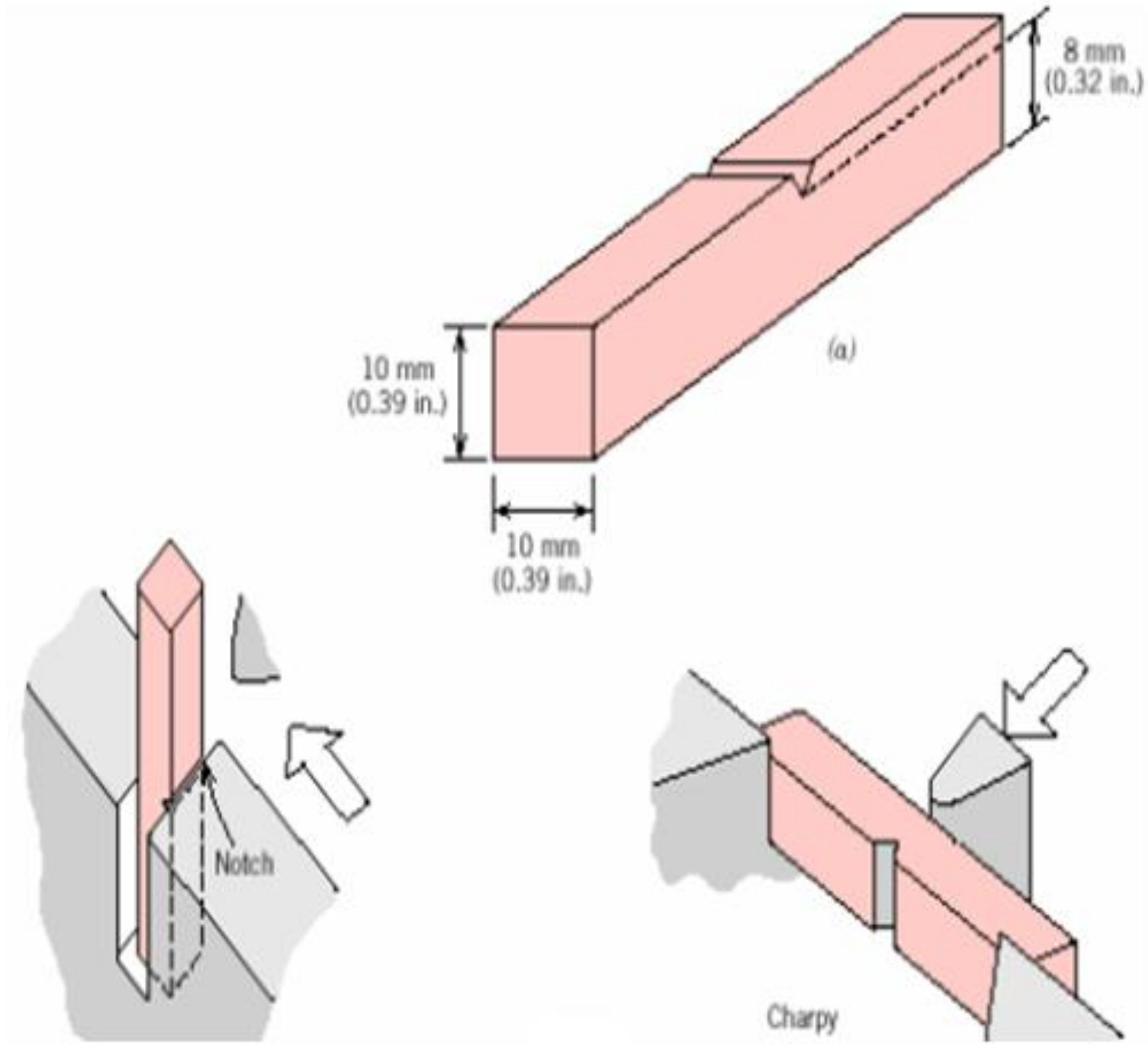
Impact Strength

The ability of a materials to sustain impact forces until fracture occurred known as its impact strength.

Types of impact test are;

- Izod impact test
- Charpy impact test

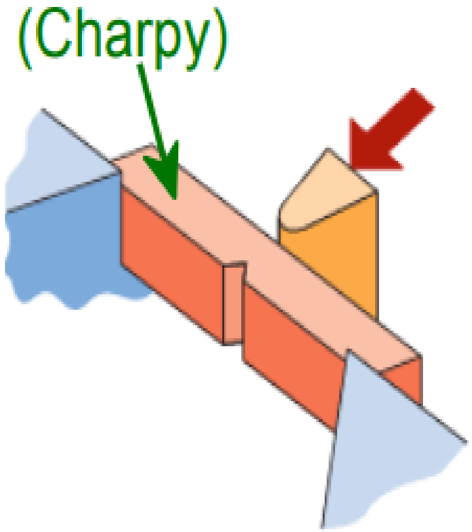
Impact test

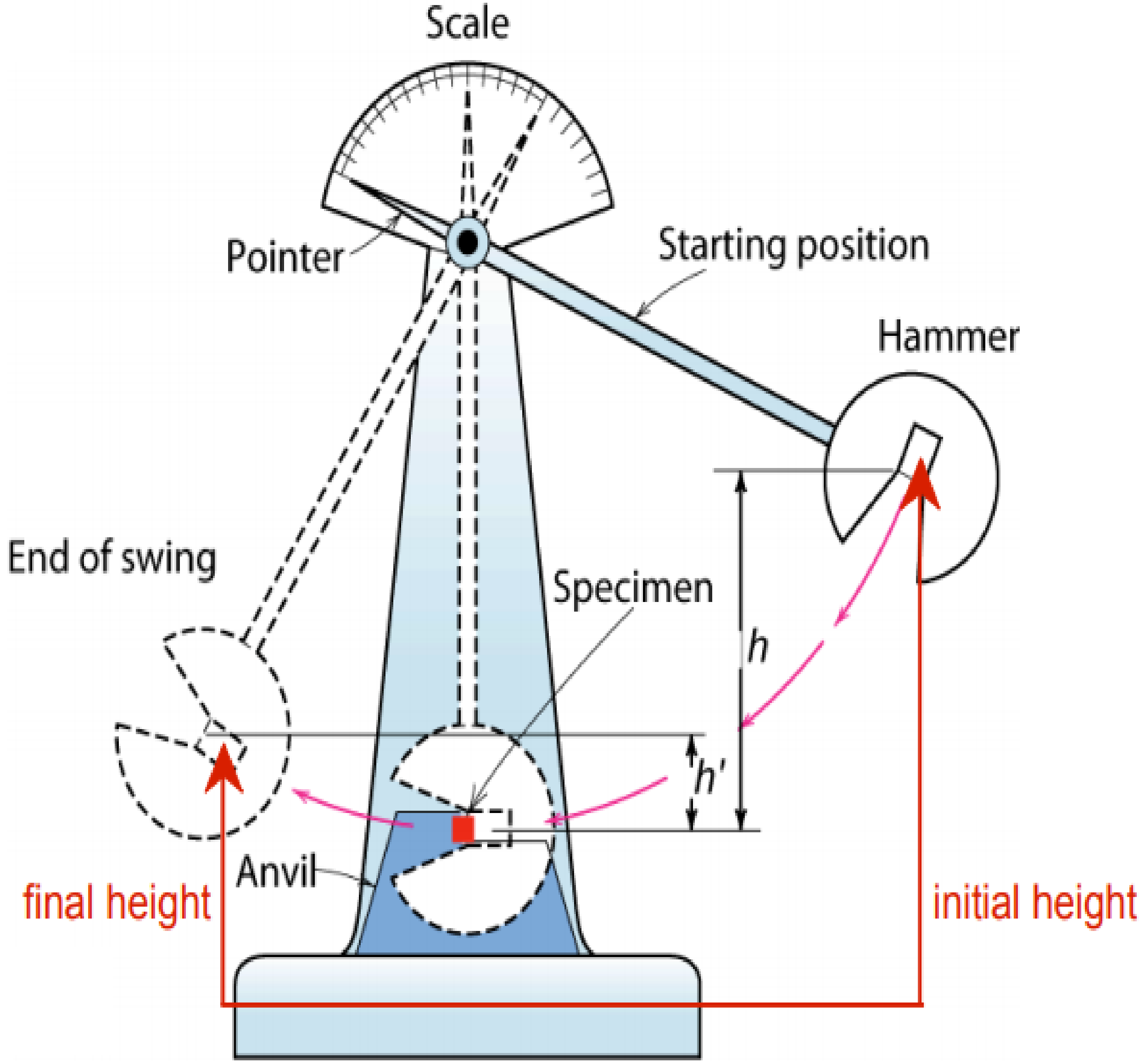


Izod

Charpy

Charpy Impact Test





	Charpy Impact Testing	Izod Impact Testing
Materials Tested	Metals	Plastics & Metals
Types of Notches	U-notch and V-notch	V-notch only
Position of the Specimen	Horizontally, notch facing away from the pendulum	Vertically, notch facing toward the pendulum
Striking Point	Middle of the sample	Upper Tip of the sample
Common Specimen Dimensions	55 x 10 x 10 mm	64 x 12.7 x 3.2 mm (plastic) or 127 x 11.43 mm round bar (metal)
Common Specifications	ASTM E23, ISO 148, or EN 10045-1	ASTM D256, ASTM E23, and ISO 180

Toughness

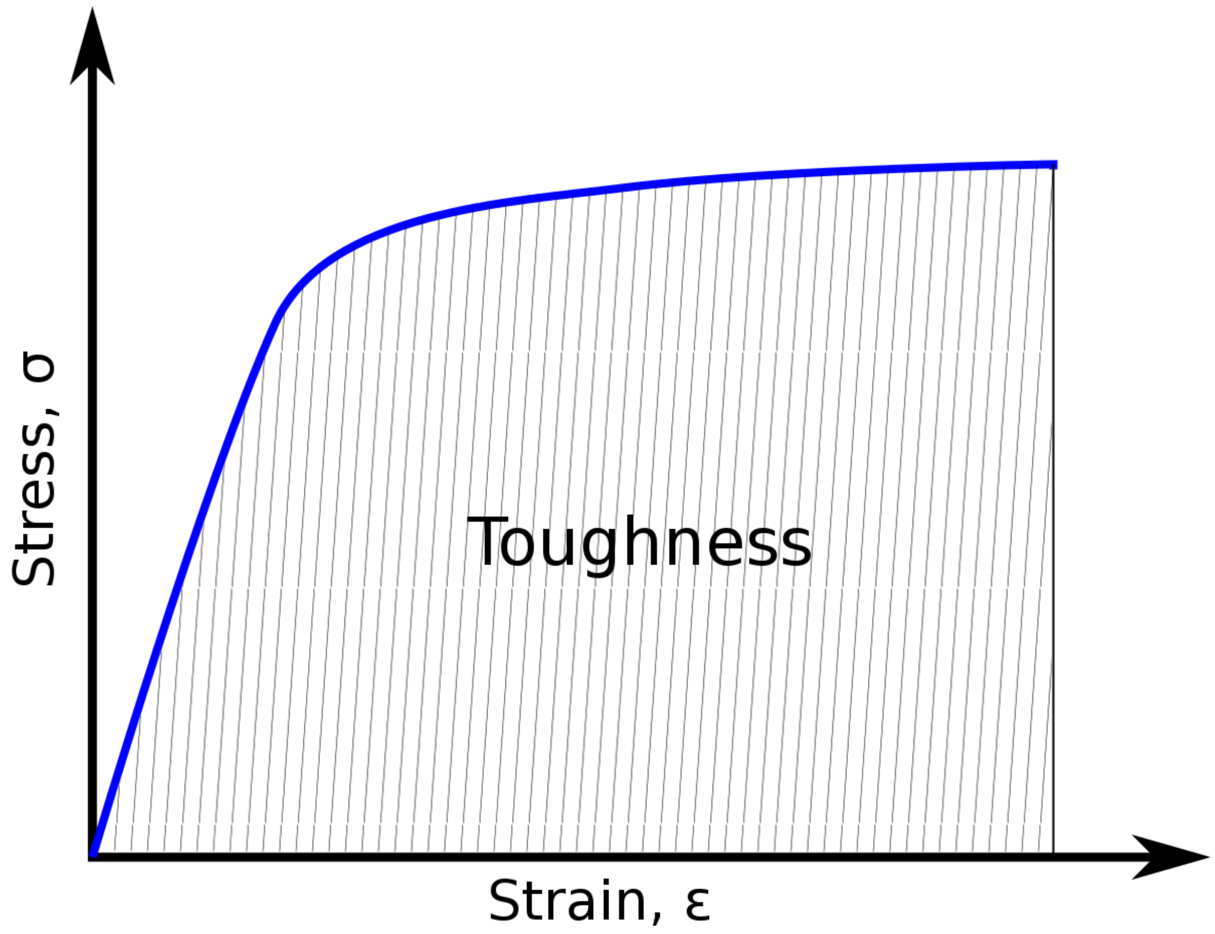
Toughness is the ability of the material to absorb energy during plastic deformation upto fracture.

.A material with high strength and high ductility will have more toughness than a material with low strength and high ductility.

Toughness is a good combination of strength and ductility.

one way to measure toughness is by calculating the area under the stress strain curve from a tensile test. This value is simply called "material toughness" and it has units of energy per volume.

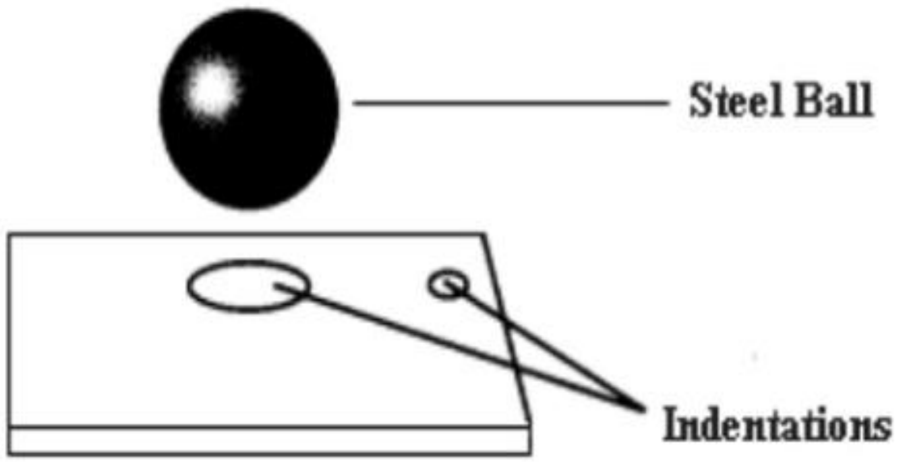
Material toughness equates to a slow absorption of energy by the material.


Stress, σ
Toughness
Strain, ε

Hardness

- It is a measure of a material's **resistance to localized plastic deformation** (e.g. A small dent or a scratch).
- Hardness tests are performed more frequently than any other mechanical test for several reasons:

1. They are **simple and inexpensive**
2. The test is **non-destructive**
3. Other mechanical properties often may be estimated from hardness data, such as tensile strength.



Types of Hardness Tests

Different types of hardness tests are:

- ➢Rockwell Hardness Tests
- ➢Brinell Hardness Tests
- ➢Vickers and Knoop Hardness Tests

Rockwell Hardness Tests

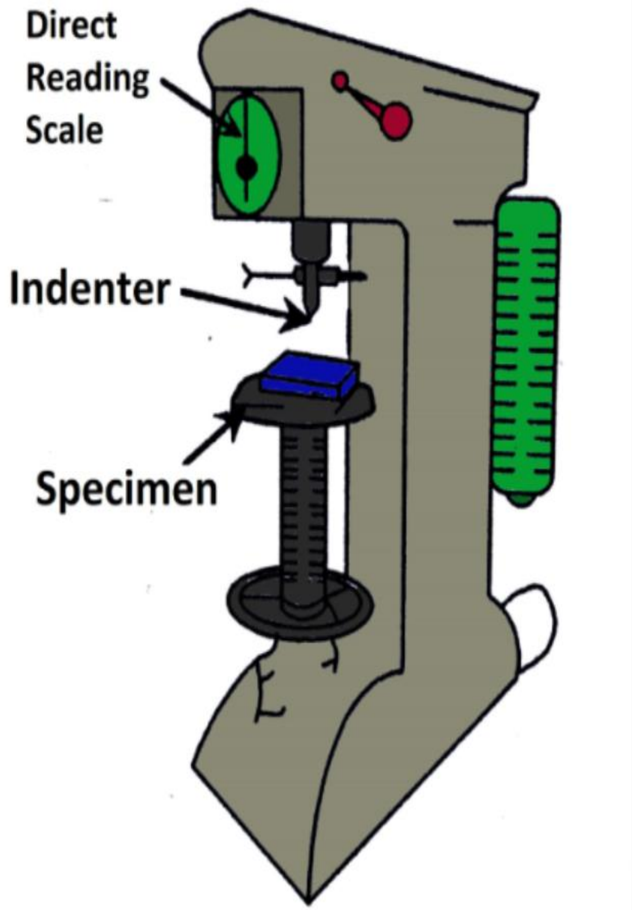
- The Rockwell tests constitute most common method used to measure hardness because they are so **simple to perform and require no special skills.**
- **Several different scales may be utilized from possible combinations of various indenters and different loads**, which permit the testing of all metal alloy and as well as some polymers.
- Indenters include **spherical and hardened steel balls having diameters of 1/16, 1/8,1/4 and 1/2 inch** and a conical diamond indenter, which is used for the hardest material.
- Types of Rockwell tests:

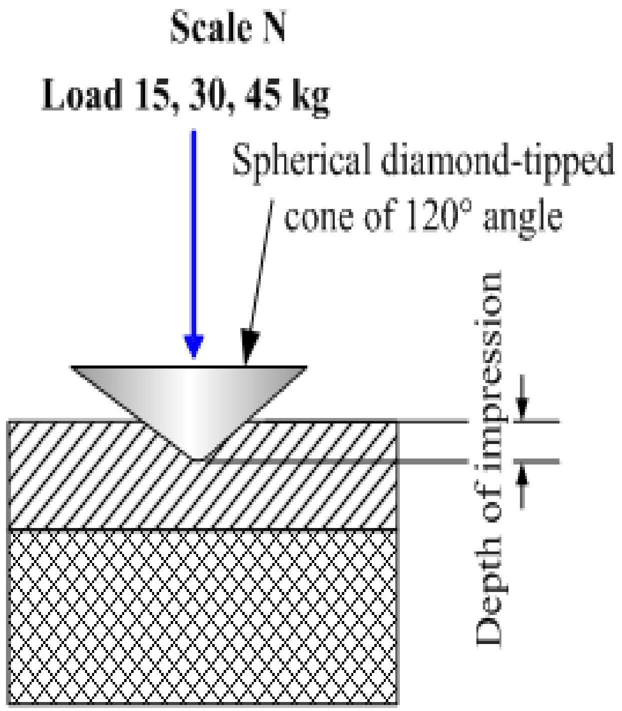
Rockwell (Minor load is 10 kg and major load are 60,100 and 150 kg)

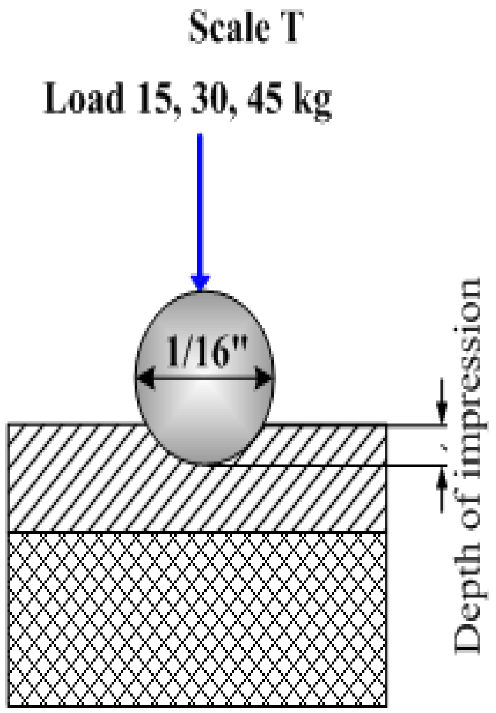
Superficial Rockwell (Minor load is 3 kg and major load are 15, 30 and 45 kg)

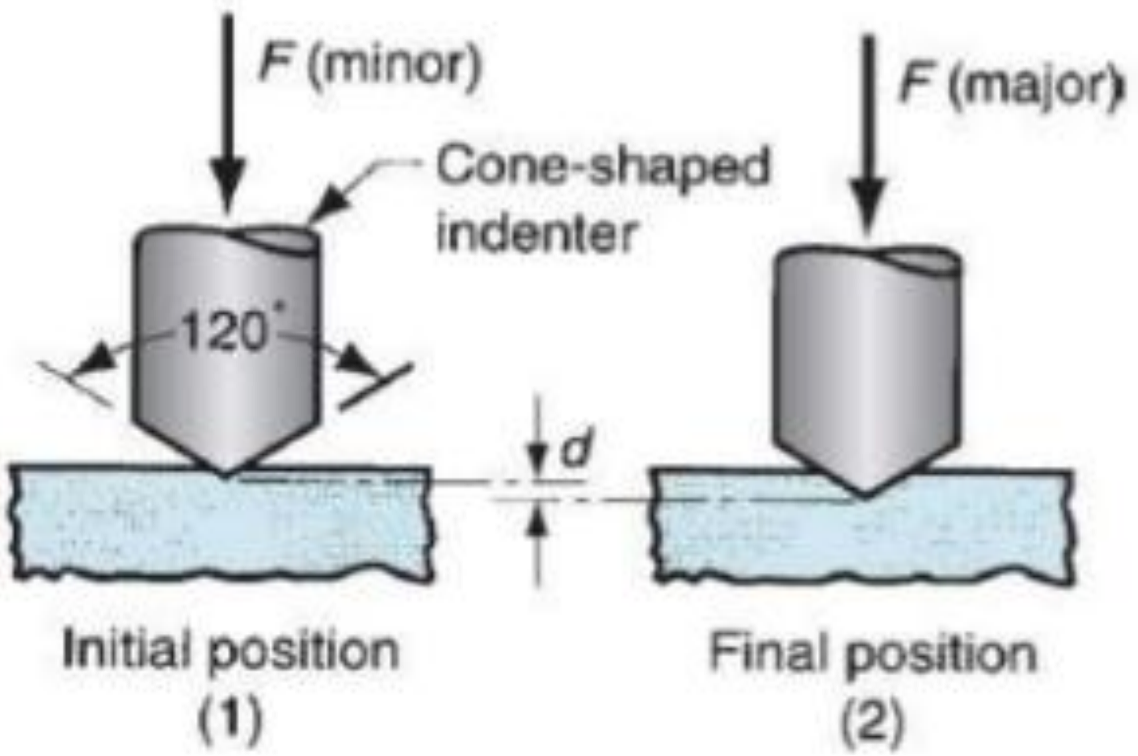
For both the scale designated y the **symbol HR**

Rockwell Superficial Hardness Test








F (minor)
Cone-shaped indenter
120°
F (major)
d
Initial position
(1)
Final position
(2)
Rockwell

Rockwell Hardness Scale

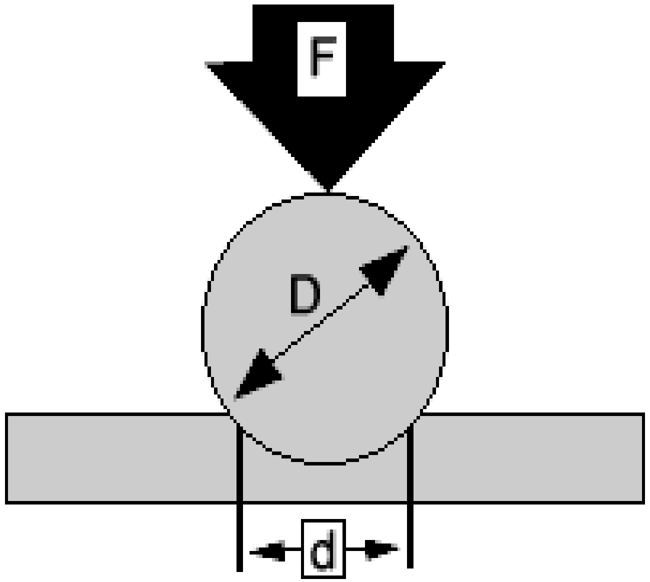
Scale symbol	Penetrator	Major load (kg.)	Dial number
A	Diamond	60	Black
B	1/16-inch ball	100	Red
C	Diamond	150	Black
D	Diamond	100	Black
E	1/8-inch ball	100	Red
F	1/16-inch ball	60	Red
G	1/16-inch ball	150	Red
H	1/8-inch ball	60	Red
K	1/8-inch ball	150	Red

Brinell Hardness

- The diameter of the hardened steel (or tungsten carbide) indenter is 10 mm.

- Standard loads range between 500 and 3000kg in 500 kg increments; during a test, the load is maintained constant for a specified time (between 10 and 30 sec).

- The Brinell hardness number, HB, is a function of both the magnitude of the load and the diameter of the resulting indentation.

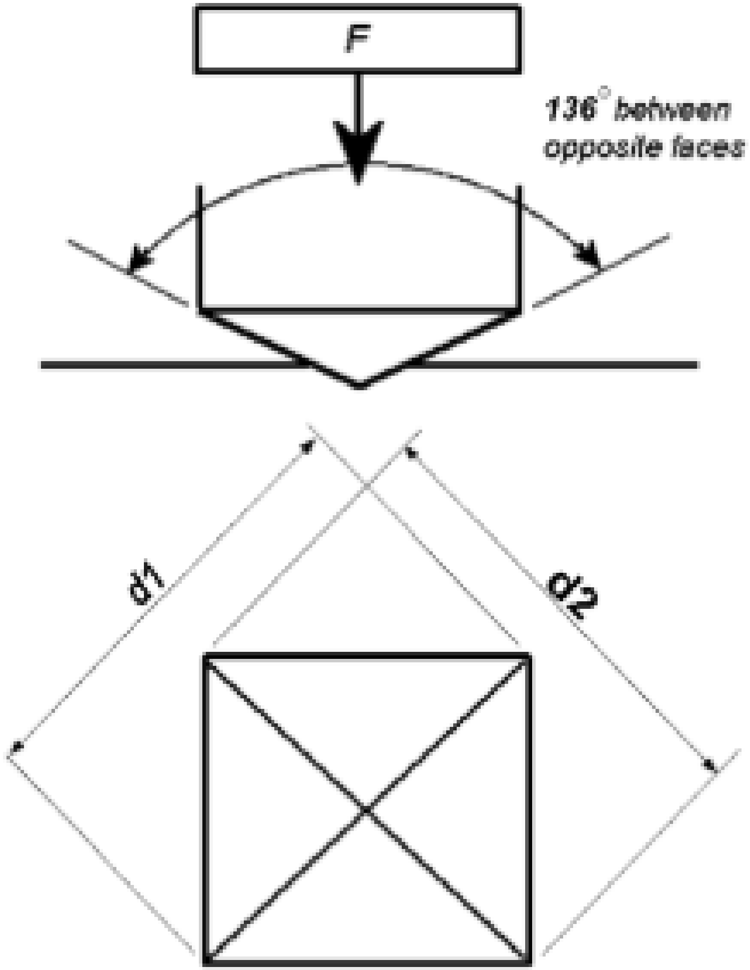


$$HB = \frac{2F}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

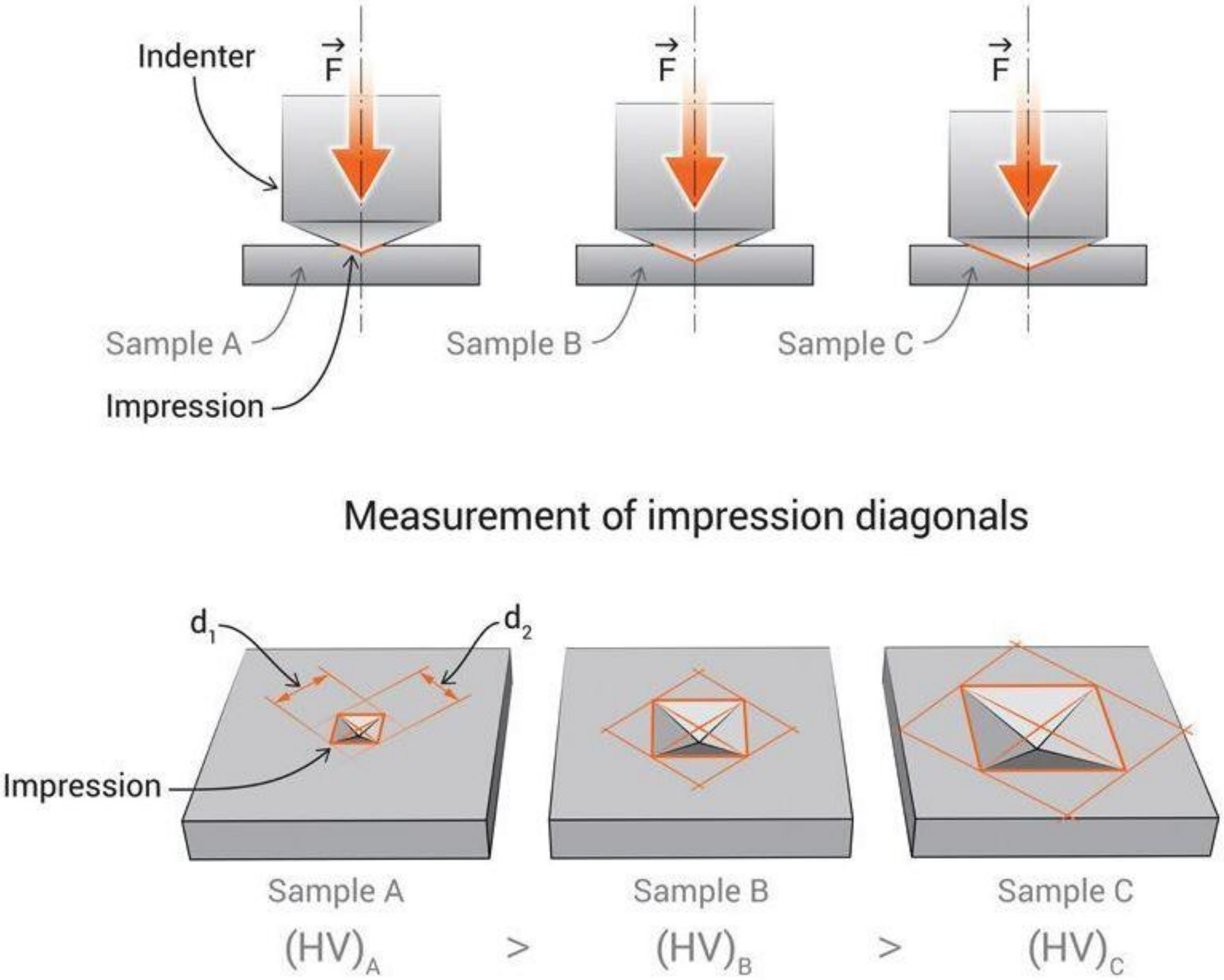
Vickers and Knoop Hardness Tests

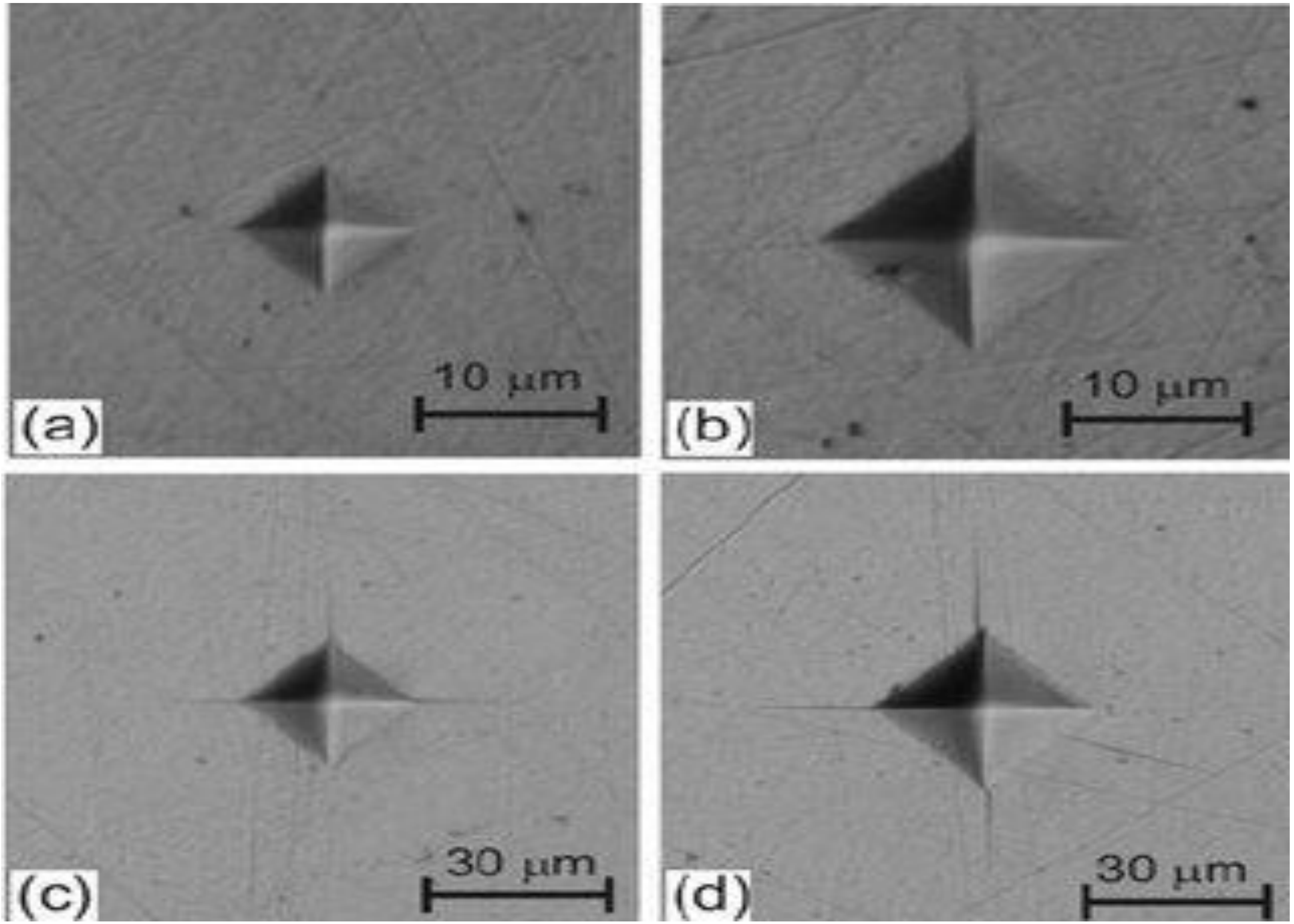
- In both the test a very small diamond indenter having pyramidical geometry is forced into the surface of the specimen.
- Applied loads are much smaller than for Rockwell and Brinell, ranging between 1 and 1000 g.
- The resulting impression is observed under a microscope and measured.
- The Vickers and Knoop hardness numbers are designated by HV and HK respectively.
- Knoop and Vickers are referred to as micro-indentation testing methods on the basis of indenter size.
- Knoop is used for testing brittle materials such as ceramics.

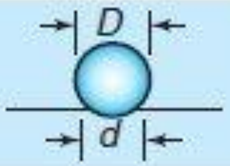
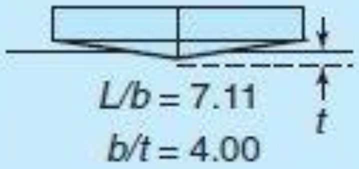
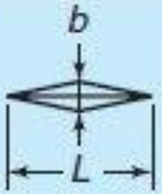
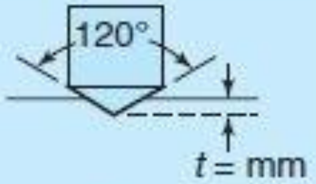
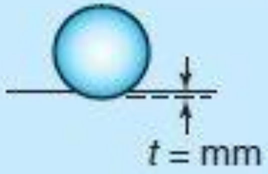
Vicker's Hardness



Vicker's Hardness




10 µm
(a)
10 µm
(b)
30 µm
(c)
30 µm
(d)

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

Fracture

The separation of a body into two or more pieces under the application of stress.

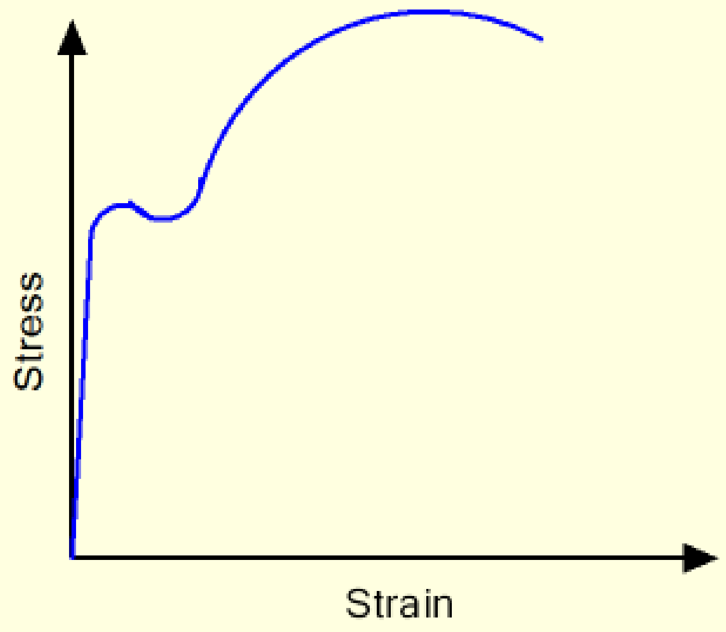
Types of fracture

- Ductile fracture
- Brittle fracture

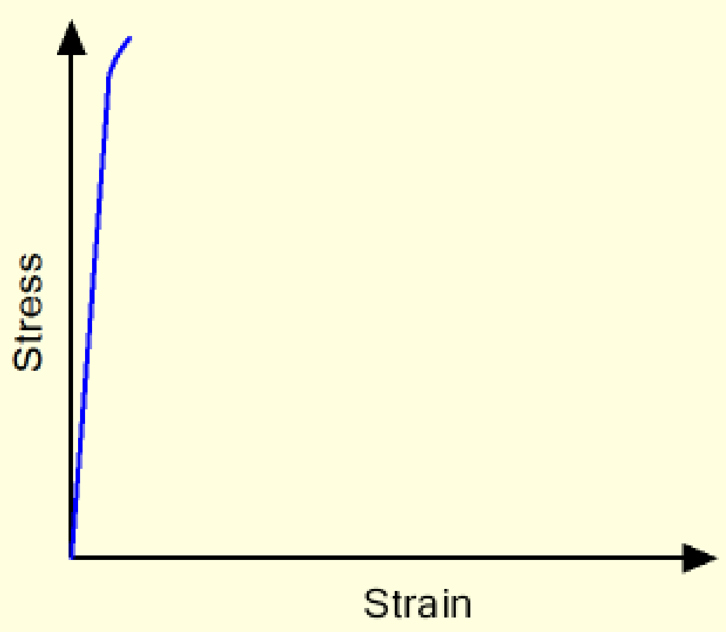
Ductile materials - extensive plastic deformation and energy absorption ("toughness") before fracture

Brittle materials - little plastic deformation and low energy absorption before fracture

Stress-Strain curve for ductile and brittle materials

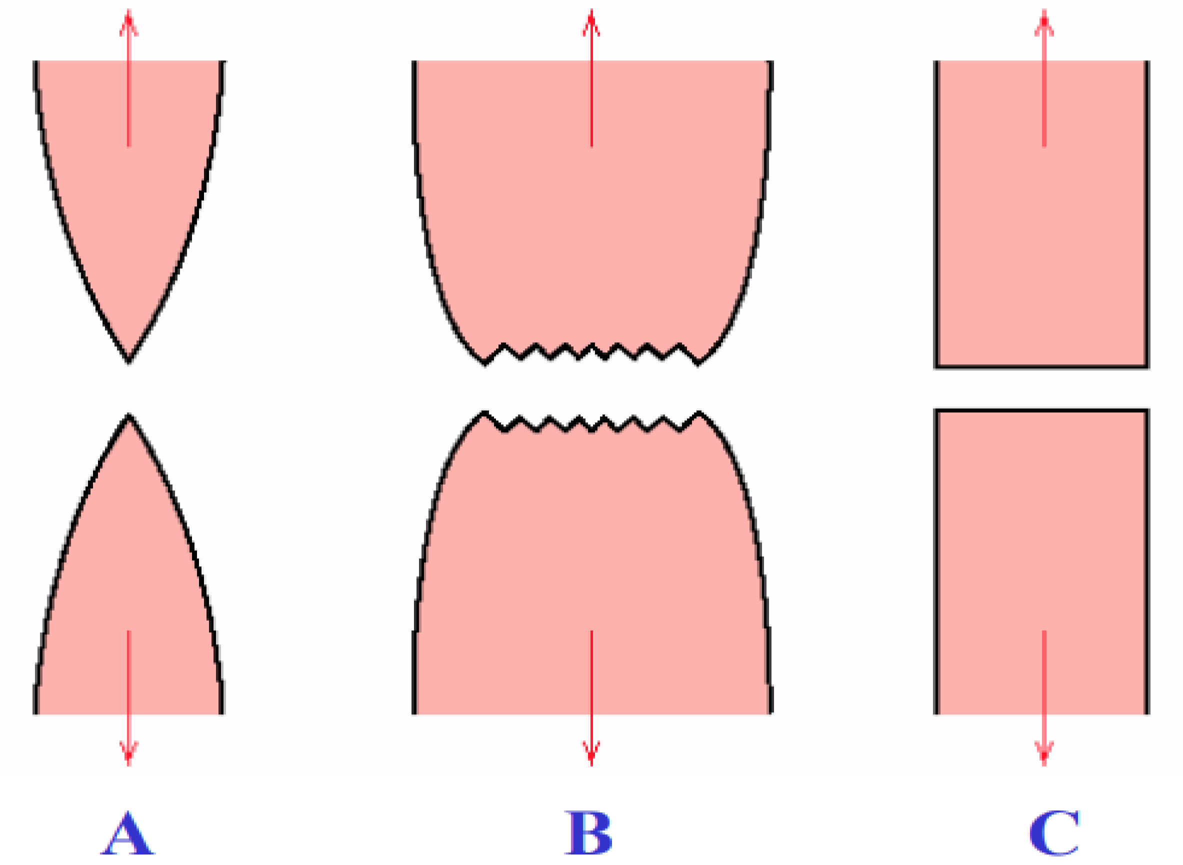


Typical Ductile Material



Typical Brittle Material

Fracture



A. **Very ductile**, soft metals (e.g. Pb, Au) at room temperature, other metals, polymers, glasses at high temperature.

B. **Moderately ductile fracture**, typical for ductile metals

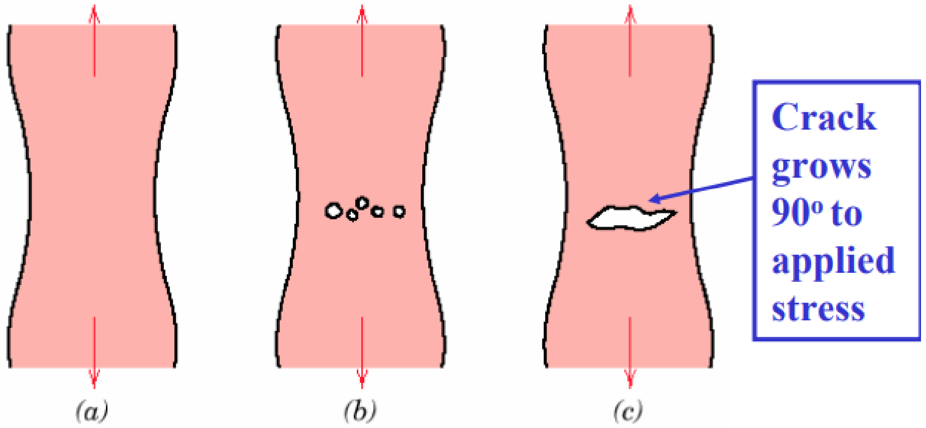
C. **Brittle fracture,** cold metals, ceramics.

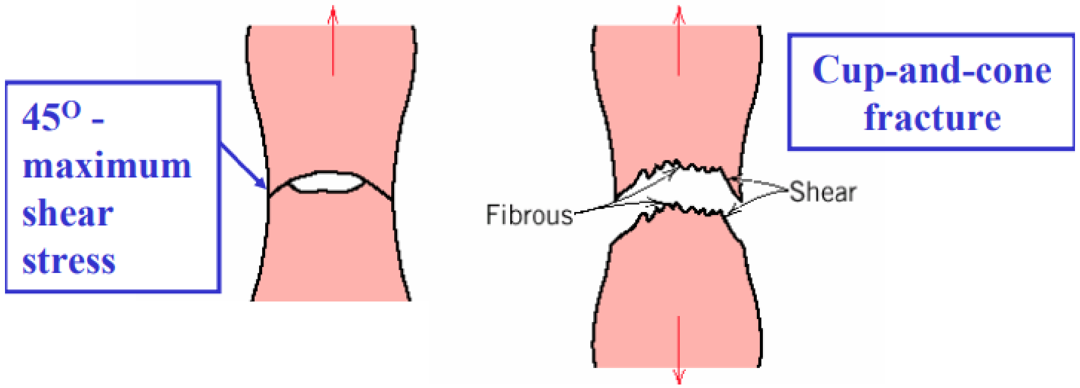
Ductile fracture

Ductile Fracture in the converse and involves large plastic deformation before separation.

(a)

cup-and-cone fracture





(a) Necking

(b) Formation of microvoids

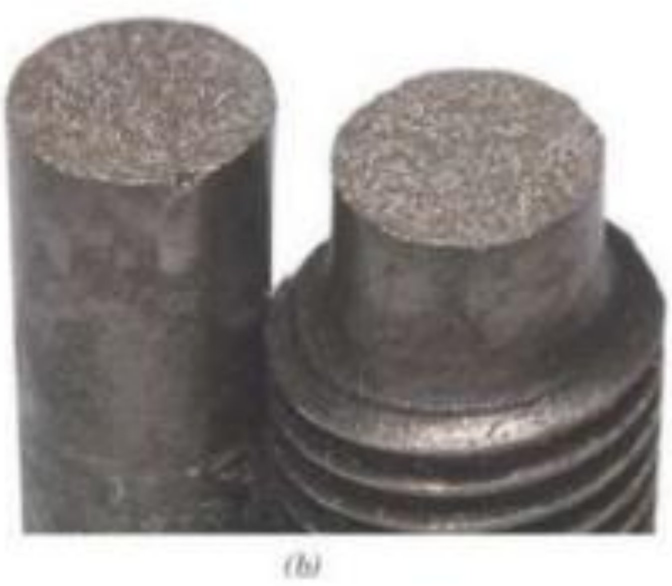
(c) Coalescence of microvoids to form a crack

(d) Crack propagation by shear deformation

(e) Fracture

Brittle fracture

Brittle Fracture involves fracture without any appreciable plastic deformation (i.e. energy absorption).

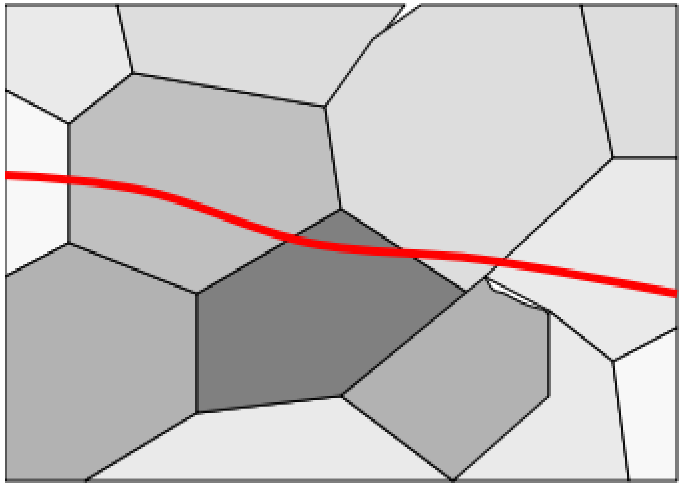


brittle fracture

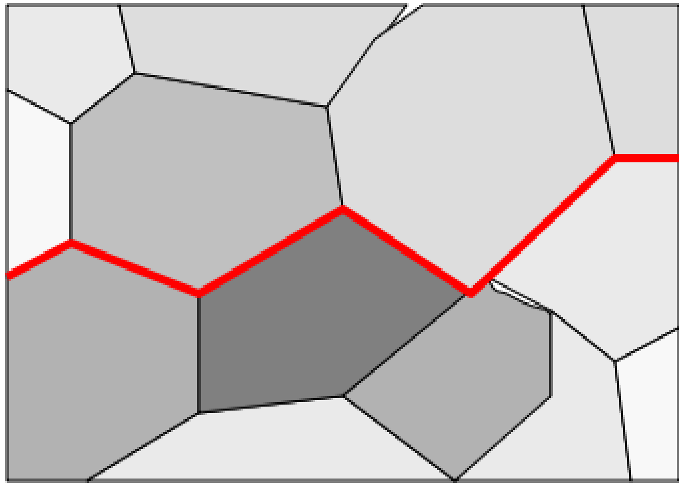
Types of Brittle fracture

Transgranular fracture: Fracture cracks pass through grains. Fracture surface have faceted texture because of different orientation of cleavage planes in grains.

Intergranular fracture: Fracture crack propagation is along grain boundaries (grain boundaries are weakened or embrittled by impurities segregation etc.)

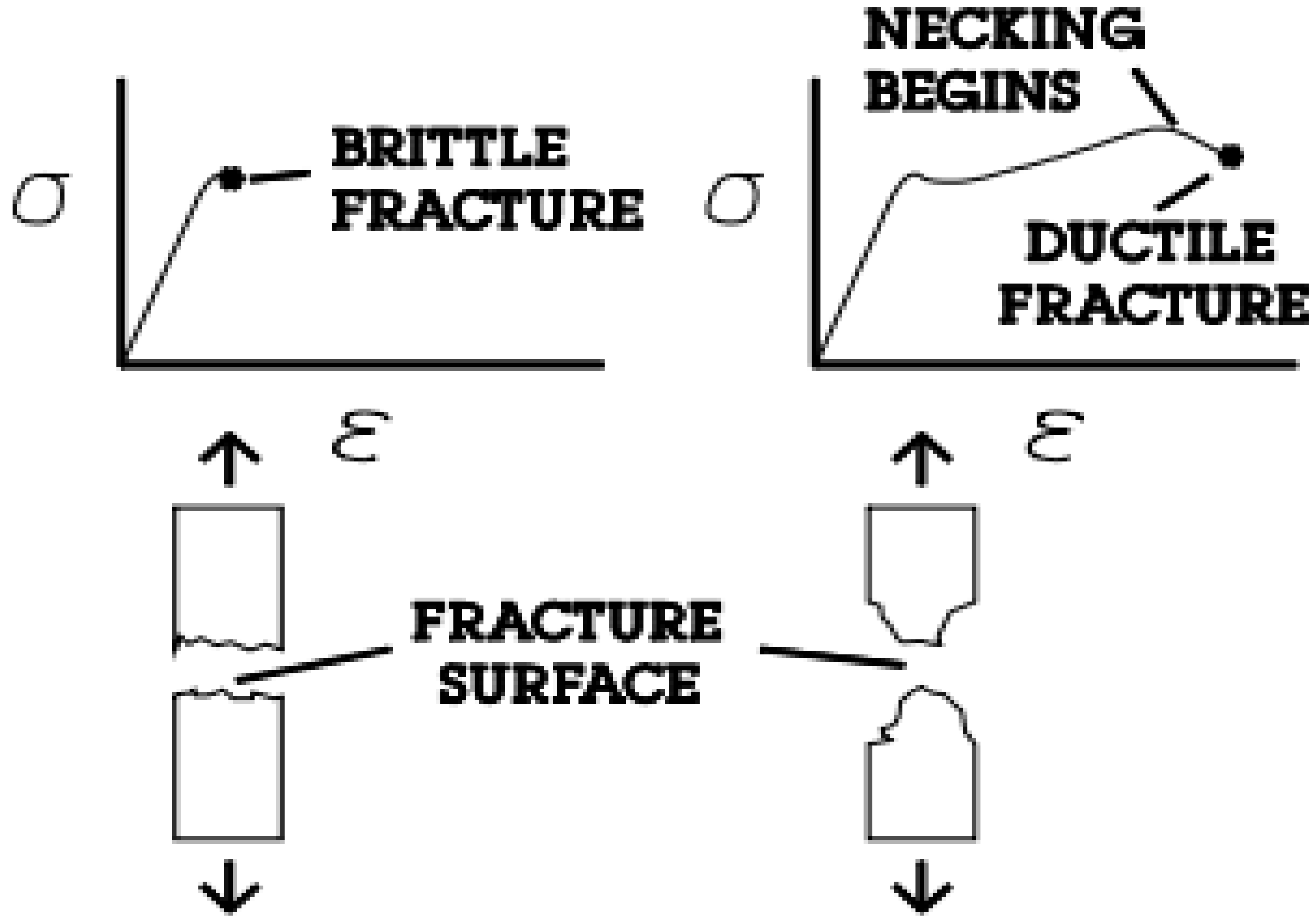


Transgranular fracture



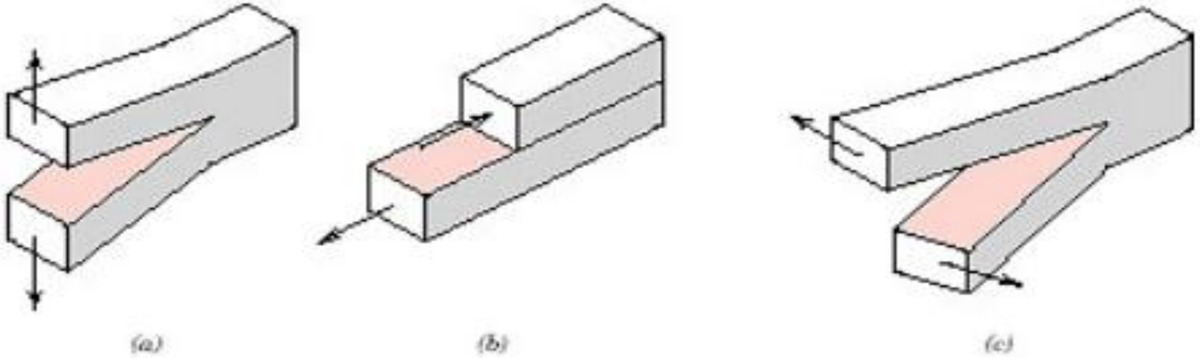
Intergranular fracture

Brittle vs. Ductile fracture



Modes of Fracture which Operate on Cracks

Mode I Mode II Mode III



Tensile Sliding Tearing

Mode I is most often encountered.

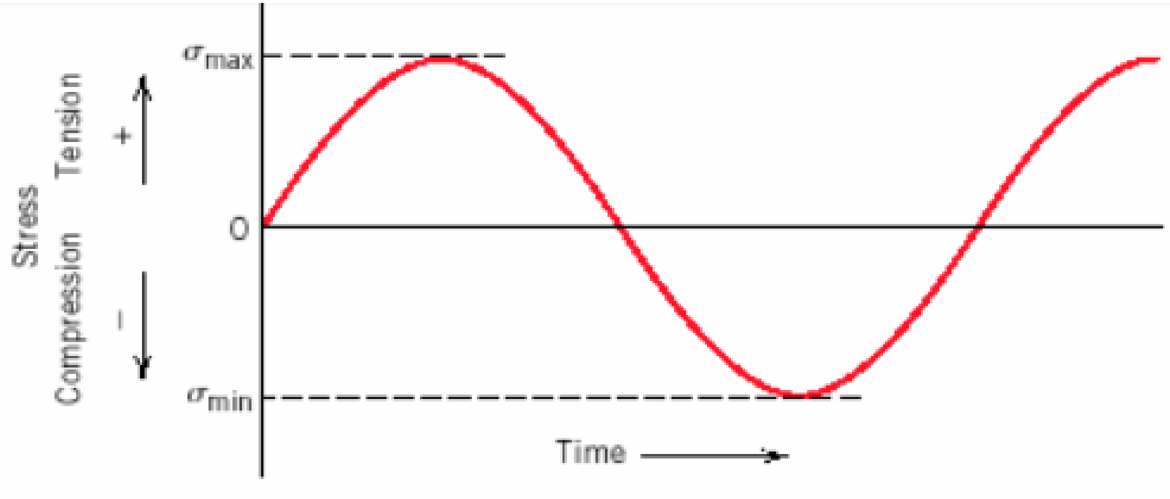
Fatigue failure

- ➢Failure that occurs **under fluctuating /cyclic loads** called fatigue failure.
- ➢Fatigue is the process by which ***most materials fails under cyclic loading (Approx. 90%)***
- ➢It occurs when material is subjected to alternative stresses, over a **long period of time**. ***Examples are bridges, turbine blades, bones etc.***

- ➢There are mainly three stress cycles with which loads may applied to the sample.

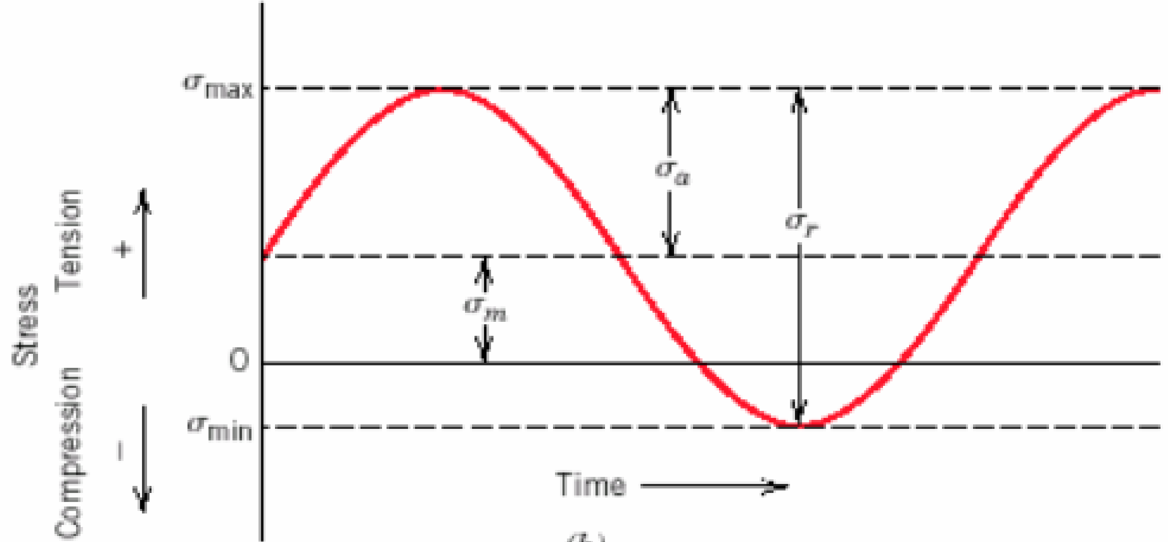
1. **Reversed stress cycle**
2. **Repeated stress cycle**
3. **Random stress cycle**

Fatigue stress cycle



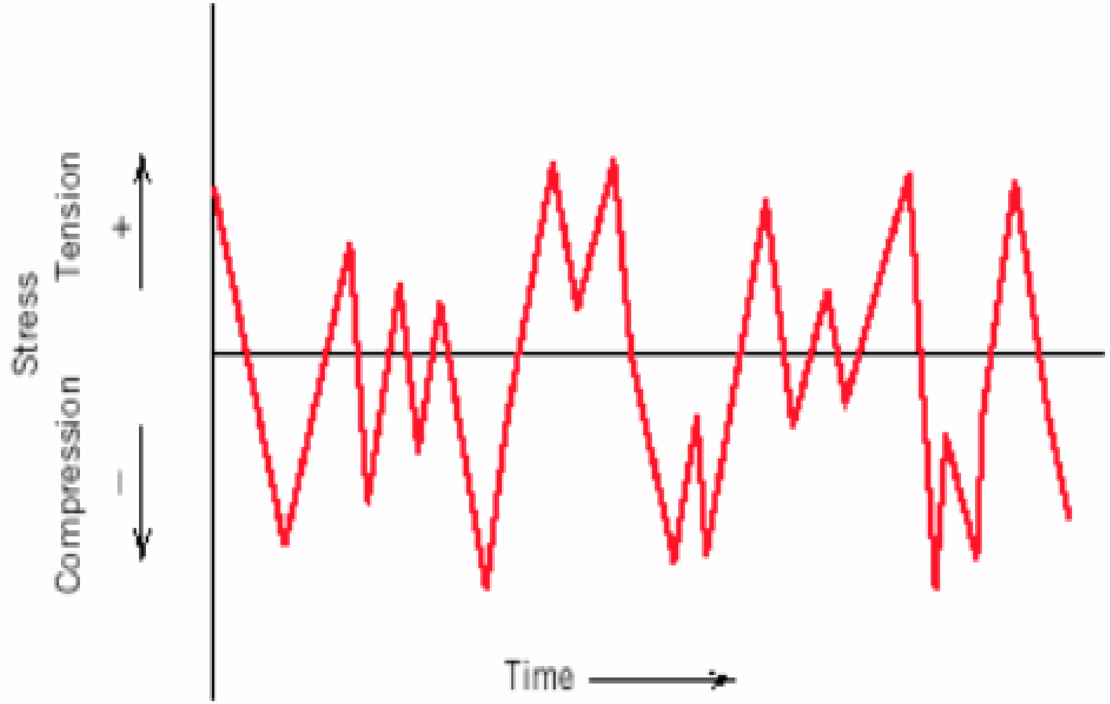
(a)

Periodic and symmetrical about zero stress



(b)

Periodic and asymmetrical about zero stress

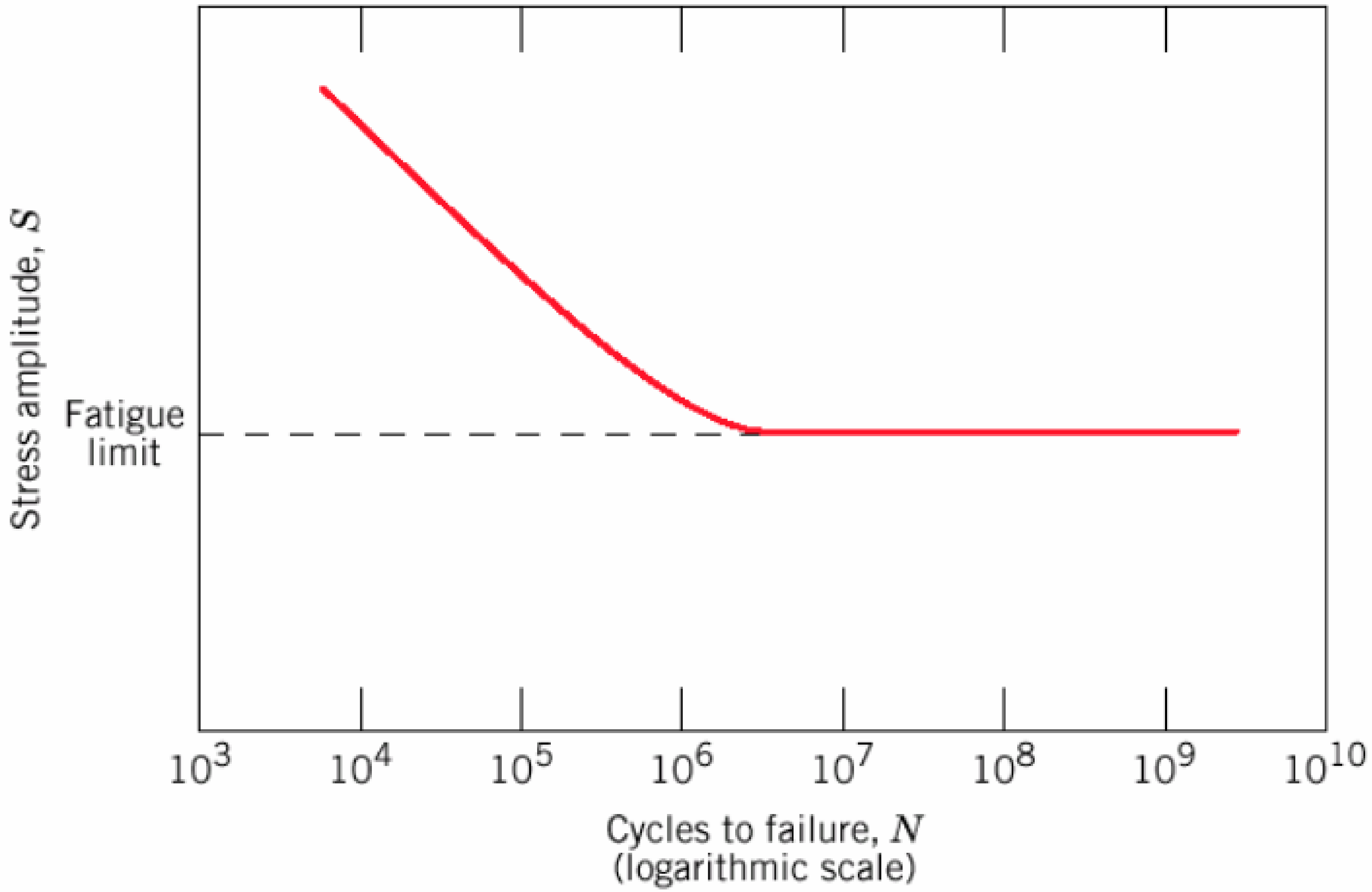


Random stress fluctuations

Stress cycles that can cause fatigue failure are characterized using the following parameters:

Range of stress,	$\sigma_r = \sigma_{max} - \sigma_{min}$
Alternating stress,	$\sigma_a = \sigma_r/2 = (\sigma_{max} - \sigma_{min})/2$
Mean stress,	$\sigma_m = (\sigma_{max} + \sigma_{min})/2$
Stress ratio,	$R = \sigma_{min} / \sigma_{max}$
Amplitude ratio,	$A = \sigma_a / \sigma_m = (1-R) / (1+R)$

S-N Curve


Stress amplitude, S
Fatigue
limit
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
Cycles to failure, N
(logarithmic scale)

Factors that affect fatigue life

- Quality of surface (Scratches, voids, etc.)
- Magnitude of stress
- Environmental effects (Thermal fatigue, Corrosion fatigue)

Solutions:

Polishing

Case Hardening

Optimizing geometry

Creep failure

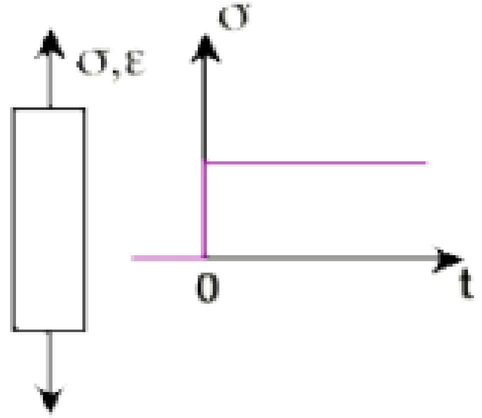
Creep is a **time-dependent and permanent** deformation of materials when subjected to a constant load at a **high temperature** (> 0.4 T_m). Examples: turbine blades, steam generators.

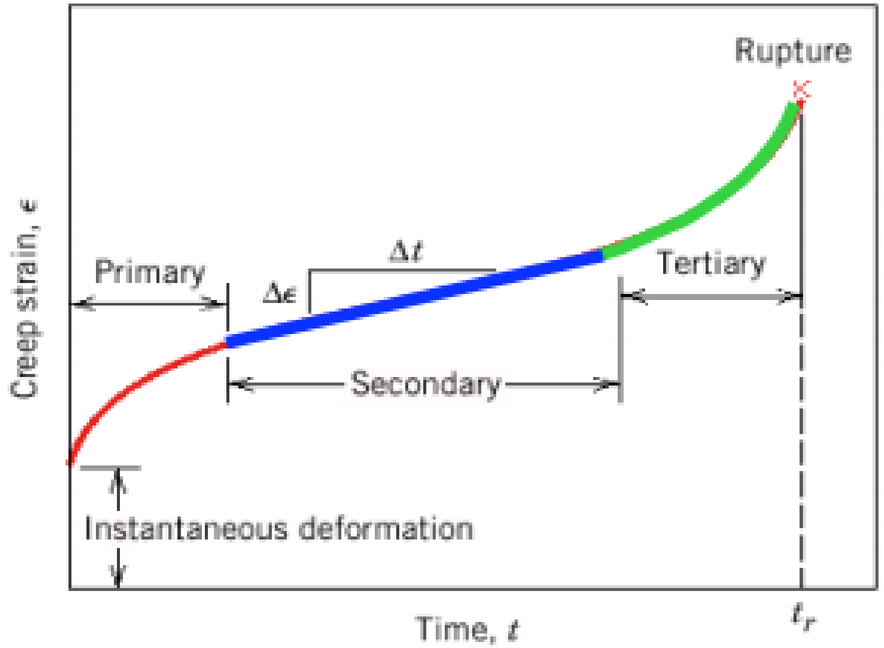
Creep rate – Stress & Temperature effects

- Two most important parameter that influence creep rate are: stress and temperature.
- With increase in either stress or temperature (a) instantaneous elastic strain increases (b) steady state creep rate increases and (c) rupture lifetime decreases.

Creep Failure

- Occurs at elevated temperature, $T > 0.4\ T_{melt}$
- Deformation at a constant stress changes with time.





Primary Creep: slope (creep rate) decreases with time.

Secondary Creep: steady-state i.e., constant slope.

Tertiary Creep: slope (creep rate) increases with time, i.e. acceleration of rate.

Non-Destructive Testing

- Non-destructive testing is the testing of materials, for surface or internal flaws or metallurgical condition, without interfering in any way with the integrity of the material or its suitability for service.

Types of NDT Tests

1. Radiography
2. Magnetic Particle Crack Detection
3. Dye Penetrant Testing
4. Ultrasonic Flaw Detection
5. Eddy Current and Electro-magnetic Testing

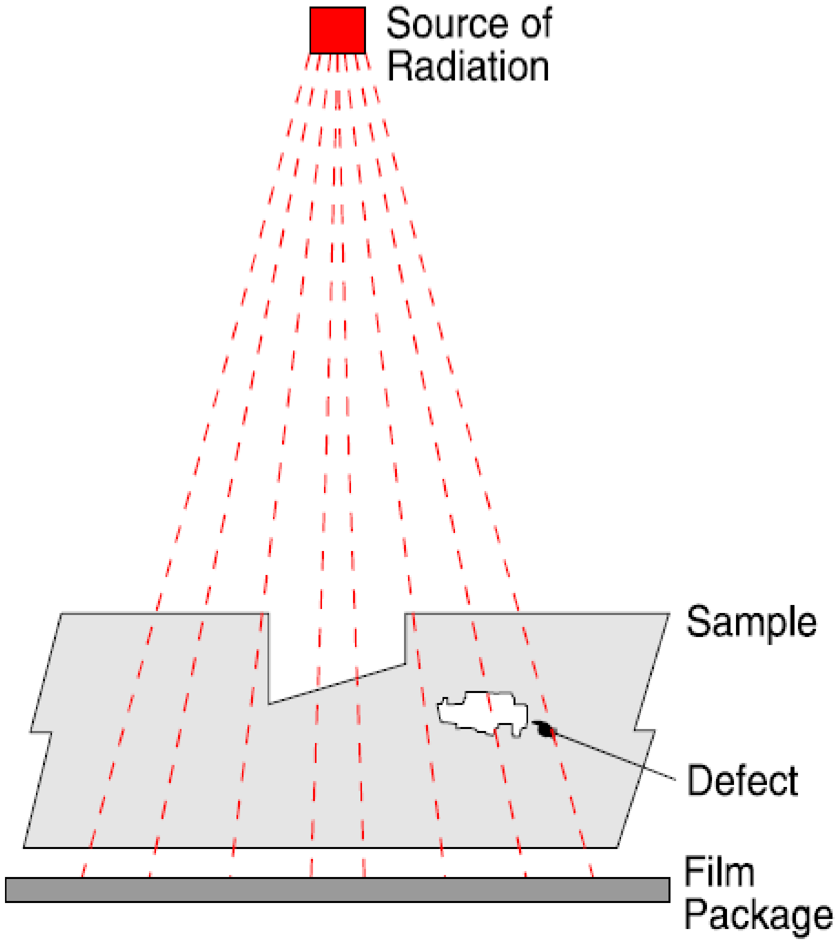
Radiography

- This technique is suitable for the detection of internal defects in ferrous and nonferrous metals and other materials.
- X-rays, generated electrically, and Gamma rays emitted from radio-active isotopes, are penetrating radiation which is differentially absorbed by the material through which it passes; the greater the thickness, the greater the absorption. Furthermore, the denser the material the greater the absorption.

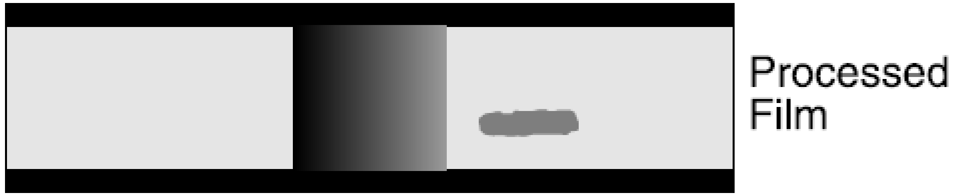
Method

- Material with internal voids is tested by placing the subject between the source of radiation and the film. The voids show as darkened areas.
- In X-radiography the penetrating power is determined by the number of volts applied to the X-Ray tube - in steel approximately 1000 volts per inch thickness is necessary.
- In Gamma radiography the isotope governs the penetrating power and is unalterable in each isotope. Thus Iridium 192 is used for 1/2" to 1" steel and Caesium 134 is used for 3/4" to 21/2" steel.

Process



Schematic illustration of a typical exposure arrangement for radiography. The source of radiation can be either an X-ray tube or a radioactive isotope.



The resultant radiograph shows the subject as seen from the source.

Advantages of Radiography

- Information is presented pictorially.
- A permanent record is provided which may be viewed at a time and place distant from the test.
- Useful for thin sections.
- Sensitivity declared on each film.
- Suitable for any material.

Disadvantages of Radiography

- Generally an inability to cope with thick sections.
- Possible health hazard.
- Need to direct the beam accurately for two-dimensional defects.
- Film processing and viewing facilities are necessary, as is an exposure compound.
- Not suitable for automation, unless the system incorporates fluoroscopy with an image intensifier or other electronic aids.
- Not suitable for surface defects.
- No indication of depth of a defect below the surface

Magnetic Particle Crack Detection

- This method is suitable for the detection of surface and near surface discontinuities in magnetic material, mainly ferritic steel and iron.

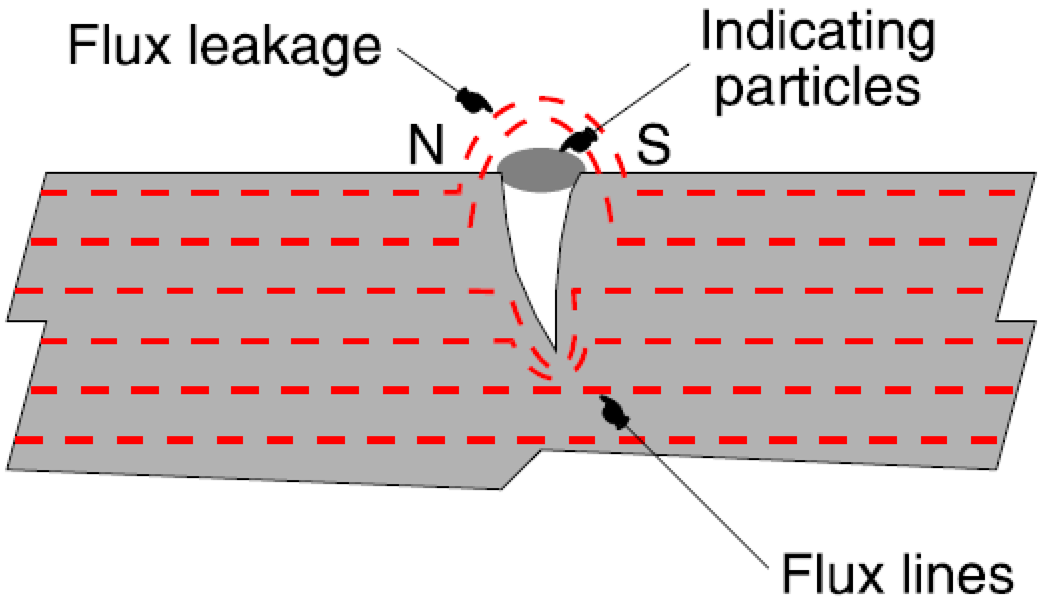


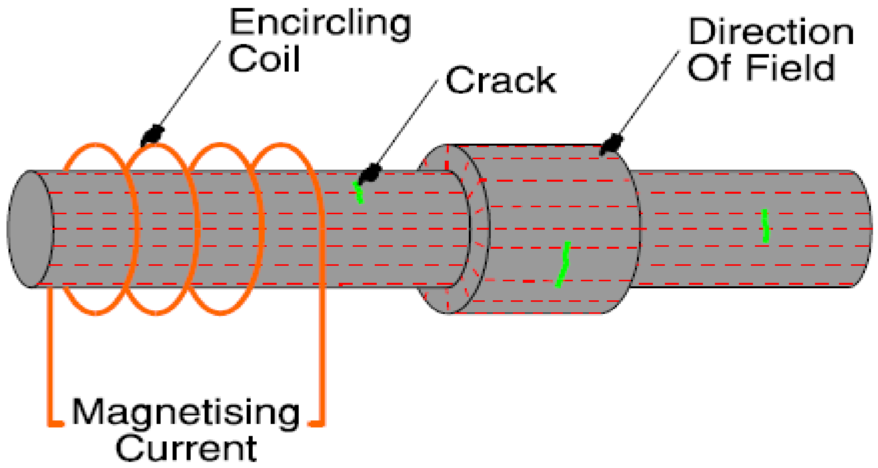
Diagram showing the Working principle of Magnetic particle crack Detection.

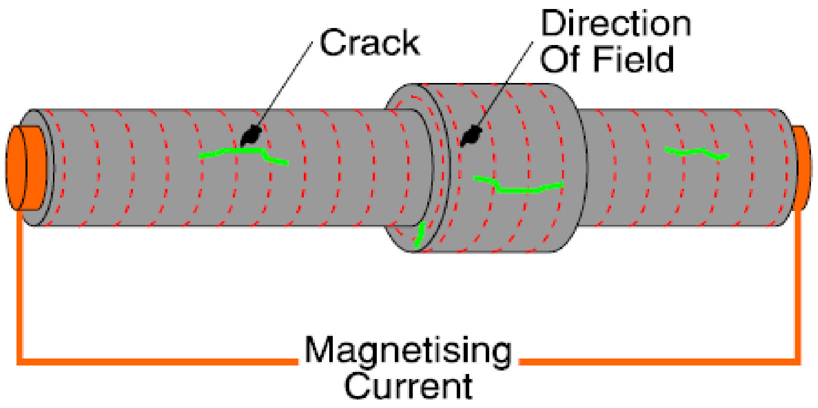
Procedure

- The principle is to generate magnetic flux in the article to be examined, with the flux lines running along the surface at right angles to the suspected defect. Where the flux lines approach a discontinuity they will stray out in to the air at the mouth of the crack.

  - The crack edge becomes magnetic attractive poles North and South. These have the power to attract finely divided particles of magnetic material such as iron fillings.

  - Usually these particles are of an oxide of iron in the size range 20 to 30 microns, and are suspended in a liquid which provides mobility for the particles on the surface of the test piece, assisting their migration to the crack edges. However, in some instances they can be applied in a dry powder form.





Figures showing the direction of Magnetic flux perpendicular to the orientation of Crack

Advantages

- Simplicity of operation and application.
- Can be automated, apart from viewing. (Though modern developments in automatic defect recognition can be used in parts of simple geometry e.g. billets and bars. In this case a special camera captures the defect indication image and processes it for further display and action)

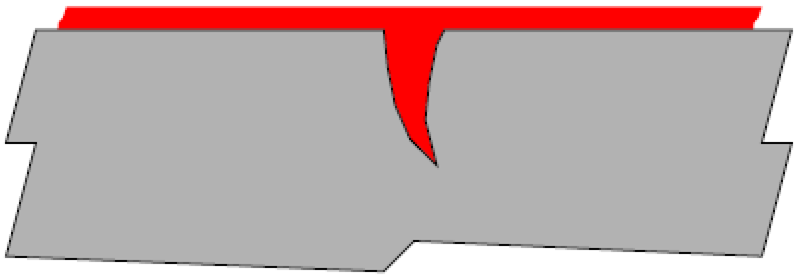
Disadvantages

- Restricted to ferromagnetic materials.
- Restricted to surface or near surface flaws.

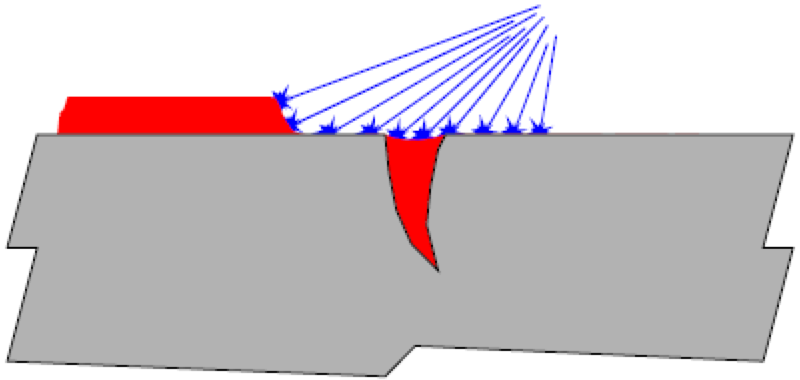
Dye Penetrant Testing

- This method is frequently used for the detection of surface breaking flaws in non-ferromagnetic materials.
- The subject to be examined is first of all chemically cleaned, usually by vapour phase, to remove all traces of foreign material, grease, dirt, etc. from the surface generally, and also from within the cracks.

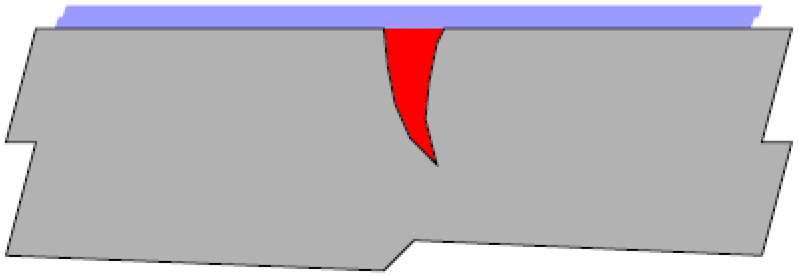
Process



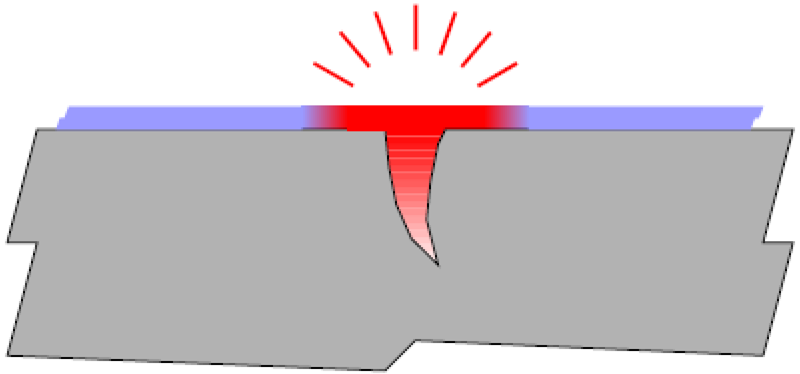
A. Penetrant applied to the surface and enters defect



B. Excess penetrant removed from surface



C. Developer powder applied to draw penetrant out of crack.



D. Accentuated indication of crack as penetrant spreads around the opening.

Advantages

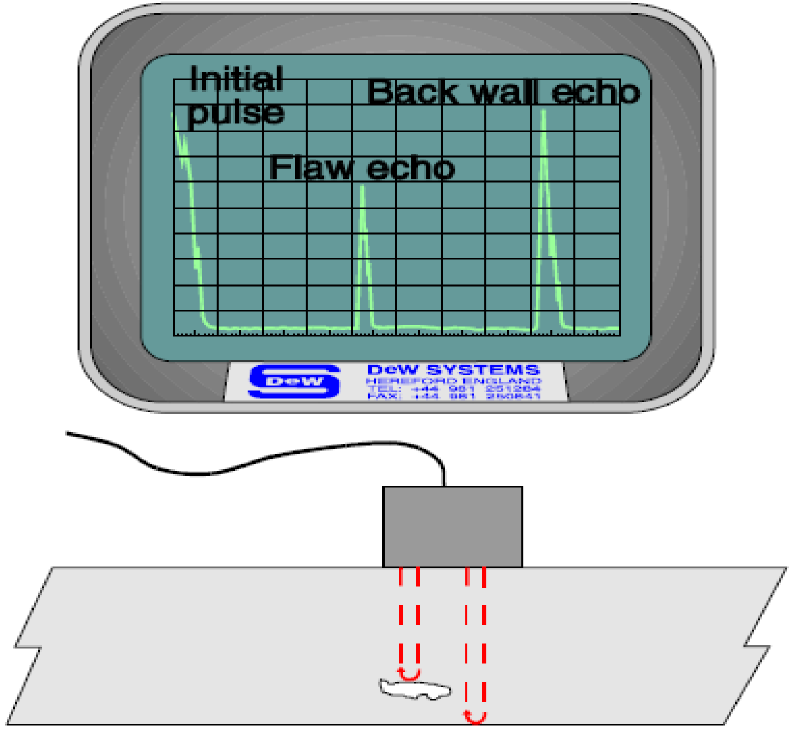
- Simplicity of operation.
- Best method for surface breaking cracks in non-ferrous metals.
- Suitable for automatic testing, with reservation concerning viewing. (See automatic defect recognition in Magnetic Particle Inspection)
- Quantative.

Disadvantages

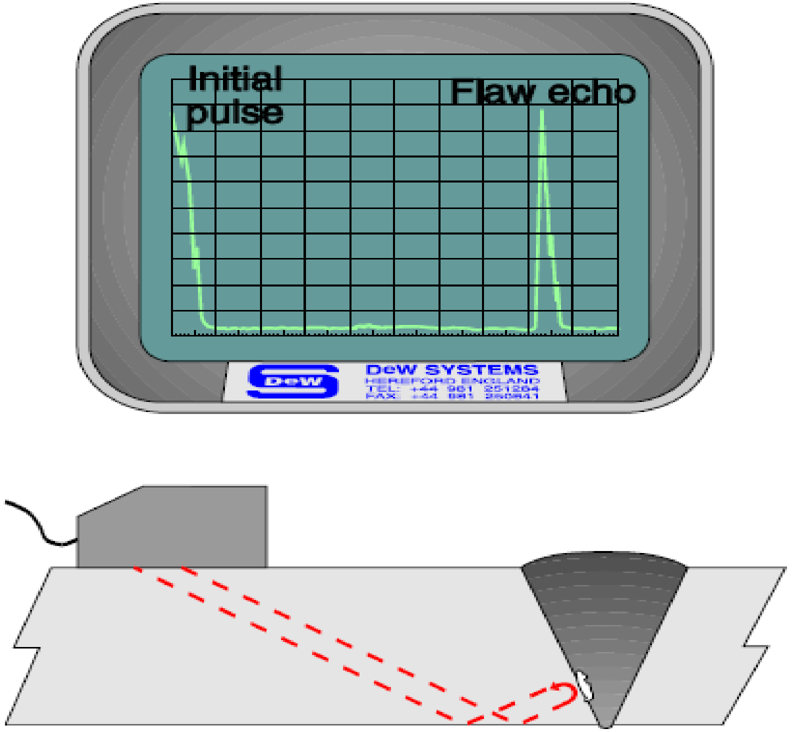
- Restricted to surface breaking defects only.
- Decreased sensitivity.
- Uses a considerable amount of consumables.

Ultrasonic Flaw Detection

This technique is used for the detection of internal and surface (particularly distant surface) defects in sound conducting materials.



Schematic diagram of ultrasonic detection of slag in steel section using a normal probe.



Schematic diagram of the use of an angle probe to detect defects not directly under the probe. Such as in weld inspection.

ULTRASONIC TEST

1. Measure of time required by ultrasonic vibrations to penetrate material of interest , reflect from opposite side or from internal discontinuity and return to point from where first introduced.
2. Behavior of waves through cycle with regard to time is recorded on CRO screen.
3. By observing this presence of defect and their location can be detected.

- Two types of Ultrasonic testing method- i)Pulse –echo method

  ii) Transmission Method

Advantages of Ultrasonic Test

- Better detection of flaws situated deep in metal due to superior penetrating power of ultrasonic waves.
- High sensitivity, better accuracy and reliability .
- The equipment is portable and easy to handle .
- Output of test can be processed by computer which lead to improved result reliability .
- Capable of being fully automated.
- Access to only one side necessary.
- No consumables.

Disadvantages of Ultrasonic Test

- Due to manual operation, careful attention and highly skilled operators are required .
- Irregular shaped and rough parts are very difficult to examine .
- Subsurface discontinuities are more difficult to detect.
- No permanent record available unless one of the more sophisticated test results and data collection systems is used.
- Very thin sections can prove difficult.

EDDY CURRENT TEST

- Basic Principle:- When coil carrying alternating current is brought near metallic specimen, eddy currents are developed in specimen due to electromagnetic induction.

Magnitude of induced EMI depend on –

i) Magnitude and frequency of alternating current flowing in coil.

ii) Electrical conductivity of specimen.

iii) Magnetic permeability of specimen

iv) Shape of specimen.

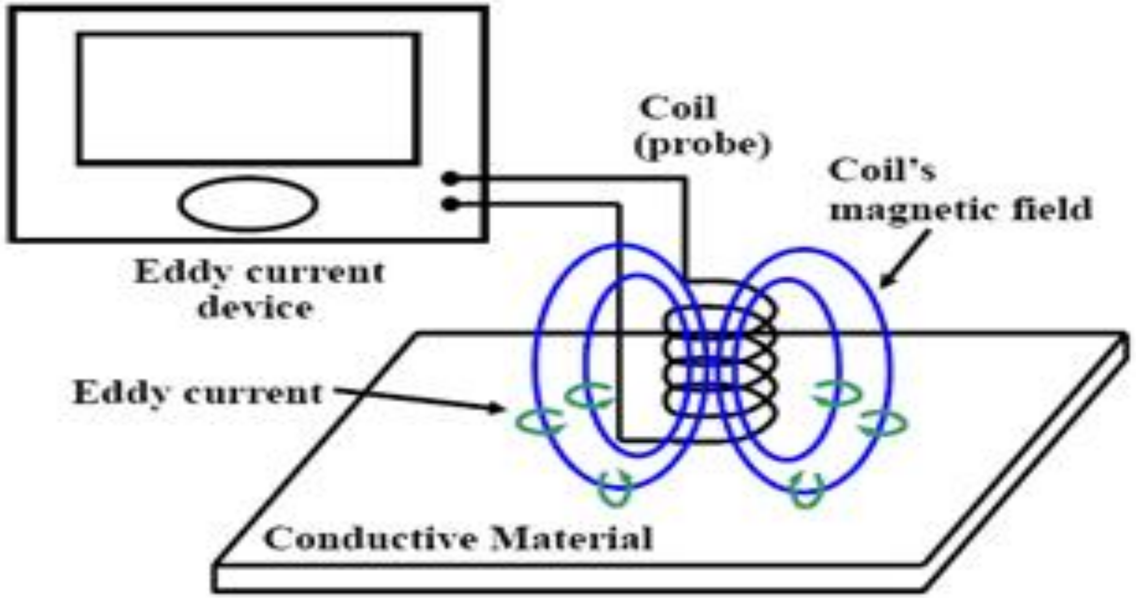
v) Relative positions of coil and specimen.

vi) Microstructure and hardness of Specimen.

vii) Amount and type of defects in the specimen

Advantages ECT

- Test is quick and less time consuming
- Test can be automated easily
- Permanent record of test results can be easily available
- Test is versatile and can be used for various applications



Disadvantages of ECT

- The instrument standardization and calibration is necessary from time to time
- Instruments and display units are costly
- Test can be applied to components of limited size and shape