DEBRE MARKOS UNIVERSITY

COLLEGE OF TECHNOLOGY

Mechanical Engineering Department

Materials Testing Laboratory

PRESENTATION OUTLINES

1. Destructive test

2. Nondestructive test

3. Metallography and Micro structural

analysis

4. Conduction and control of heat treatments

1. DESTRUCTIVE TEST

- ✓ It is accomplished by forcing a part to fail by the application of various load factors.
- ✓ Typically destructive tests are **tensile test, compressive test, hardness test** and **impact test.**
- ✓ **It is also called mechanical properties test.**

- ✓ Some of mechanical properties test of engineering materials are;
  - ✓ Hardness test
  - ✓ Impact test
  - ✓ Torsion test
  - ✓ Tensile test

1.1 HARDNESS TEST

❑ It is resistance to **indentation** and to **scratching** or **abrasion** under a locally applied load**.**

Moh's Hardness Scale

✓ Moh's hardness scale simply consists of 10 minerals arranged in order from 1 to 10.

✓ Diamond is rated as the hardest and is indexed as 10; talc as the softest with index number 1.

Diamond	10
Corundum	9
Topaz	8
Quartz	7
Orthoclase (Feldspar)	6
Aptite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1

The most common hardness tests are;

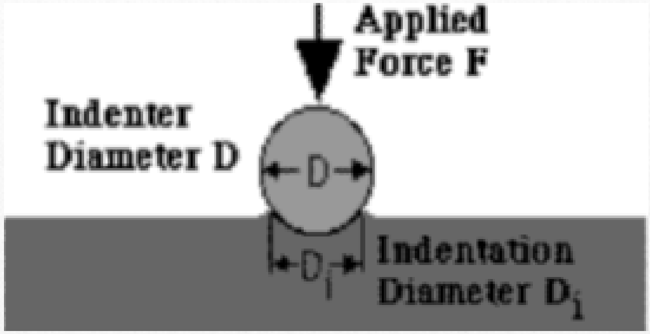
- **Brinell test,**
- **Vickers test** and
- **Rockwell test.**

1.1.1 BRINEL HARDNESS TEST

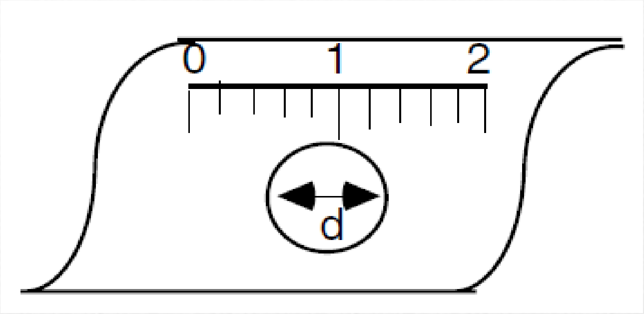
- ✓ A **known load** is applied for a given period of time to a specimen surface using a hardened steel or tungsten-carbide ball.

- ✓ The ball causes **a permanent indentation.**
- ✓ Standard ball diameter is 10 millimeters.
- ✓ The diameter of the resulting permanent indentation is then measured and converted to **a Brinell hardness number.**

...Cont



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot \left(D - \sqrt{D^2 - D_i^2}\right)}$$



- ✓ A well structured Brinell hardness number looks like as **"75 HB 10/500/30"** which means that a Brinell Hardness of **75** was obtained using a **10mm** diameter hardened steel with a **500 kilogram** load applied for a period of **30 seconds.**

...Cont

Figure 1 - Brinell Hardness Tester Model HB3000B

Example;

Impression on Brinell hardness test sample

(1020 Steel) Brinell Hardness Number, BHN

D = 10-mm

P = 3000 kg

d = 4.37-mm

$$BHN = \frac{P}{\frac{\pi \times D}{2} \times (D - \sqrt{(D^2 - d^2)}}$$

$$BHN = \frac{3000}{\frac{\pi \times 10}{2} \times (10 - \sqrt{(10^2 - 4.37^2)}}$$

$$BHN = 190$$

Tensile Strength = BHN x 500

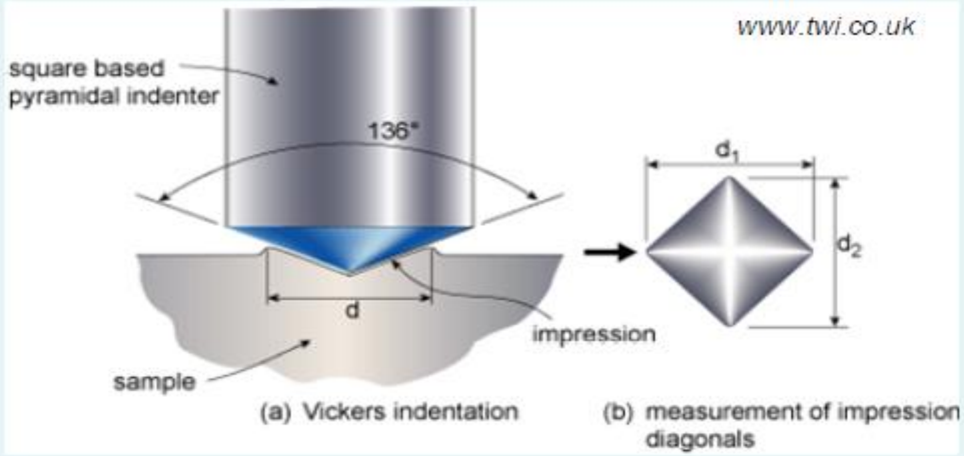
= 190 x 500

= 95000 psi

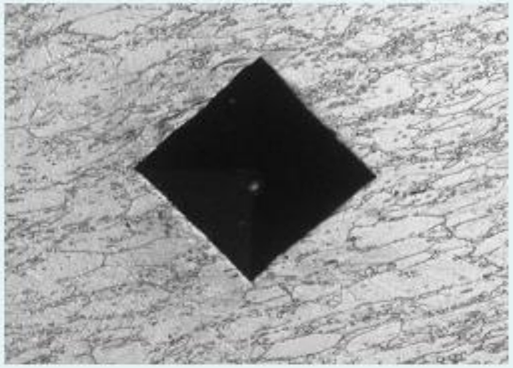
Non-destructive Video\Brinell Hardness Test - TubeUnblock.MP4

1.1.2 VICKERS HARDNESS TEST

- ✓ It consists of indenting the test material with a **diamond indenter**, in the form of a **right pyramid with a square base**
- ✓ It is subjected to a load of **1 to 100 kgf.**
- ✓ The full load is normally applied for **10 to 15 seconds.**



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


c) Impression on Vickers hardness test sample

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

Where	P	is	the applied load, kg
	d	is	the average length of the diagonals = $(d_1+d_2)/2)$, mm
	θ	is	the angle between the opposite faces of the diamond) = 136^{o}

...Cont

- ✓ The Vickers hardness should be reported like **800 HV/10**, which means a Vickers hardness of 800, was obtained using a 10 kgf force.

- ✓ Most Vickers hardness testing machines use forces of 1, 2, 5, 10, 30, 50 and 100 kgf.

1.1.3 ROCKWELL HARDNESS TEST

- ✓ It involves the use of an indenter for penetrating the surface of a material by;
  - ❑ Applying a minor, or initial load, and then
  - ❑ Applying a major, or final load under specific conditions.
- ✓ The Rockwell Test measures depth of indentation **not diameter as in the Brinell Test.**
- ✓ The **difference between** the minor and major penetration depths is then **noted as a hardness value**.
- ✓ The Rockwell Hardness Tester has **a gauge on the machine** that will display the Rockwell Hardness Number after the load is removed.
- ✓ The harder the material the higher the number.

…Cont

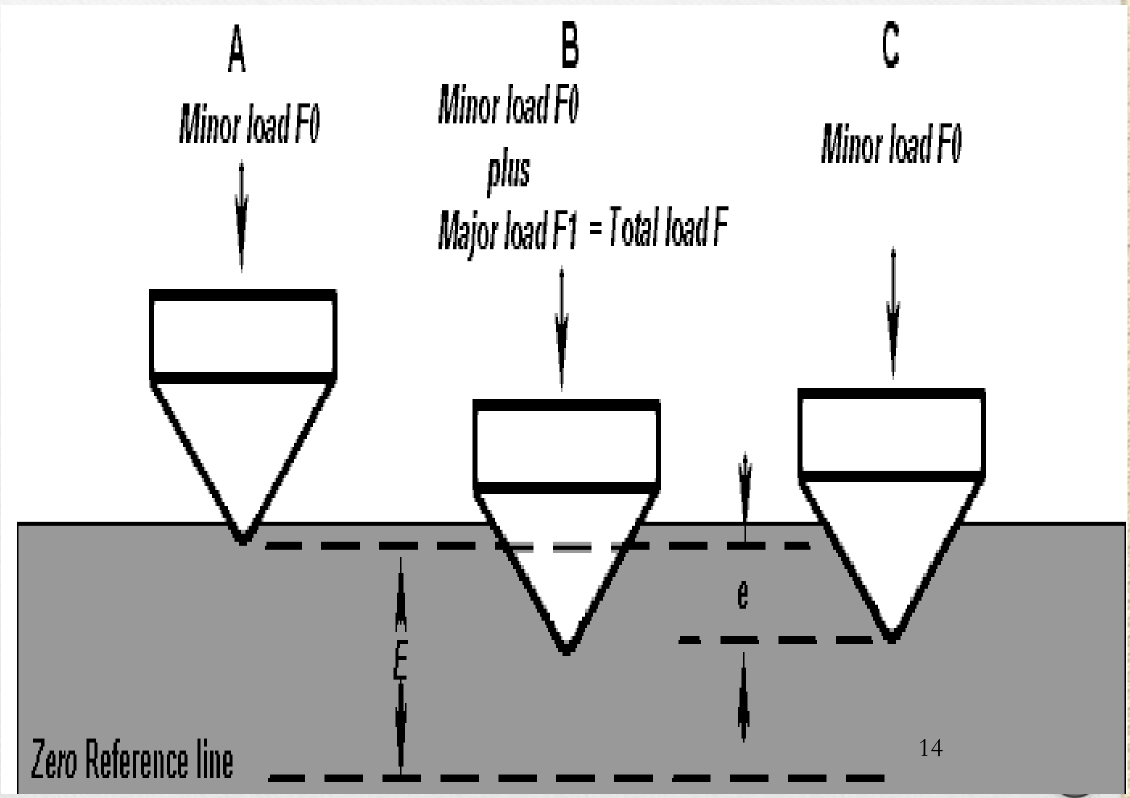
- ✓ The Rockwell hardness number; $HR = E - e$

Where ***F0, F1*** and ***F*** is preliminary minor load in kgf , additional major load in kgf and total load in kgf ; respectively.

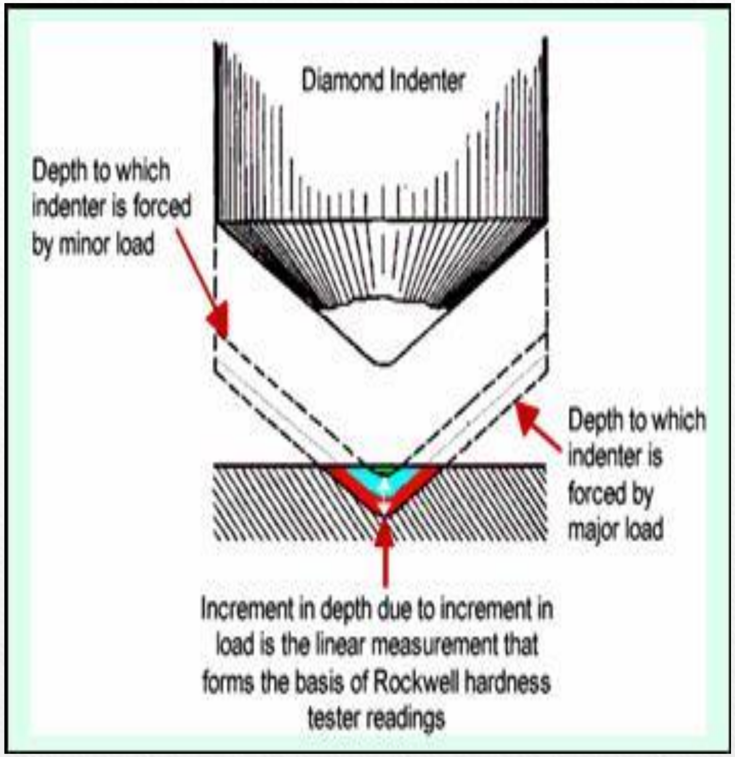
***e* =** permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm and ***E* =** a constant depending on form of indenter (100 units for diamond indenter, 130 units for steel ball indenter).

HR = Rockwell hardness number.

$$e = \frac{(h_2 - h_1)}{0.002}$$



...Cont



Non-destructive Video\Rockwell Hardness Test - TubeUnblock.MP4

…Cont

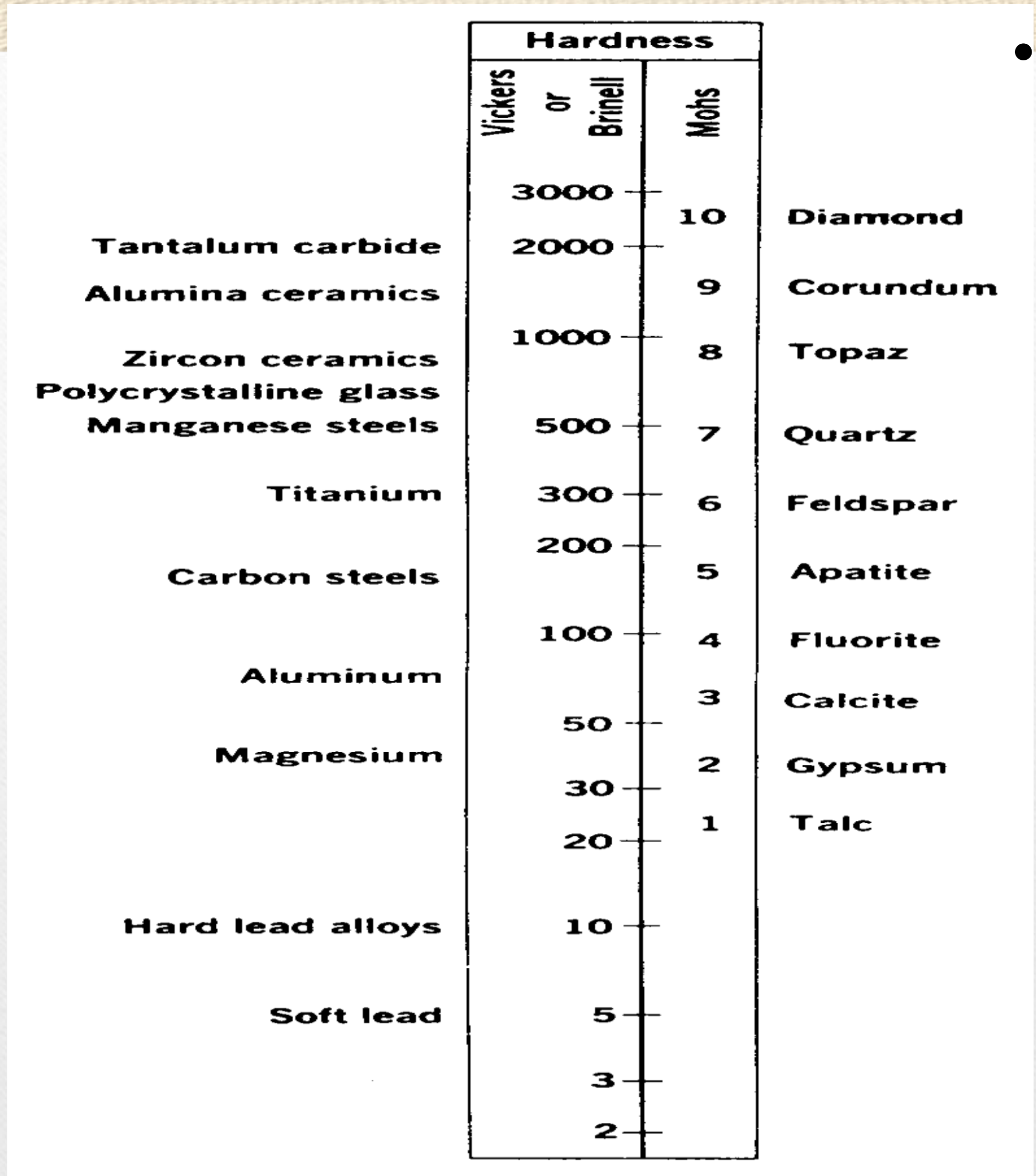


Figure: Approximate relative harnesses of metals and ceramics for Mohs scale and indention scales.

1.2 IMPACT TEST

- ✓ When a material is subjected to **a sudden intense blow** in which the strain rate is extremely rapid.
- ✓ The test specimen should be **notched**, because **V-notched** specimens better measure the resistance of the material to crack propagation.
- ✓ The ability of a material to withstand an impact blow is often referred to as the **toughness.**
- ✓ A material high impact resistance is said to be a tough material.

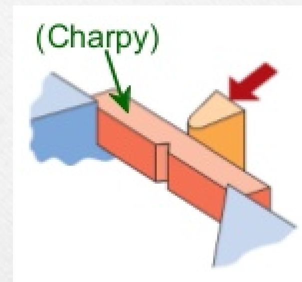
- ✓ There are two standard impact tests;

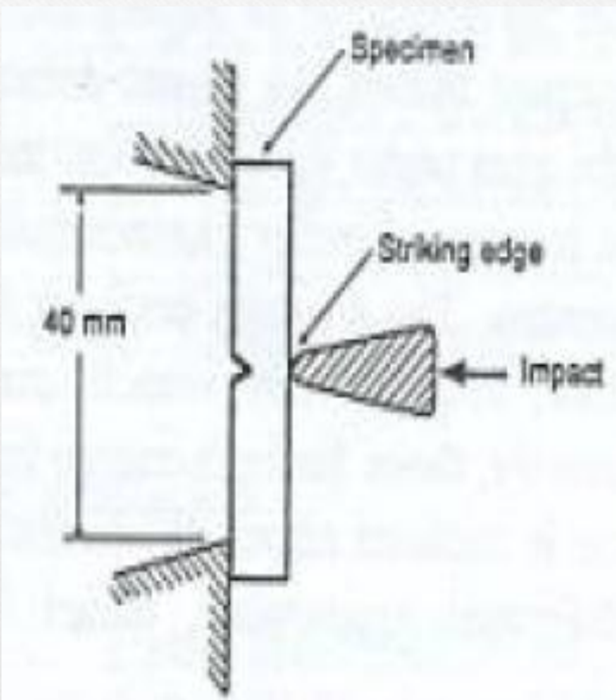
    - ❑ **Charpy impact test** and
    - ❑ **Izod impact test**

- ✓ They are commonly used to measure Impact Energy (sometimes referred to as Notch Toughness) and also evaluate the **brittleness of a material.**

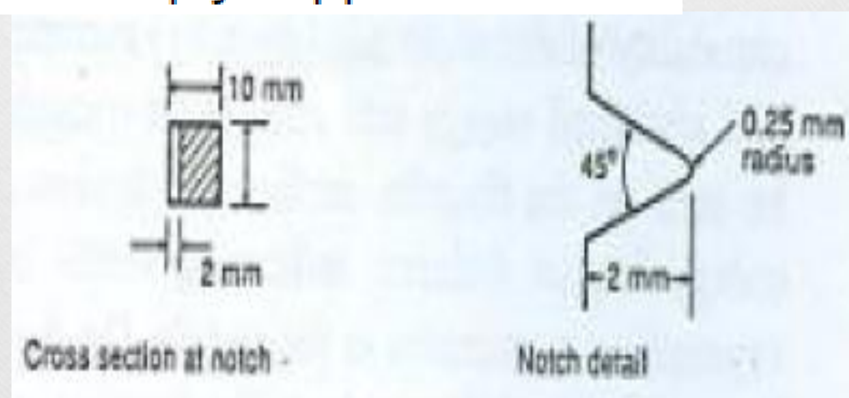
1.2.1 CHARPY TEST

- ✓ The load is applied as an impact blow from a weighted pendulum hammer that is released from a cocked position at a fixed height "h".





Held horizontally on anvil as simply supported beam



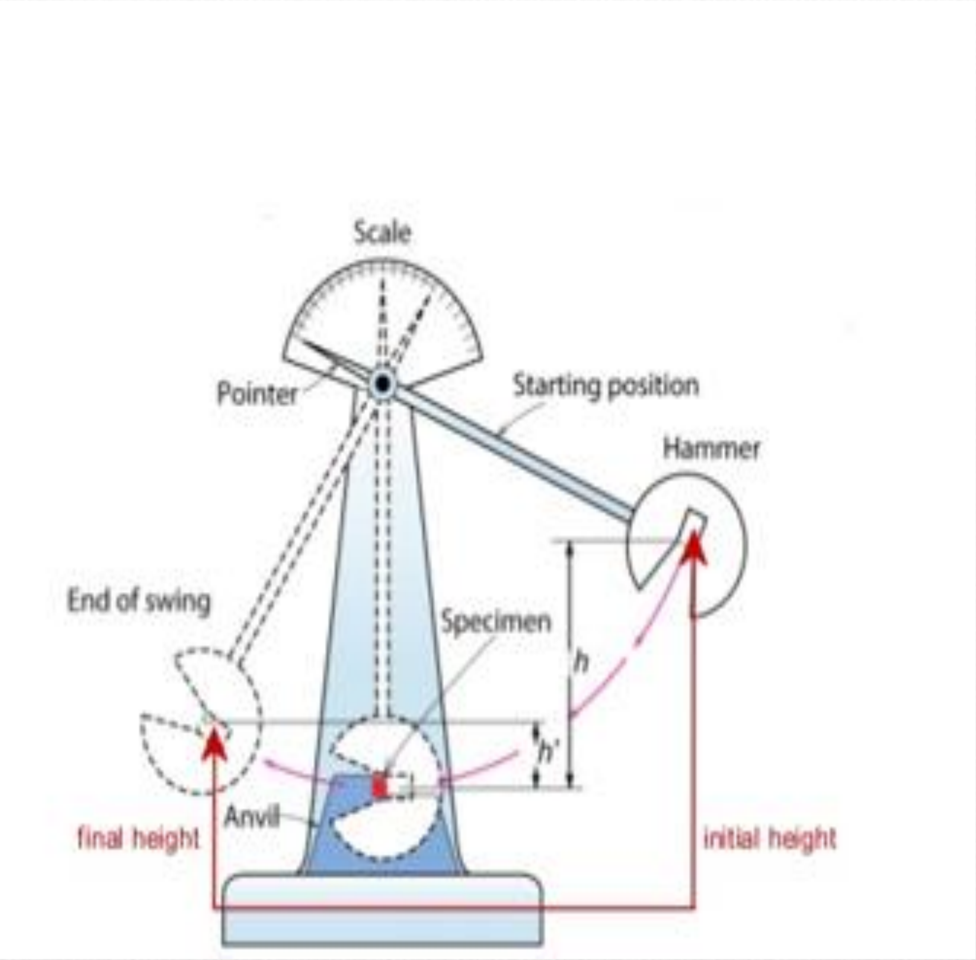
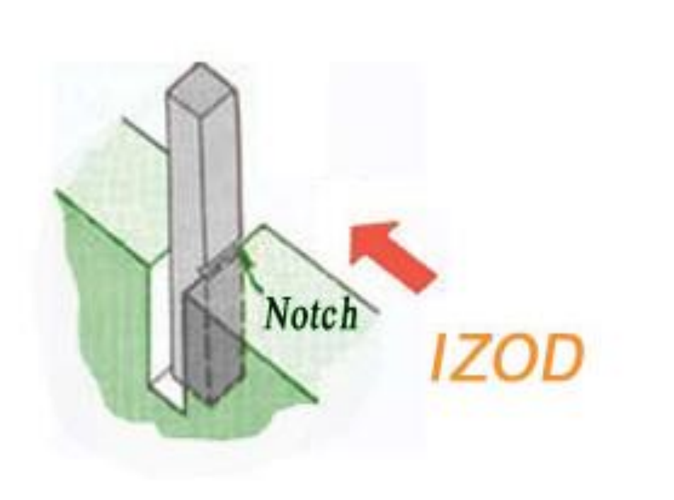


Figure: Setup of the Charpy and Impact test

Non-destructive Video\Charpy Impact Test - TubeUnblock_2.MP4

1.2.2 IZOD TEST



Held vertically on anvil as cantilever

✓ Generally, the chief differences between these two impact tests are the **way the test specimen is held and in the pendulum hammer design.**

Non-destructive Video\Izod impact testing - TubeUnblock.MP4

1.3 TORSION TEST

- Torsion occurs when any shaft is subjected to a torque.
- This is true whether the shaft is **rotating** such as:
  - Drive shafts on engines,
  - Motors and turbines

Or **stationary** (such as with a bolt or screw).

- It makes the shaft twist and one end rotates relative to the other **inducing shear stress** on any cross section.
- Failure might occur **due to** shear alone or because the shear is accompanied by **stretching or bending.**

Non-destructive Video\Torsion Test on 1045 Steel - YouTube.MKV

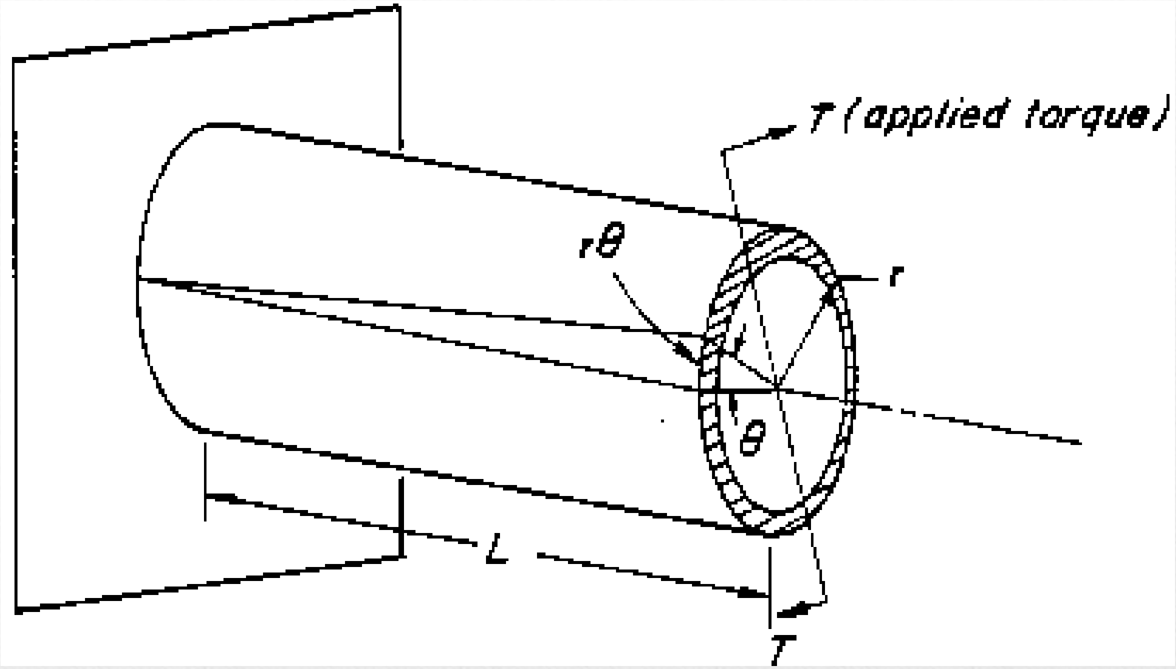


Figure: Torsion of cylindrical test bar

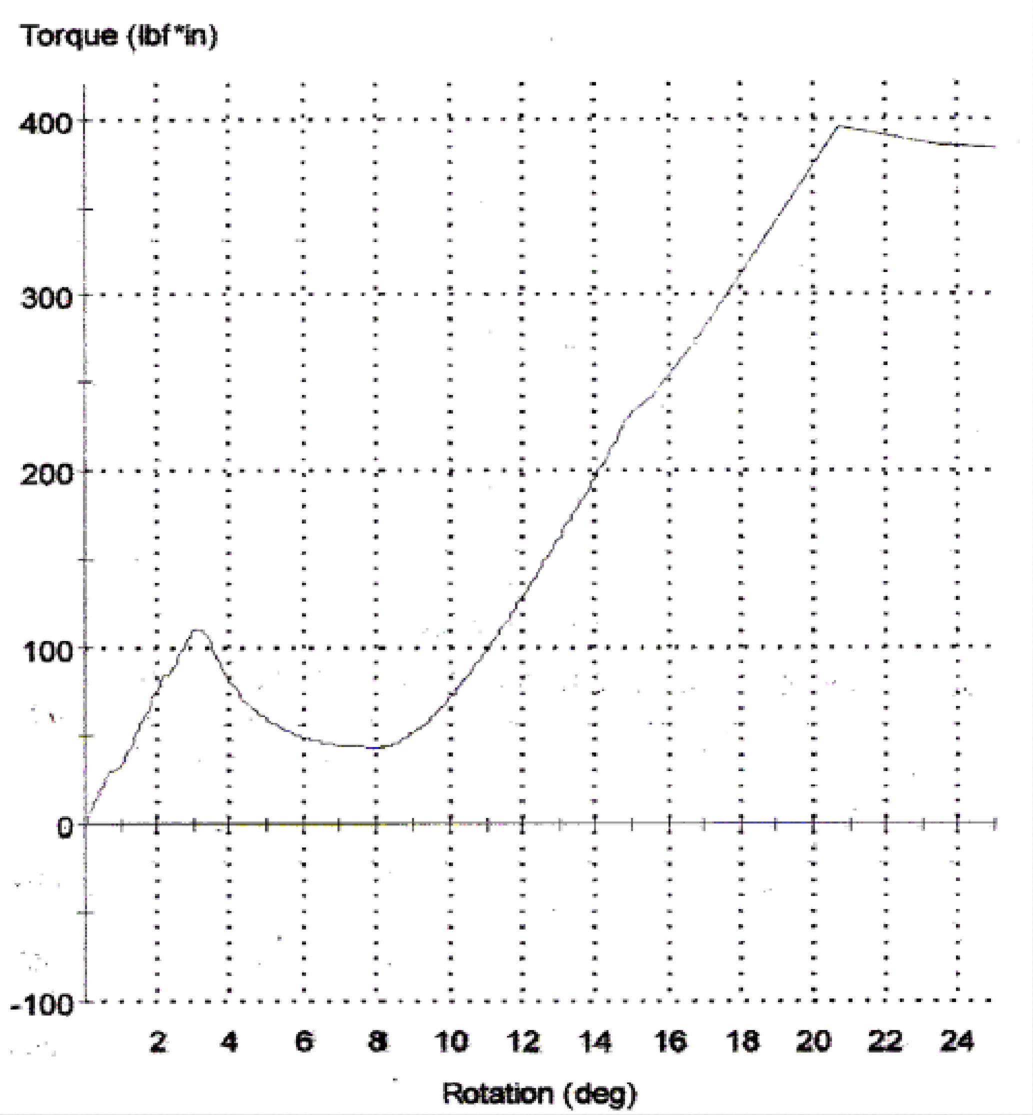


Fig: Example of torque-twist curve

- A plot of shear stress vs. shear strain for each rod is made by using the following formulas:

$$T = GJ\frac{\theta}{L}$$

$\tau = TR/J$ shear stress

$\gamma = R\theta/L$ shear strain

$G = \tau / \gamma$ shear modulus

where:

T = torque applied to rod
R = radius of rod
J = Polar moment of inertia of rod ($J = \pi r^4/2$)
L = gage length of rod
θ = maximum rotation of rod (radians)

1.4 TENSILE TEST

- ❖ The tensile test measures the resistance of a material to a static or slowly applied force.
- ❖ It is designed to demonstrate mechanical properties as:
  - ✓ Modulus of elasticity,
  - ✓ Yield strength,
  - ✓ Ultimate tensile strength (UTS),
  - ✓ Elongation and
  - ✓ Reduction in area at rupture.

Non-destructive Video\Tensile Test - TubeUnblock.MP4

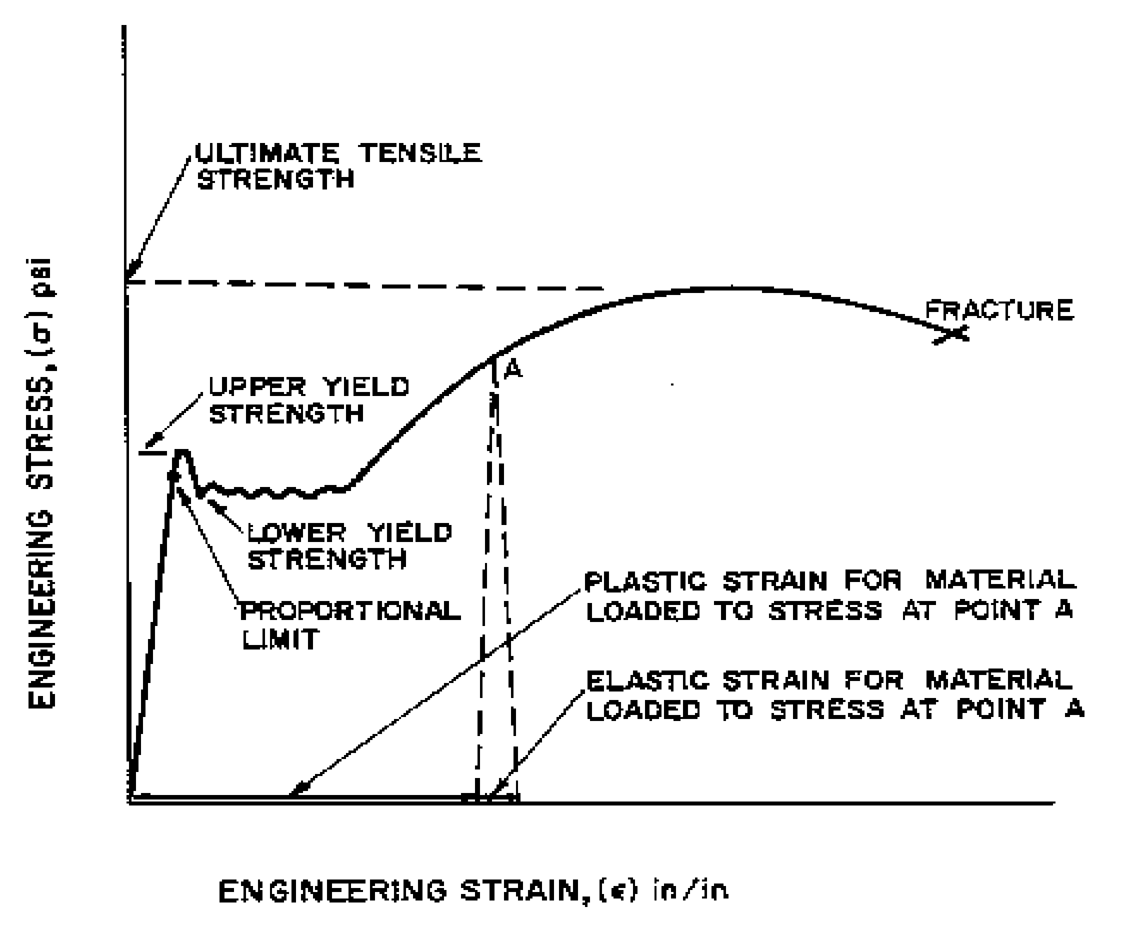


Figure: Engineering stress-strain diagram for hot-rolled carbon steel

- ✓ As shown in Fig., often basic stress-strain relations are plotted using engineering stress, σ, and engineering strain, ε. defined as:

$$\sigma = \frac{\text{Load}}{\text{Original Area}} = \frac{P}{A_o}$$

$$\varepsilon = \frac{\text{Deformed length - Original length}}{\text{Original length}} = \frac{L - L_o}{L_o}$$

- The **ductility of a material** is its ability to deform under load and can be measured by either a length change or an area change.
- The **percent elongation**, which is the percent strain to fracture is given by:

$$\%EL = 100\varepsilon_f = 100\left(\frac{L_f - L_o}{L_o}\right) = 100\left(\frac{L_f}{L_o} - 1\right)$$

- The **percent reduction in area** is a cross-sectional area measurement of ductility defined as

$$\%RA = 100\left(\frac{A_o - A_f}{A_o}\right) = 100\left(1 - \frac{A_f}{A_o}\right)$$

2. NON-DESTRUCTIVE TESTS

- ✓ It does not affect the part's future usefulness.
- ✓ There are different techniques for non-destructive test;

1. Visual inspection
2. Radiography
3. Liquid (Dye) penetrant method
4. Eddy current testing
5. Ultrasonic Inspection
6. Magnetic particle

2.1 VISUAL INSPECTION

- ✓ VI is particularly effective detecting **macroscopic** flaws, such as poor welds.
- ✓ Most simple, quickly and easily performed method.
- ✓ Limited to detecting **only surface defects.**

2.2 RADIOGRAPHY

- ✓ Based on the ability of ***x-rays*** and ***gamma rays*** to penetrate all materials and thicknesses differently.
- ✓ The radiation is directed through the part and ***imprints on a film stock*** or an electronic device.
- ✓ The resulting image reveals the internal characteristics of the part, with possible imperfections showing up as ***density changes*** in the image.
- ✓ This process is used primarily on welds and is *difficult to use on complex shapes.*

- ✓ If **a void present** in the object being radiographed, ***more x-rays will pass*** in that area and;
  - the film under the part in turn will have more exposure than in the non-void areas.

- ✓ However this method is **less popular** the process is **costly**, **health risks** for process operators and high interpretive **skills** in reading the x-ray images are required.

2.3 LIQUID (DYE) PENETRANT METHOD

- This is one of the simplest non-destructive testing methods primarily used for detecting the presence of surface defects only.
- A liquid penetrant dye is applied for a specific time.
- Later a developer (like talc or chalk powder) is applied which causes the dye to be drawn out from the defect and mark the flaw's location.

Non-destructive Video\Dye Penetrant Inspection(1).mp4

2.4 EDDY CURRENT TESTING

- Eddy currents are created through a process called **electromagnetic induction.**
- When alternating current is applied to the conductor, such as copper wire, **a magnetic field develops** in and around the conductor.
- It has a sensor to detect such failure of materials.

- Eddy currents can be used for:
    - ✓ Crack detection,
    - ✓ Material thickness measurements,
    - ✓ Coating thickness measurements,
    - ✓ Conductivity measurements.
- Advantages; **sensitivity to small cracks** and other defects, ability to detect surface and near surface defects
- Limitation; applicability just **on conductive materials** and limited **depth** of penetration.

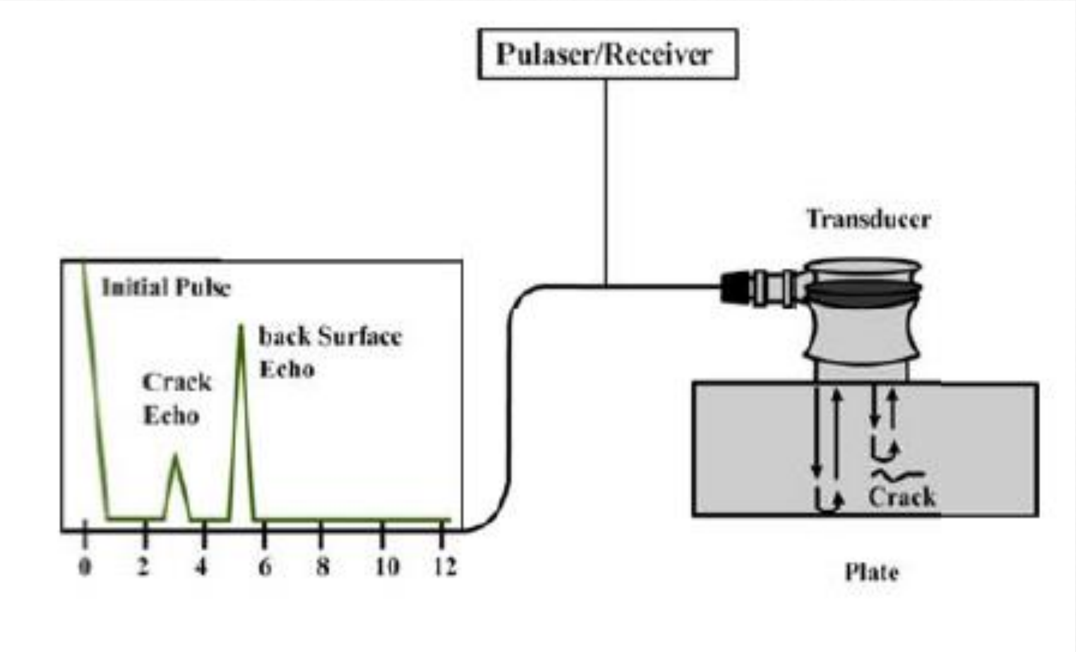
Non-destructive Video\Eddy Current Testing - TubeUnblock.MP4

2.5 ULTRASONIC INSPECTION

- ✓ It uses a high frequency **sound energy** to conduct examinations and make measurements.
- ✓ Sound energy is introduced and **propagates** through the materials in the form of waves and **reflected** from the opposing surface.
- ✓ An internal defect such as crack or void **interrupts the waves' propagation** and reflects back a portion of the ultrasonic wave.

- ✓ The **amplitude** of the energy and the **time** required for return indicate the presence and location of any flaws in the work-piece.

Non-destructive Video\Ultrasonic Testing.mp4



2.6 MAGNETIC PARTICLE INSPECTION

- This method uses magnetic fields and small magnetic particles, such as iron filings to detect flaws in components.
- The only requirement is that the component being inspected must be made of **a ferromagnetic material** such iron, nickel, cobalt, or some of their alloys.
- Since these materials are materials that can be magnetized.

- If **there is a discontinuity** such as a crack or a flaw on the surface of the part, **magnetic flux will be broken** and a new south and north pole will form at each edge of the discontinuity.

Non-destructive Video\Magnetic Particle Inspection - TubeUnblock.MP4

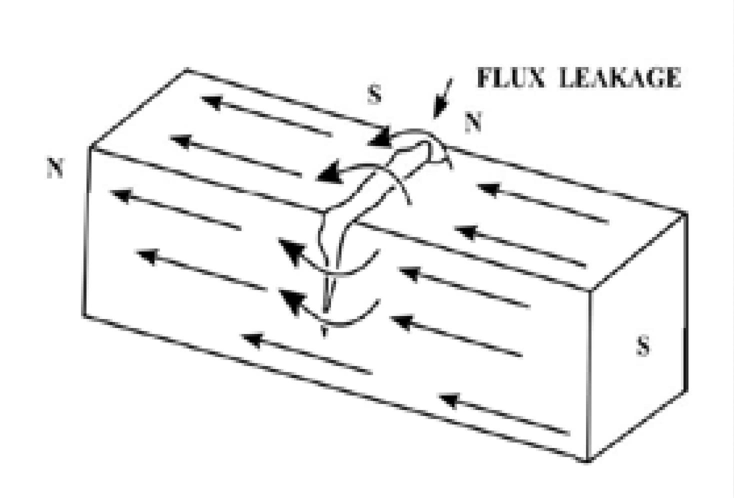


Fig: Principle of magnetic particle test

3. METALLOGRAPHY AND MICRO STRUCTURAL ANALYSIS

- **Metallography** is the study of metals by optical and electron microscopes, to characterize the microstructures of the materials.
- Structures which are coarse enough to be discernible by the naked eye or under low magnifications are termed **macrostructures.**
- Those which require high magnification to be visible are termed microstructures.
- A reasonable working definition of **microstructure** is:

"The arrangement of phases and defects within a material."

- Microstructure can be observed using a range of optical and electronic microscopy techniques.

How microstructures form?

- ✓ Microstructures form through a variety of different processes.
- ✓ Microstructures are almost always ***generated when a material undergoes a phase transformation*** brought about by changing temperature and/or pressure;

  (e.g. a melt crystallizing to a solid on cooling).
- ✓ Microstructures can be created through ***deformation or processing of the material;***

  (e.g. rolling, pressing, welding).
- ✓ Finally, microstructures can be created ***artificially by combining different materials*** to form **a composite material;**

  (e.g. carbon-fibre reinforced plastic).

- Metallography or microstructural analysis includes, but is not limited to, the following types of analysis:
  - Grain size
  - Porosity and voids
  - Phase analysis
  - Dendritic growth
  - Cracks and other defects
  - Inclusion size, shape and distribution
  - Weld and heat-affected zones (HAZ)

- The process is done according the following procedures:
  - (a) Sample cutting
  - (b) Sample cleaning
  - (c) Sample mounting
  - (d) Grinding by using SiC papers
  - (e) Polishing by using diamond paste, alumina paste, Magnesium oxide
  - (f) Acid etching (HNO3, HCl, HF, etc)
  - (g) Acquisition of the microstructure's image by using optical and/or electronic microscopy

Non-destructive Video\Metrology Lab Experiment Microstructure Analysis of Ferrous and Non ferrous Metals - Aluminium Bar - TubeUnblock.MP4

...Cont

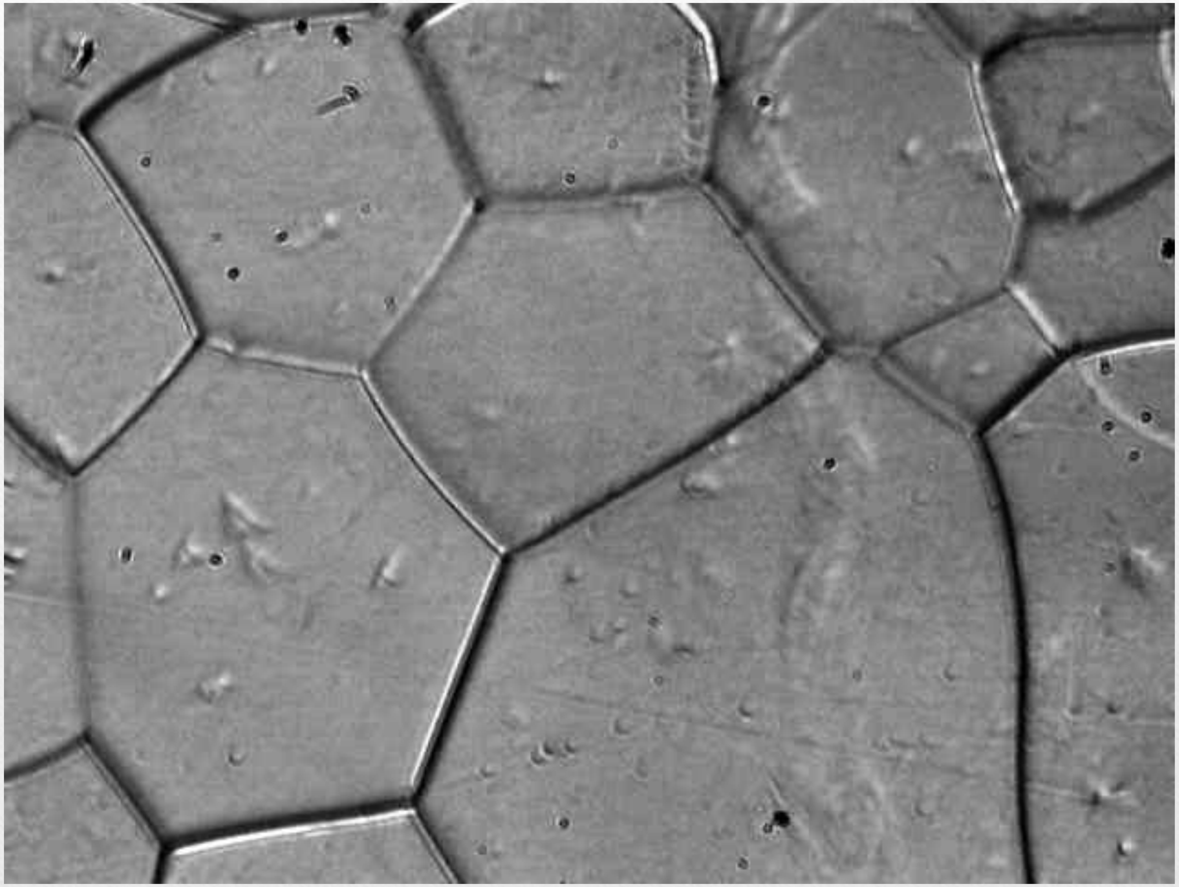


Figure: Rhenium grain size

Non-destructive Video\Properties and Grain Structure - YouTube.MKV

…Cont

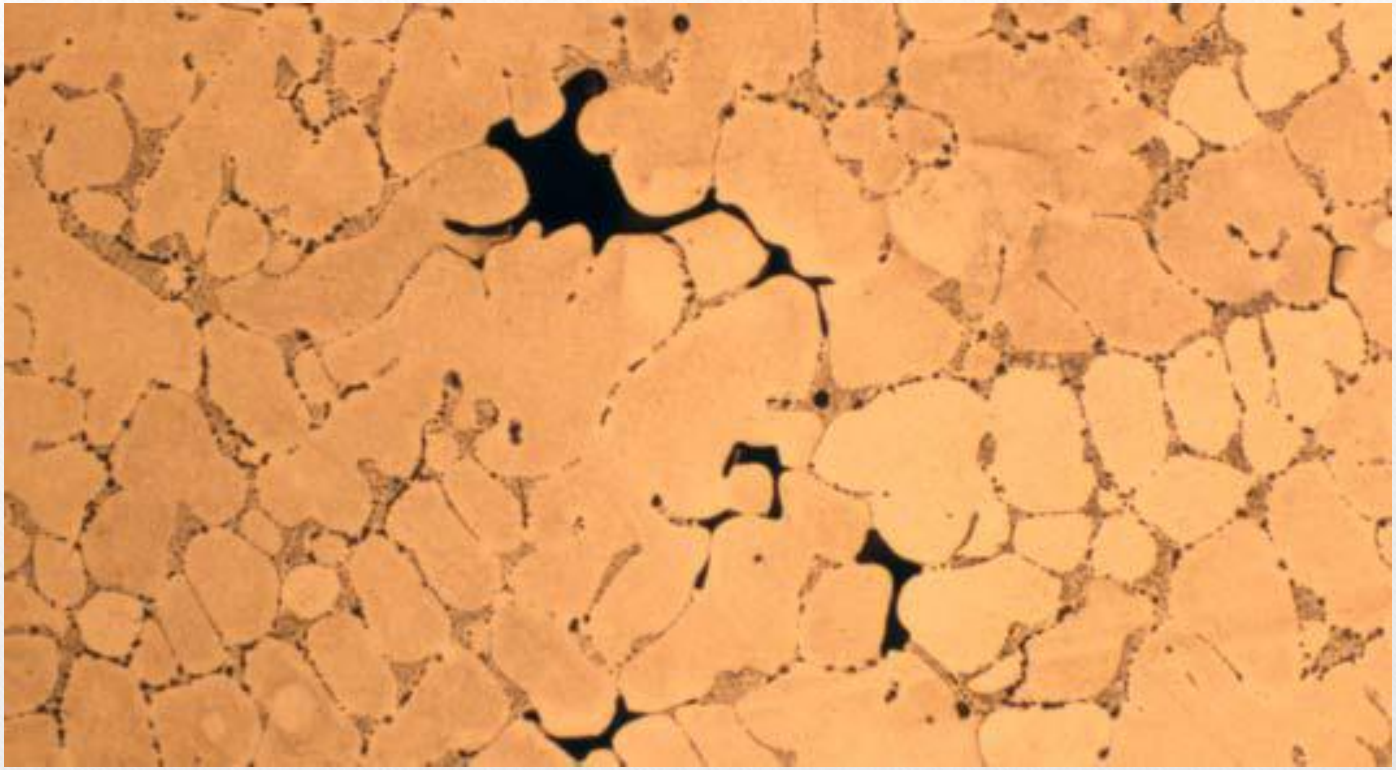


Figure: Casting porosity in copper

4. CONDUCTION AND CONTROL OF HEAT TREATMENTS

- ✓ **Heat treatment** is an operation or combination of operations involving ***heating*** at a specific rate, **soaking**(holding) at a temperature for a period of time and **cooling** at some specified rate.
- ✓ The furnace must be of the proper size and type and controlled, so the **temperatures are kept within** the prescribed limits for each operation.
- ✓ Even the **furnace atmosphere affects** the condition of the metal being heat-treated.

4.1 Stages of heat treatment

Heat treating is accomplished in three major stages:

Stage l: Heating the metal slowly to ensure a uniform temperature.

Stage 2: Soaking (holding) the metal to a specified time.

Stage 3: Cooling the metal to the cooling medium.

❑ Cooling medium may be:

- ✓ Water
- ✓ Oil
- ✓ Air and
- ✓ In side furnace room.

4.2 Types of heat treatment

There are four basic types of heat treatment processes;

- ✓ Annealing,
- ✓ Normalizing,
- ✓ Hardening, and
- ✓ Tempering.

Tempering relieves the internal stresses and also allows some iron carbide to form. It also restores ductility.

- ✓ If a steel is **quenched** into water or oil from **(870ºC)** a metastable phase called martensite forms.
- ✓ This phase sets up **large internal stresses** and prevents carbide from forming.
- ✓ The internal stresses produce ***a high hardness*** and unfortunately, ***low toughness***.
- ✓ To restore toughness, steels are tempered by *reheating* them to a lower temperature around 800ºF (426ºC) and cooling.

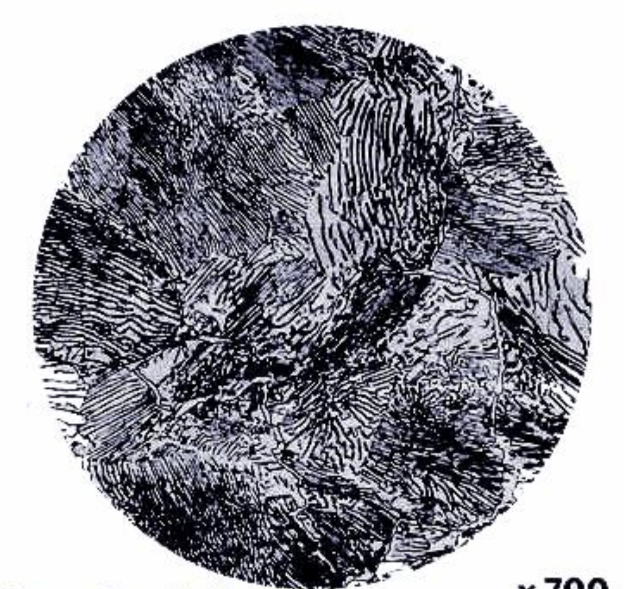
Normalizing is applied to reverse the ***embrittling effects*** of cold work.

- ✓ By heating the sample into the austenite range and allowing recrystallization.
- ✓ The grain structure is refined and relatively small grains are formed by allowing the sample to **slow-cool in air.**

Annealing is used to relieve stresses,

increase ductility and modify the microstructure.

- ✓ A previously **cold-worked;** SAE 1040 specimen, held for 1 hour in 900°C, then allowed to cool in the furnace itself by turning the oven off thus facilitating a very slow cooling of the sample.



Coarse Pearlite (Annealing) x 700

Normalizing SAE 1040 specimen, At 900°C for 1 hour then allowed to cool in **air.**

Fine Pearlite (Normalizing) X 700

Hardening: SAE 1040 specimen, Heated at 900°C for 1 hour, then ***rapidly quenched in cold water.***

- ✓ **Martensite** is the hardest and strongest and, in addition, the most brittle.

Tempering: SAE 1040 specimen, heated at 900°C for 1 hour then water quenched.

- ✓ The specimens are reheated to ***400°C*** in another furnace for **30 minutes** and are then removed and ***allowed to cool to room temperature in air.***

Thank you!