2014

ENGINEERING METALLURGY LABORATORY MANUAL

Dr. Mohammedtaher M. Mulapeer
Department of Mechanical Engineering
University of Salahaddin-Erbil
Kurdistan

Dr. Mohammedtaher M. Mulapeer
Department of Mechanical Engineering
University of Salahaddin-Erbil
Kurdistan

ENGINEERING METALLURGY LABORATORY MANUAL

September 2014

Experiment No. 01

Aim: - Study of Metallurgical Microscope

Introduction: - Historians credit the invention of the compound microscope to the Dutch spectacle maker, Zacharias Janssen, around the year 1590. The compound microscope uses lenses and light to enlarge the image and is also called an optical or light microscope (vs./ an electron microscope)**.** The simplest optical microscope is the magnifying glass and is good to about ten times (10X) magnification. The **compound microscope** has two systems of lenses for greater magnification, 1) the ocular or eyepiece lens that one looks into and 2) the objective lens, or the lens closest to the object. Before purchasing or using a microscope, it is important to know the functions of each part. The metallurgical microscope is the most important tool of the metallurgist. Its primary function is to reveal the details of an object that cannot be revealed with naked eyes. Metallurgical microscope is used to observe structural defects and different phases of the metal alloys.

Principle: - A horizontal beam of light from the light source is reflected by means of a plane glass reflector downwards through the microscope objective on the surface of the specimen some of these incident light reflected from the specimen surface will be magnified and passing through the plane glass reflector and magnified again by upper lens system of the eye-piece.

Constructional Details: - as shown by figure below; the table type microscopes are consist of the following parts:-

1. **Stage**: - A flat movable table supporting specimen. This can be moved up or down by knobs.
2. **Tubes**: - The vertically movable tube containing eyepiece, objective and plane reflector. The tube length varies from 160 mm to 250 mm.

3. **Rough & fine focus Adjustments:** - The limbs of microscope carry the coarse & fine adjustments to facilitate the

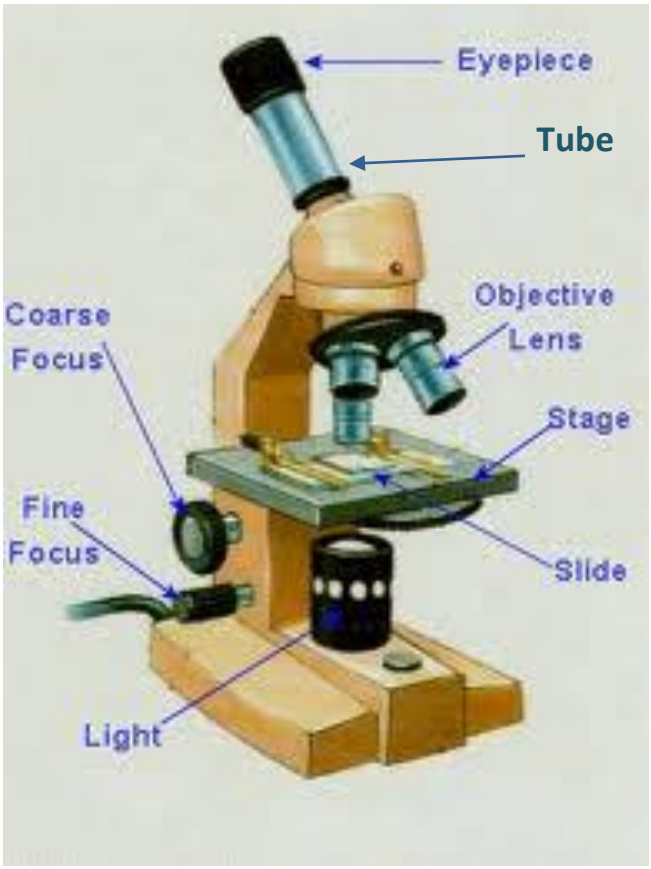
4. **Objective lenses**: - Usually you will find 3 or 4 objective lenses on a microscope. They almost always consist of 4X, 5X, 10X, 40X and 100X powers. When coupled with a 10X (most common) eyepiece lens, we get total magnifications of 40X (4X times 10X), 100X, 400X and 1000X. To have good resolution at 1000X, you will need a relatively sophisticated microscope with an Abbe condenser. The shortest lens is the lowest power; the longest one is the lens with the greatest power. Lenses are color coded and if built to DIN standards are interchangeable between microscopes. The high power objective lenses are retractable (i.e. 40XR). This means that if they hit a slide, the end of the lens will push in (spring loaded) thereby protecting the lens and the slide.

5. **Eyepiece Lens:** the lens at the top that you look through. They are usually 10X or 15X power.

6**. Illuminator:** A steady light source (may be 12 or 24 volts) used to illuminate the object being investigated.

Questions:

1. Why optical microscopes are so named?
2. What is the essential difference between biological and metallurgical microscope?
3. What is the essential difference between optical and electronic microscope?
4. Why the magnification power of an optical microscope is limited to about 1500X?
5. Why some times we use blue and red filters with the illumination system of an optical microscope?
6. What is meant by metallugraphy?



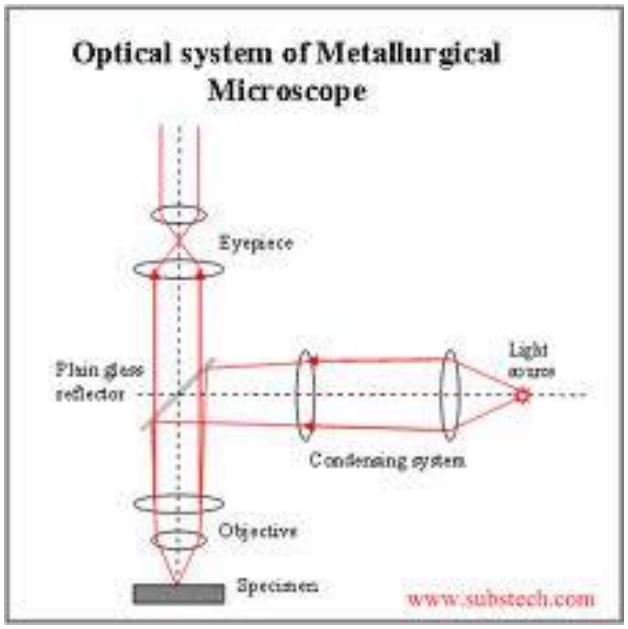


Figure 1: illustration of Microscope parts and illumination system of a metallurgical microscope.

Experiment No. 02

Aim - Preparation of a Specimen for metallographic examination.

Introduction - Metallographic or microscopy consists of the microscopic study of the Structural characteristics of material or an alloy. The microscope is thus the most important tool of a metallurgist from both, scientific & technical study point view. It is possible to determine grain size & the size, shape & distribution of various phases & inclusions which have a great effect on the mechanical properties of metal. The microstructure will reveal the mechanical & thermal treatment of the metal & it may be possible to predict its behavior under a given set of conditions.

Experience had indicated the success in microscopic study depends upon the case taken in the preparation of specimen. The most expensive microscope will not reveal the structure of a specimen that has been poorly revealed .The procedure to be followed in the preparation of a specimen is comparatively similar and simple & involves a technique which is developed only after constant practice. The ultimate objective is to produce a flat, scratch free, mirror like surface. The steps involved or required to prepare a metallographic specimen properly are covered in the coming section explained below.

Sampling - The choice of sample for microscopic study may be very important. If a failure is to be investigated the sampling should be chosen as close as possible to the area of the failure & should be compared with one taken from the normal section. If the material is soft, such as non ferrous metals or alloy & non-heat treated steels, the section is obtained by manual hack sawing /power saw. If the material is hard, the section may be obtained by use of an abrasive cut off wheels. This wheel is thin disk of suitable cutting abrasive rotating at high speed. The specimen should be kept cool during the cutting operation.

Mounting:- small size samples are mounted by placing it in a mould--usually cylindrical in shape--and filling the mould with a suitable material that embeds the sample and holds it firmly during the grinding and polishing operations that ensue. Two kinds of mounting procedure may be used: cold mounting and hot mounting. Cold mounting involves use of synthetic resins--such as epoxy, polyester, and acrylic resins that are introduced into the mould and cure or harden at room temperature.

In hot mounting, the mould is filled with a synthetic powdered material that liquefies and embeds the sample when the mould is heated and subjected to a moderate pressure. Special devices, known as mounting presses, are needed for this operation. The mounting material is usually opaque, but it is often considerably harder, when set, than the cold-mounting resins.

Grinding: - Once the sample has been mounted, the resin block must be ground flat. The standard procedure at this stage is to use wet silicon carbide papers with grit sizes progressively finer from 120 grit to 600 grit. Intermediate stages are 240 and 400 grit. The sample must be held so that it does not rock or move out of a single grinding plane, otherwise severe difficulty in obtaining an optically flat surface will be experienced later. Starting with the coarsest grit paper, the sample is moved backwards and forwards over the paper until a uniform ground finish is obtained. It is then carefully washed under running water, examined, and returned to the next grade of paper, rotating the sample through 90º before grinding recommences as shown by **figure 2.** This process is repeated for the subsequent grinding papers, rotating the specimen through 90o on each paper. It is very important completely to eliminate the scratches from the previous grinding stage otherwise they will not be removed in polishing.

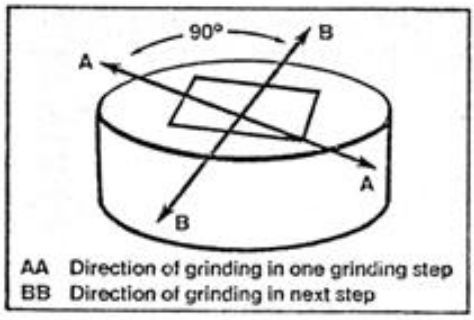


Figure2: Rotate the mount through 90º on each successive grinding paper

Polishing:- The best results for most ancient metals are obtained by polishing on diamond-impregnated rotary polishing wheels lubricated with a mineral oil. The diamond powders are usually supplied as tubes of paste. The usual range of diamond powder sizes are: **6µm, 1 µm and 0.25 µm**. Some of the polishing can be carried out automatically using a variety of machines or polishing attachments. Hand-finishing, however, is usually preferable for best results on **1 µm and 0.25 µm** diamond paste. Polishing with diamond powders produces less rounding of surface details than is apparent when using Alumina, or Magnesium oxide pastes.

Polishing is carried out by holding the specimen against the rotating polishing cloth. It is difficult to specify how much pressure must be used: too little pressure retards the rate of polishing and may result in some pitting of the surface; too much pressure may distort the surface. The correct polishing pressure varies with different metals and can only be learned through practice.

After initial polishing on **6µm** diamond paste, the sample should be washed in water, rinsed in ethanol or acetone and dried. It can then be polished on **1µm** diamond for at least 5 minutes. For many routine purposes this is sufficient and the sample should then be carefully washed to remove all traces of polishing compound and oil before it is ready for examination with the metallurgical microscope. For very high quality works, finish by final polishing on **0.25 µm** diamond. To minimize directional polishing effects, the sample should be rotated in a direction opposite to that of the wheel rotation as shown by **figure 3**.

Figure 3: The direction of rotation of the sample during polishing

Etching - The purpose of etching is to make the many structural characteristics of the metal or alloy visible. The process should be such that the various parts of the microstructure may be clearly differentiated. This is to subject the polished surface to chemical action.

In the alloys composed of two or more shapes. The competent are revealed during etching by a preferential attack of one or more of the constituents by the reagent because of difference in chemical composition of the phases. In uniform single phase alloy contact is obtained and the grain boundaries are made visible because of difference in the rate at which various grains are attacked by the reagent This difference in the rate of attack by reagent which is mainly associated with angle of the different grain structure section to the plane of the polished surface. Because of chemical attack of the chemical reagent the grain boundary appears as valleys in the polished surface light from the microscope hitting the side of these valleys will be reflected but of the microscope making the grain boundaries appears dark lines. The section of the appropriate etching reagent is determined by metal or alloys & the specific structure desired for viewing.

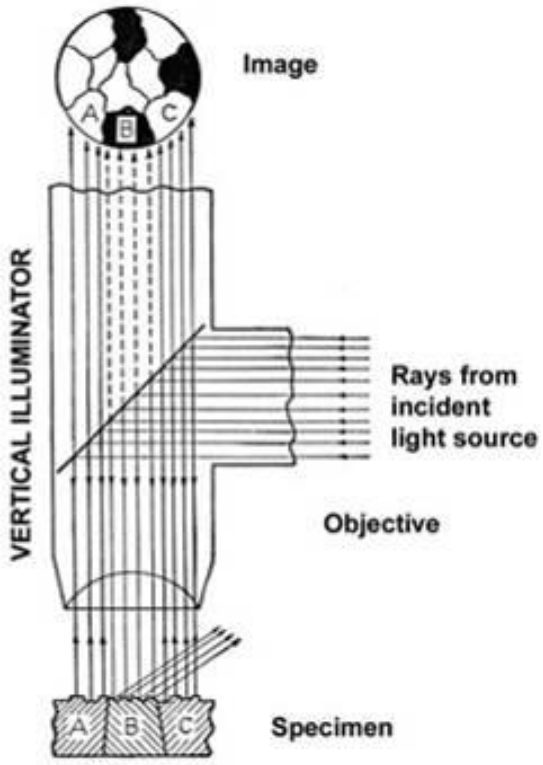


Figure 4. Specimen image under bright-field illumination.

Etching solutions for iron and steel

Etchants for Iron and Steel

Etchant	Composition		Use
Nitric acid (nital)	HNO_3	1-5 ml	Etching rate is increased or selectively decreased with amount of HNO_3. SWAB for a few second to 1 min. In carbon steels: (1) to darken pearlite and give contrast between pearlite colonies; (2) to reveal ferrite boundaries; (3) to differentiate ferrite from martensite.
	Ethyl or Methyl alcohol	100 ml	
Picric acid (picral)	Picric acid	4 g	More dilute solutions occasionally useful. SWAB for a few seconds to 1 min. or more. Does not reveal ferrite grain Boundaries as readily as nital. Use for all grades of carbon steels.
	Ethyl alcohol	100 ml	

Other etching solutions can be found in ASTM E3 section.

Questions:

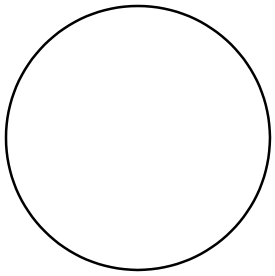
1. **What is meant by metallugraphy**?
2. **What is the main purpose of grinding operation?**
3. **What is the main purpose of polishing operation**?
4. **What is electro- polishing?**
5. **Which one is better, hand polishing or electro-polishing?**
6. **Why we see grain boundaries as dark lines within the structure of metals and alloys?**

Experiment No. 03

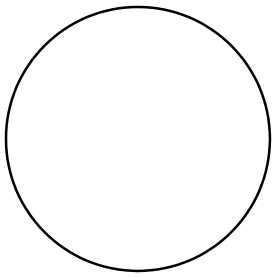
Aim: Study and drawing of microstructures of Steels.

Look through the microscope and try to draw the following microstructures of different steels.

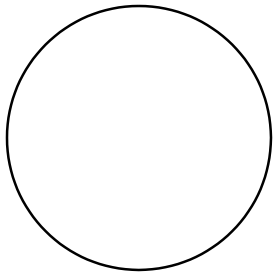
1. Iron (0.0% C)



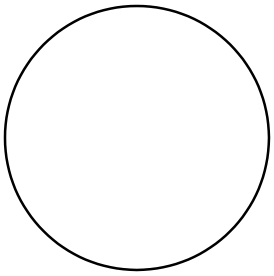
2. Hypo eutectoid Steel (0.2% C)



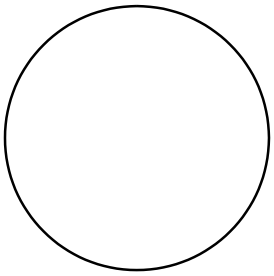
3. Hypo eutectoid Steel (0.4 % C)



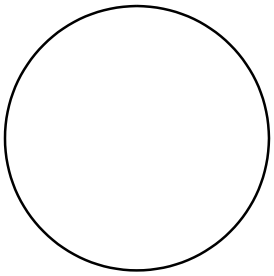
4. Hypo eutectoid Steel (0.6% C)



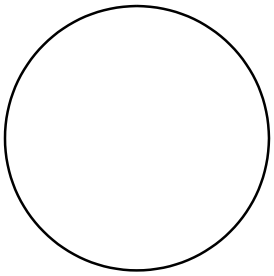
5. Eutectoid Steel (0.8% C)



7. Hypereutectoid Steel (1.2% C)



8. Hypereutectoid Steel (2 % C)



Questions:

1. **Are there any relation between carbon content and steel strength? How?**
2. **Define each of the followings:**

1.Ferrite 2. Pearlite 3. Cementite 4. Eutectoid steel

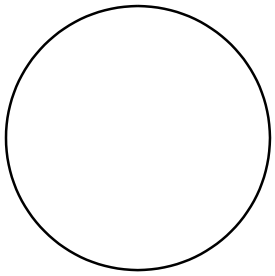
3. **How carbon content affects microstructure constituents of steel? Explain with the aid of sketches**

Experiment No. 04

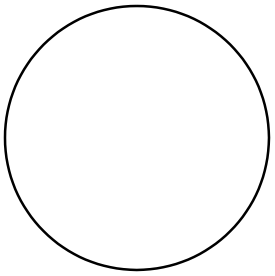
Aim: Study and drawing of microstructures of Cast Iron.

Draw the microstructures of following Cast Irons

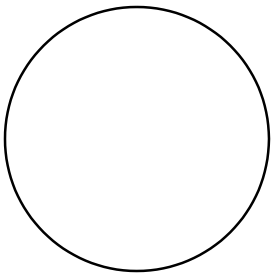
1. White Cast Iron



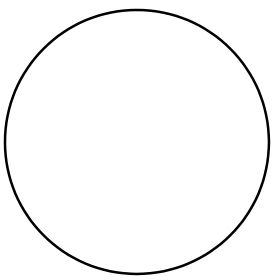
2. Flakes Graphite Grey Cast Iron



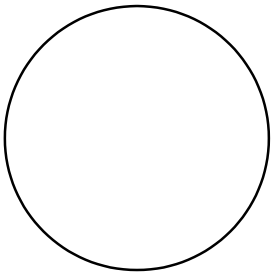
3. Nodular Graphite Grey Cast Iron



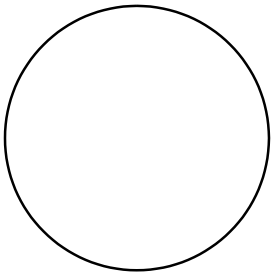
4. White Heart Malleable Cast Iron



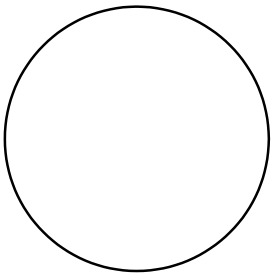
5. Ferritic Grey Cast Iron



6. Pearlitic Grey Cast Iron

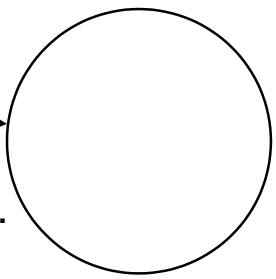


7- Black Heart Malleable Cast Iron.



<u>Questions:</u>

1. **How can you recognize white cast iron from grey cast iron?**
2. **How silicon content affect microstructure and consequently mechanical properties of Cast iron?**
3. **What is meant by ductile iron? Draw its microstructure.**



4. **What are the procedures required for the manufacture of ductile iron.**

Experiment No. 05

Aim: Hardness and Hardness Testing Machines

HARDNESS TESTING THEORY:

Hardness is usually defined as the resistance of a material to localized plastic penetration or deformation of its surface. There are three main types of tests used to determine hardness:

1. Scratch tests are the simplest form of hardness tests. In this test, various materials are rated on their ability to scratch one another. ***Mohs*** hardness test is of this type. This test is used mainly in mineralogy.

2. In Dynamic Hardness tests, an object of standard mass and dimensions is bounced back from a surface after falling by its own weight. The height of the rebound is indicated. Shore hardness is measured by this method.

3. Static Indentation tests are based on the relation of indentation of the specimen by a penetrator under a given load. The relationship of total test force to the area or depth of indentation provides a measure of hardness. The Rockwell, Brinell, Knoop, Vickers, and ultrasonic hardness tests are of this type.

For engineering purposes, only the static indentation tests are used.

1. BRINELL HARDNESS TEST-HBN:

This test consists of applying a constant load, usually between 500 and 3000 kgf for a specified time (10 to 30 s) using a 5 or 10mm diameter hardened steel or tungsten carbide ball on the flat surface of a workpiece.

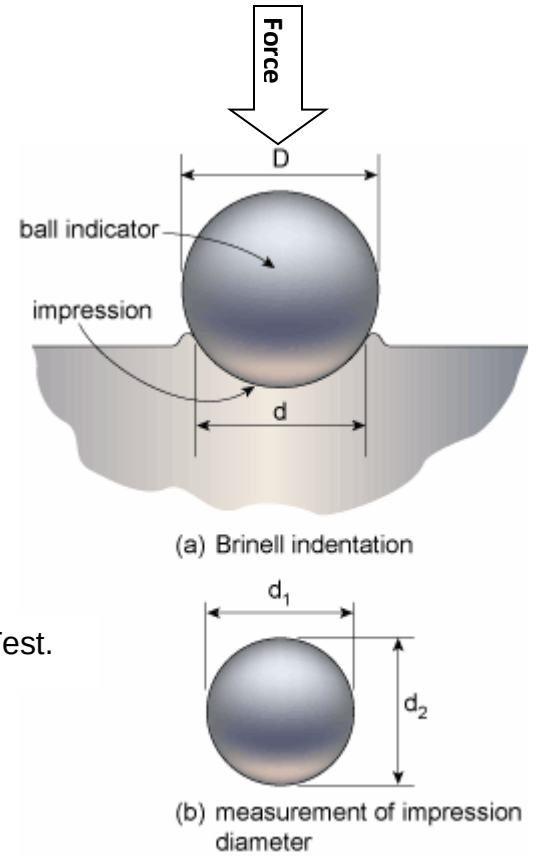


Figure 5: Principle of Brinell Hardness Test.

Hardness is determined by taking the mean diameter of the indentation and calculating the Brinell hardness number (BHM or HB) by dividing the applied load by the surface area of the indentation according to following formula:

$$HBN = \frac{2F}{\pi D[D - \sqrt{D^2 - d^2}]} = \frac{\text{Kg}}{\text{mm}^2}$$

where ***F*** is load in kg; ***D*** ball diameter in mm; and ***d*** is the diameter of the indentation in mm.

The Brinell hardness number followed by the symbol HB without any suffix numbers denotes standard test conditions using a ball of 10 mm diameter and a load of 3,000 kg applied for 10 to 15 s. For other conditions, the hardness number and symbol HB are supplemented by numbers indicating the test conditions in the following order: diameter of ball, load, and duration of loading. For example, **75 HB 10/500/30** indicates a Brinell hardness of 75 measured with a ball of 10 mm diameter and a load of 500 kg applied for 30s.

2. **VICKERS HARDNESS TEST- HVN:**

The Vickers hardness test uses a square base diamond pyramid as the indenter. The included angle between the opposite faces of the pyramid is **l36°.** The Vickers hardness tester operates on the same basic principle as the Brinell tester, the numbers being expressed in the terms of load and area of the impression. As a result of the indenter's shape, the impression on the surface of the specimen will be a square. The length of the diagonal of the square is measured through a microscope fitted with an ocular micrometer that contains movable knife-edges. The Vickers hardness values are calculated by the formula:

$$HVN = 1.854\frac{F}{d^2} = \frac{\text{Kg}}{\text{mm}^2}$$

where;

F is the force in Kg

D is the diagonal length in mm

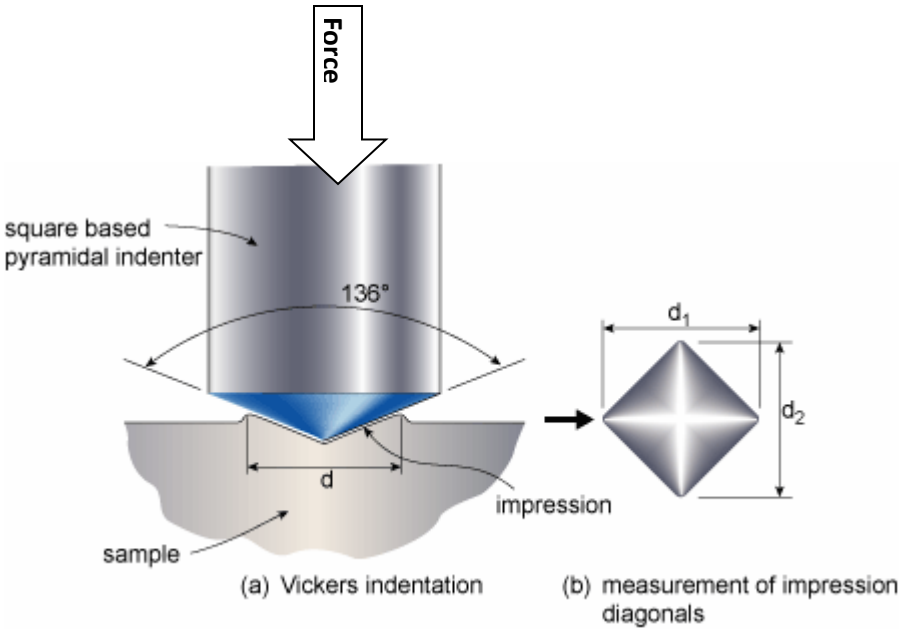


Figure 6: Principle of Vickers Hardness Test.

3. ROCKWELL HARDNESS TEST- HR:

This hardness test uses a direct reading instrument based on the principle of differential depth measurement. Rockwell testing differs from Brinell testing in that the Rockwell hardness number is based on an inverse relationship to the measurement of the additional depth to which an indenter is forced by a heavy (major) load beyond the depth resulting from a previously applied (minor) load. Initially a minor load is applied, and a zero datum position is established. The major load is then applied for a specified period and removed, leaving the minor load applied. The resulting Rockwell number represents the difference in depth from zero datum position as a result of the application of major load. The entire procedure requires only 5 to 10 s.

Use of a minor load greatly increases the accuracy of this type of test, because it eliminates the effects of backlash in the measuring system and causes the indenter to break through slight surface roughness.

The 120^{o} sphero-conical diamond indenter is used mainly for testing hard materials such as hardened steels and cemented carbides. Hardened steel ball indenters with diameters 1/16, 1/8, 1/4, 1/2 in. are used for testing softer materials such as fully annealed steels, softer grades of cast irons, and a wide variety of nonferrous metals.

In Rockwell testing, the minor load is 10 kgf, and the major load is 60, 100 or 150 kgf. In superficial Rockwell testing, the minor load is 3 kgf, and major loads are 15, 30 or 45 kgf. In both tests, the indenter may be either a diamond cone or steel ball, depending principally on the characteristics of the material being tested.

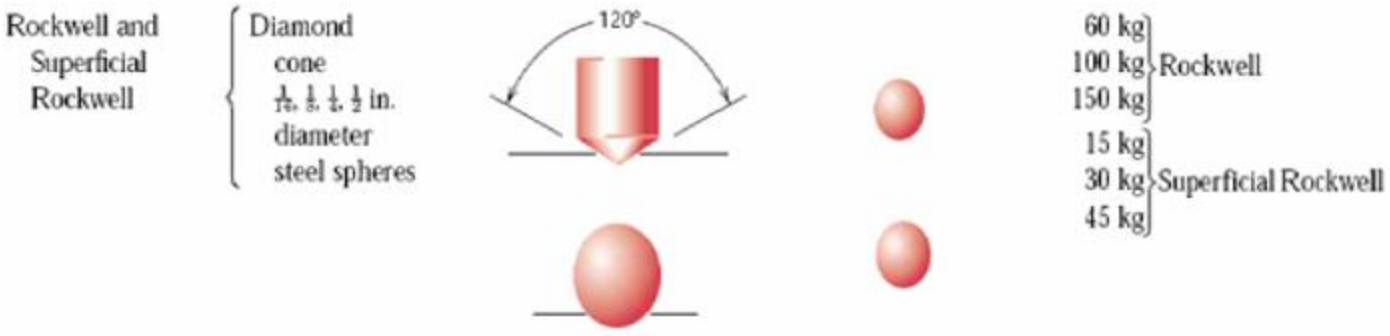


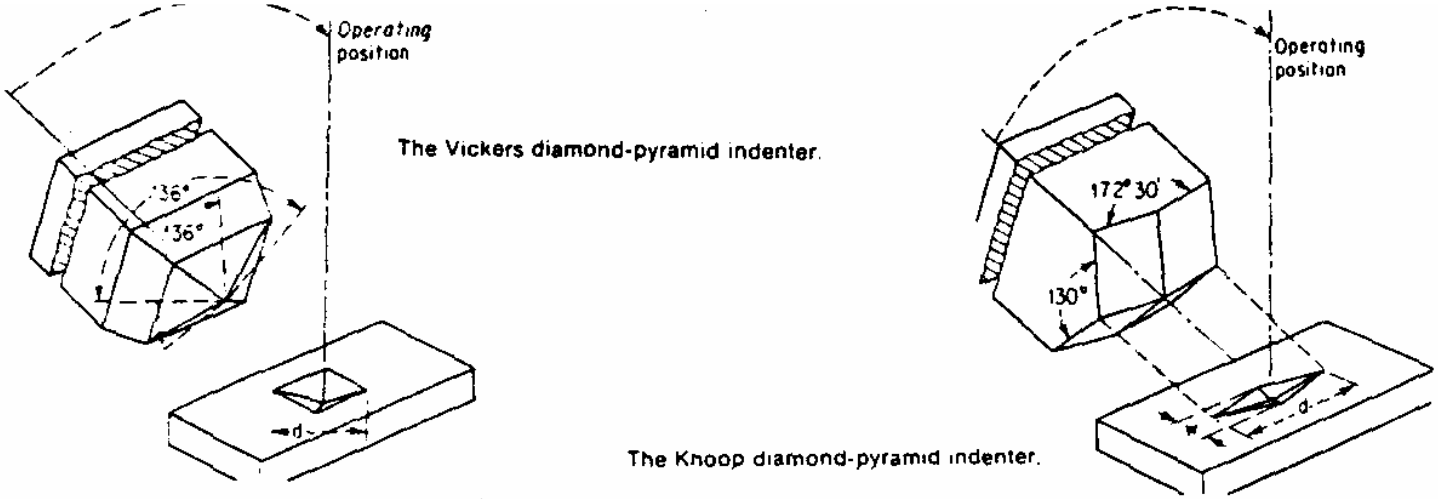
Figure 7: Rockwell Hardness method.

4. Microhardness [Knoop hardness] Test:

This term, unfortunately, is misleading, as it could refer to the testing of small hardness values when it actually means the use of small indentations. Test loads are between 1 and 1,000 g. Two types of indenters are used for Microhardness testing: the 136° square-base Vickers diamond pyramid described previously, and the elongated Knoop diamond indenter. Knoop microhardness can be determined by the following equation:

$$KHN = 14.2\frac{F}{l^2} = \frac{Kg}{mm^2}$$

Where ***F*** is the force and ***l*** is the length of the impression.



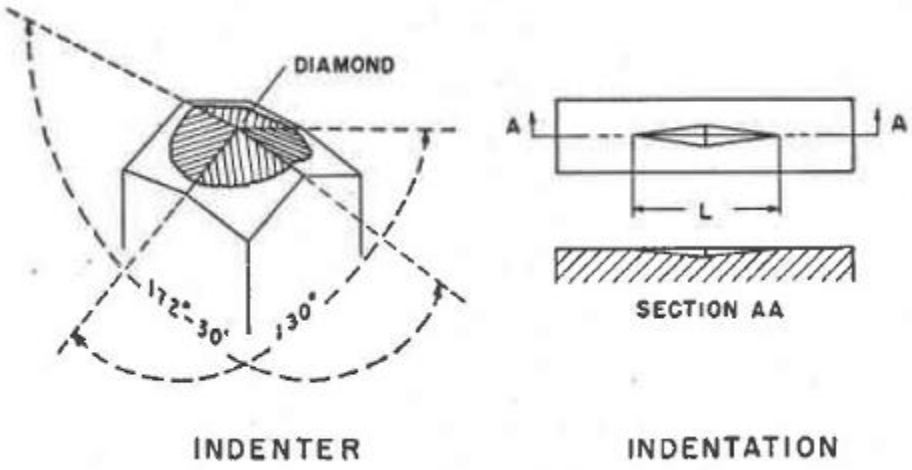


Figure 8: illustration of the microhardness principle

Questions:

1. **Is there any relation between hardness and strength property of metals? Explain.**
2. **List the advantages and disadvantages of each of the above hardness testing method.**
3. **Which of the methods mentioned above is more accurate.**
4. **List some applications of microhardness method.**

Experiment No. 06
Aim: Study of the effect of heat treatments on the mechanical properties of steel articles

Theory: The various types of heat-treating processes are similar because they all involve the heating and cooling of metals; they differ in the heating temperatures and the cooling rates used and the final results. The usual methods of heat-treating ferrous metals (metals with iron) are annealing, normalizing, hardening, and tempering. Most nonferrous metals can be annealed, but never tempered, normalized, or case-hardened.

Successful heat treatment requires close control over all factors affecting the heating and cooling of a metal. This control is possible only when the proper equipment is available. 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.

STAGES OF HEAT TREATMENT: Heat treating is accomplished in three major stages:

Stage I— Heating the metal slowly to predetermined temperature to ensure a uniform heating of the whole part.

Stage 2— Soaking (holding) the metal at that temperature for a given time.

Stage 3— Cooling the metal to room temperature.

Types of heat treatments:

1. Annealing treatment
2. Normalizing treatment
3. Hardening or quenching treatment
4. Tempering treatment

Annealing: Annealing in general, involves heating to sufficient high temperatures, Holding at this temperature & finally cooling at a very slow rate. The temperature to which steel is heating & holding time are determined by various factors such as the chemical composition of the steel, size & shape of steel component & final properties desired. Annealing can form either the final treatment or a preparatory step for further treatment. The various purposes of this treatment are:

i) To relive internal stresses developed during solidification, machining, forging, rolling or welding etc.
ii) To improve or restore ductility or toughness
iii) To enhance machinability.
iv) To eliminate chemical non-uniformity.
v) To refine grain size
vi) To reduce gaseous content in steel.

Types of Annealing

1. Full Annealing
2. Spherodizing annealing
3. Process or Re crystallization Annealing

Normalizing: Normalizing is a technique used to provide uniformity in grain size and composition throughout an alloy. The term is often used for ferrous alloys that have been heated above the upper critical temperature and then cooled in open air.

The type of structure obtained by normalizing will depend largely upon the thickness of cross-section, as this will affect the rate of cooling. Thin sections will give a much finer grain than thick sections, the latter differing little in structure from an annealed section.

Hardening or quenching treatment: Fundamentally, the objective of the quenching process is to cool steel from the austenitizing temperature sufficiently quickly to form the desired microstructural phases such as the hard and brittle martensite phase, thus hardness increased. The quick cooling is called quenching and the cooling media is called quenchant. The most common quenchant is water and sometimes oil and other liquids are used as cooling media.

Tempering Treatment: TEMPERING is a process by which previously hardened or normalized steel is usually heated to a temperature below the lower critical temperature and cooled at a suitable rate, primarily to increase ductility and toughness, but also to increase the grain size of the matrix. Steels are tempered by reheating after hardening to obtain specific values of mechanical properties and also to relieve quenching stresses and to ensure dimensional stability. Tempering usually follows quenching from above the upper critical temperature; however, tempering is also used to relieve the stresses and reduce the hardness developed during welding and to relieve stresses induced by forming and machining.

Figure 9 show part of the Iron-Carbon diagram in which the heating range of all the above heat treatments are shown for clarity.

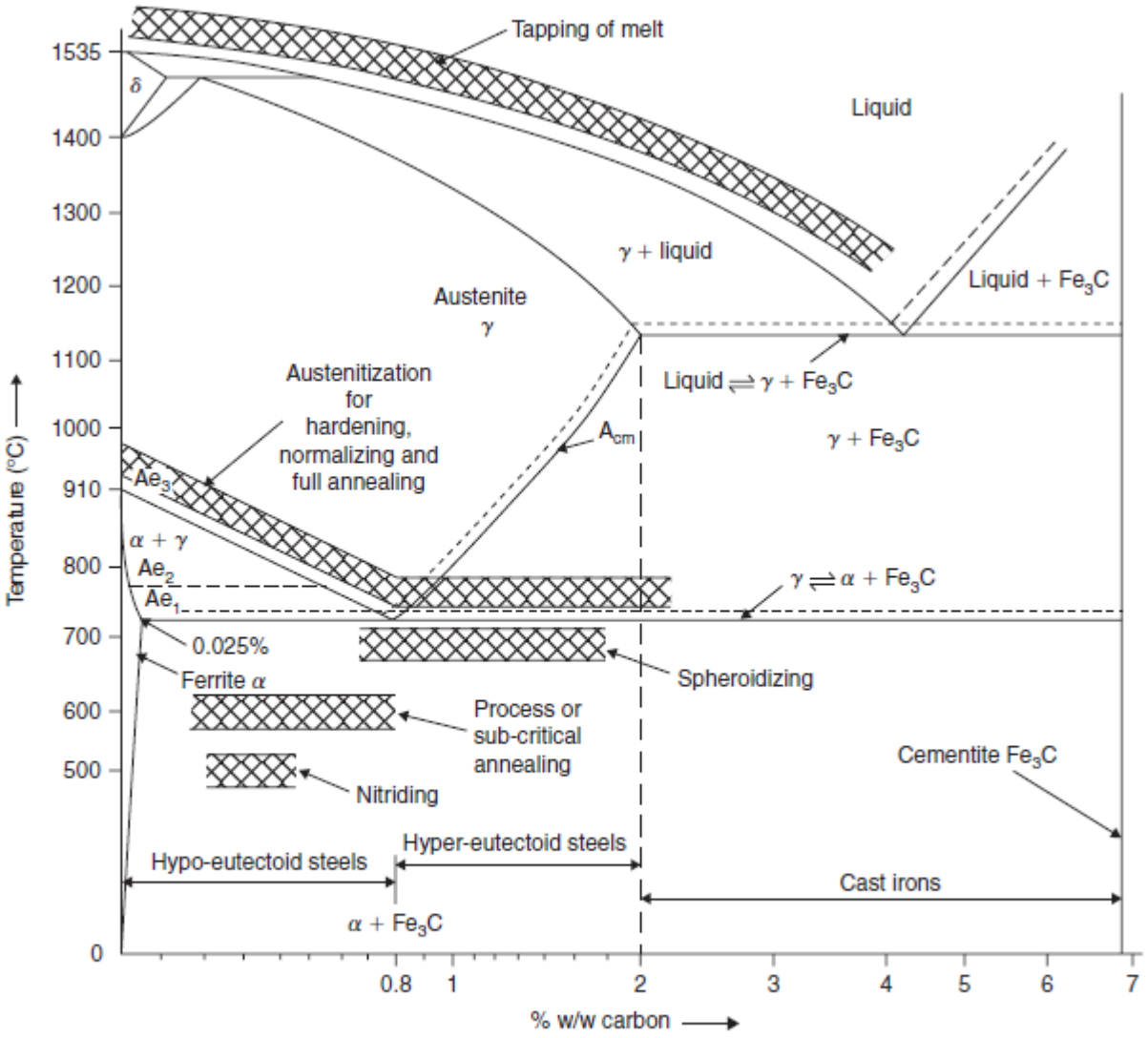


Figure 9: part of the Iron-Carbon diagram showing heating range of different heat treatments

Questions:

1. What is the essential difference between annealing and normalizing?
2. Is it always necessary to perform tempering after quenching? Explain.
3. What is purpose of process annealing and Spherodizing annealing?
4. What microstructural changes occur so that the quenched steel becomes hard and brittle?

Experiment No. - 07

Aim: Determination of Hardenability of steel by Jominy end Quench Test

Theory :- When a piece of steel of any appreciable size is heated to its austenization temperature & then quenched, the cooling rates during quenching vary across the cross section. The cooling rate at the surface & the center are not same. The difference in their rate increases with rise in severity of quenches or decreases in the speed of heat absorption. At the centre of the cross section, the cooling rate is slowest. This may give rise to the formation of pearlite.

The relatively permanent & most common method of determining the hardability of steel is the Quench test. This is also called as '**Jominy End Quench Test**'**.** In this test, the steel bar of **1 inch** diameter & **4 inch** long is heated to proper austenization temperature. After being soak for sufficient time the specimen is quickly placed in a fixture as shown in **figure 10**. A water jet is opened quickly. Water comes out at a constant pressure through the orifice of ½ inch diameter. The distance between orifice and bottom of steel is 0.5 inch. The temperature of water is kept around 24^0 C (R.T). A stream of water strikes at lower end of specimen. The end is quenched and is continued to about 20 min. to cool.

Determination of Hardenability:-.

The Jominy end-quench test is of great practical use in determining the hardenability of steel. Here a standard test piece is made (Figure 10) and heated up to its austenitic state. It is then dropped into position in a frame, as shown in Fig. 10, and quenched at its end only, by means of a pre-set standard jet of water at 24°C. Thus different rates of cooling are obtained along the length of the bar. After the cooling, a 'flat', 0.4 mm deep, is ground along the side of the bar and hardness determinations made every millimeter along the length from the quenched end. The results are then plotted as in Figure 11.

These curves show that the depth of hardening of nickel-chromium steel is greater than that of a plain carbon steel of similar carbon content, whilst the depth of hardening of chromium-molybdenum steel is greater than that of the nickel-chromium steel.

With modifications, the results of the Jominy test can be used as a basis in estimating the 'ruling section' of particular steel. There is no simple mathematical relationship between the two, however, and it is often more satisfactory to find by trial and error how a particular section will harden, after a preliminary Jominy test has been conducted.

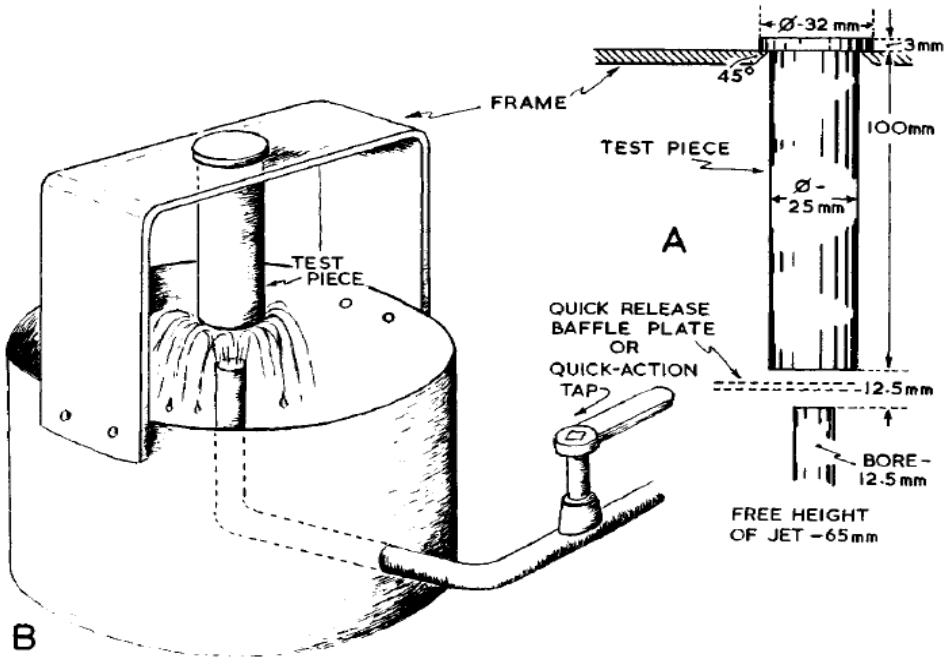


Figure 10 The Jominy end-quench test.
(A) The standard form of test piece used. (B) A simple type of apparatus for use in the test.

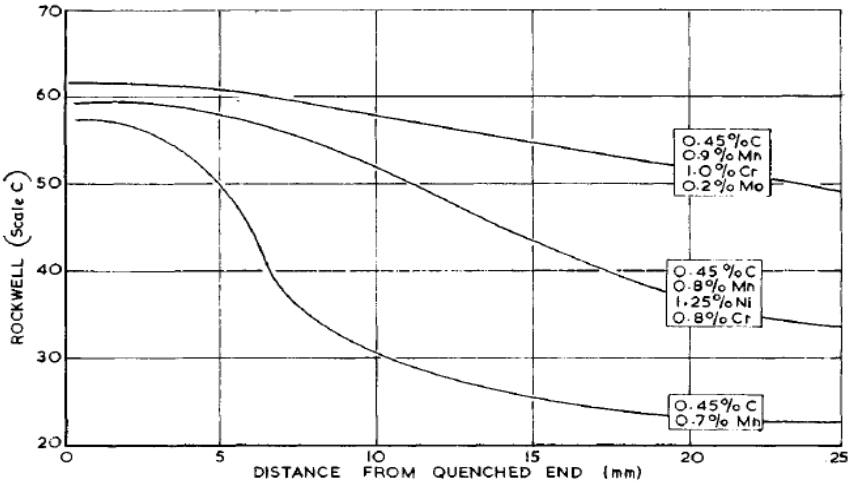


Figure 11 The relative depth of hardening of three different steels as indicated by the Jominy test.

Questions:

1. Differentiate between hardness and hardenability.
2. What are the factors that affect hardenability of steel articles?
3. What is meant by RULING section? How can Jominy end quench test be used to determine Ruling section of steel articles?
4. Which of the hardness methods is best suited for determining hardenability? Prove.

Experiment No. – 08
Tensile Testing of Metals

Objectives

- Students are required to understand the principle of a uniaxial tensile testing and gain their practices on operating the tensile testing machine to achieve the required tensile properties.
- Students are able to explain load-extension and stress-strain relationships and represent them in graphical forms.
- To evaluate the values of ultimate tensile strength, yield strength, % elongation, fracture strain and Young's Modulus of the selected metals when subjected to uniaxial tensile loading.
- Students can explain deformation and fracture characteristics of different materials such as aluminum, steels or brass when subjected to uniaxial tensile loading.

1. Literature Review

1.1 Uniaxial tensile testing

Uniaxial tensile test is known as a basic and universal engineering test to achieve material parameters such as ultimate strength, yield strength, % elongation, % area of reduction and Young's modulus. These important parameters obtained from the standard tensile testing are useful for the selection of engineering materials for any applications required. The tensile testing is carried out by applying longitudinal or axial load at a specific extension rate to a standard tensile specimen with known dimensions (gauge length and cross sectional area perpendicular to the load direction) till failure. The applied tensile load and extension are recorded during the test for the calculation of stress and strain. A range of universal standards provided by Professional societies such as American Society of Testing and Materials (ASTM), British standard, JIS standard and DIN standard provides testing are selected based on preferential uses. Each standard may contain a variety of test standards suitable for different materials, dimensions and fabrication history. For instance, **ASTM E8**: is a standard test method for tension testing of metallic materials and **ASTM B557** is standard test methods of tension testing wrought and cast aluminum and magnesium alloy products.

A standard specimen is prepared in a round or a square section along the gauge length as shown in **figures 1 a) and b)** respectively, depending on the standard used. Both ends of the specimens should have sufficient length and a surface condition such that they are firmly gripped

during testing. The initial gauge length **Lo** is standardized (in several countries) and varies with the diameter (**Do**) or the cross-sectional area (**Ao**) of the specimen as listed in **table 1.** This is because if the gauge length is too long, the % elongation might be underestimated in this case. Any heat treatments should be applied on to the specimen prior to machining to produce the final specimen readily for testing. This has been done to prevent surface oxide scales that might act as stress concentration which might subsequently affect the final tensile properties due to premature failure. There might be some exceptions, for examples, surface hardening or surface coating on the materials. These processes should be employed after specimen machining in order to obtain the tensile properties results which include the actual specimen surface conditions.

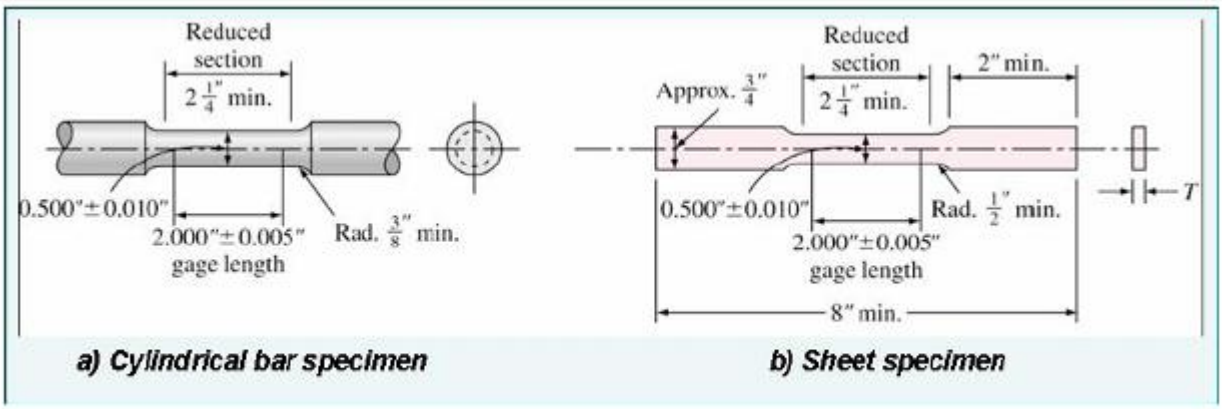


Figure 1: *Standard tensile specimens*

Type specimen	United State (ASTM)	Great Britain	Germany
Sheet $(L_o / \sqrt{A_o})$	4.5	5.65	11.3
Rod $(L_o / \sqrt{D_o})$	4.0	5.0	10.0

Table 1: *Dimensional relationships of tensile specimens used in different countries.*

The equipment used for tensile testing ranges from simple devices to complicated controlled systems. The so-called universal testing machines are commonly used, which are driven by mechanical screw or hydraulic systems. **Figure 2 a)** illustrates a relatively simple screw-driven machine using large two screws to apply the load whereas **figure 2 b)** shows a hydraulic testing

machine using the pressure of oil in a piston for load supply. These types of machines can be used not only for tension, but also for compression, bending and torsion tests. A more modernized closed-loop servo-hydraulic machine provides variations of load, strain, or testing machine motion (stroke) using a combination of actuator rod and piston. Most of the machines used nowadays are linked to a computer-controlled system in which the load and extension data can be graphically displayed together with the calculations of stress and strain.

General techniques utilized for measuring loads and displacements employs sensors providing electrical signals. Load cells are used for measuring the load applied while strain gauges are used for strain measurement. A Change in a linear dimension is proportional to the change in electrical voltage of the strain gauge attached on to the specimen.

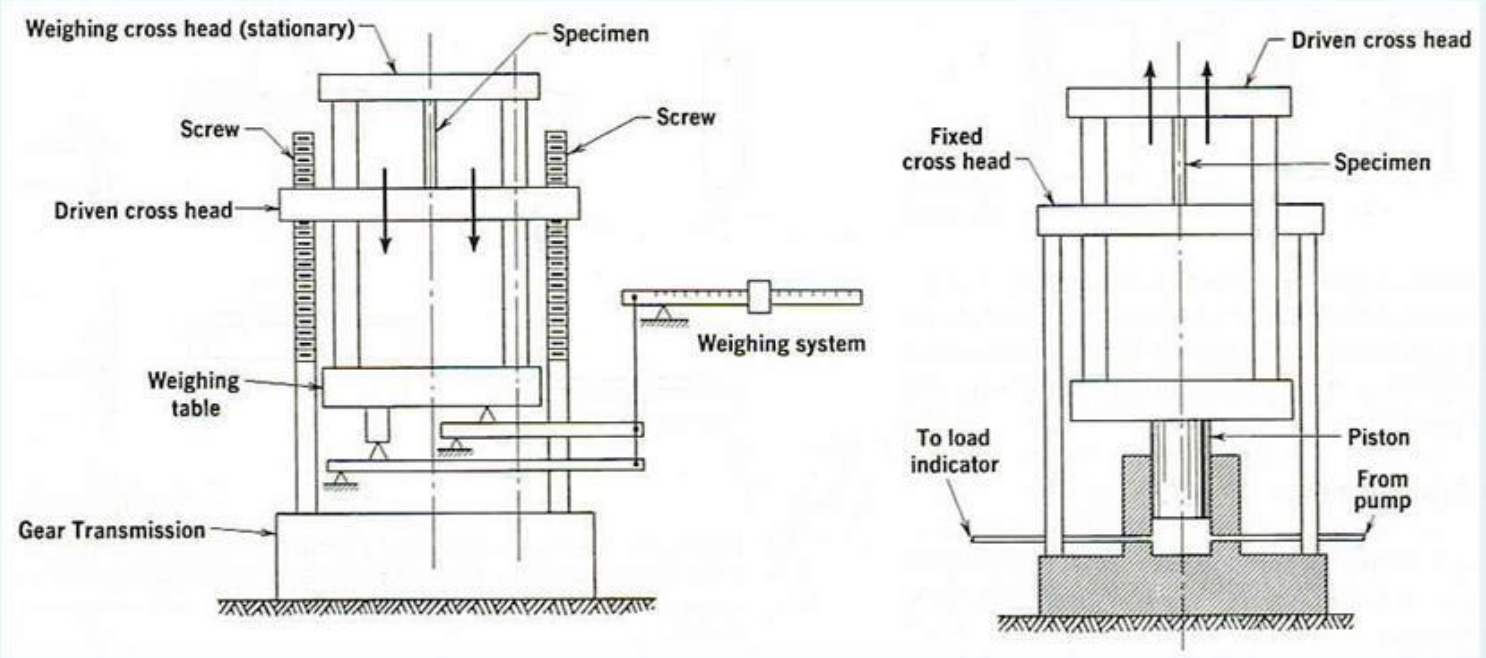


Figure 2: Schematics showing a) a screw driven machine and b) a hydraulic testing machine.

1.2 Stress and strain relationship:

When a specimen is subjected to an external tensile loading, the metal will undergo elastic and plastic deformation. Initially, the metal will elastically deform giving a linear relationship of load and extension. These two parameters are then used for the calculation of the engineering stress and engineering strain to give a relationship as illustrated in figure 3 using equations 1 and 2 as follows;

$$\sigma = \frac{P}{A_o} \qquad \ldots(1)$$

$$\varepsilon = \frac{L_f - L_o}{L_o} = \frac{\Delta L}{L_o} \qquad \ldots(2)$$

where σ is the engineering stress

ε is the engineering strain

P is the external axial tensile load

A_o is the original cross-sectional area of the specimen

L_o is the original length of the specimen

L_f is the final length of the specimen

The unit of the engineering stress is Pascal (Pa) or N/m^2 according to the SI Metric Unit whereas the unit of psi (pound per square inch) can also be used.

1.2.1 Young's modulus, E;

During elastic deformation, the engineering stress-strain relationship follows the Hook's Law and the slope of the curve indicates the Young's modulus (E)

$$E = \frac{\sigma}{\varepsilon} \qquad \ldots(3)$$

Young's modulus is of importance where deflection of materials is critical for the required Engineering applications. This is for examples: deflection in structural beams is considered to be crucial for the design in engineering components or structures such as bridges, building, ships, etc. The applications of tennis racket and golf club also require specific values of spring constants or Young's modulus values.

1.2.2 Yield strength, σy:

By considering the stress-strain curve beyond the elastic portion, if the tensile loading continues, yielding occurs at the beginning of plastic deformation. The yield stress, **σy**, can be obtained by dividing the load at yielding (**Py**) by the original cross-sectional area of the pecimen (**Ao**) as shown in equation 4.

$$\sigma_y = \frac{P_y}{A_o} \qquad \ldots(4)$$

The yield point can be observed directly from the load-extension curve of the BCC metals such as iron and steel or in polycrystalline titanium and molybdenum, and especially low carbon steels, see figure 3. The yield point elongation phenomenon shows the upper yield point followed by a sudden reduction in the stress or load till reaching the lower yield point. At the yield point elongation, the specimen continues to extend without a significant change in the stress level.

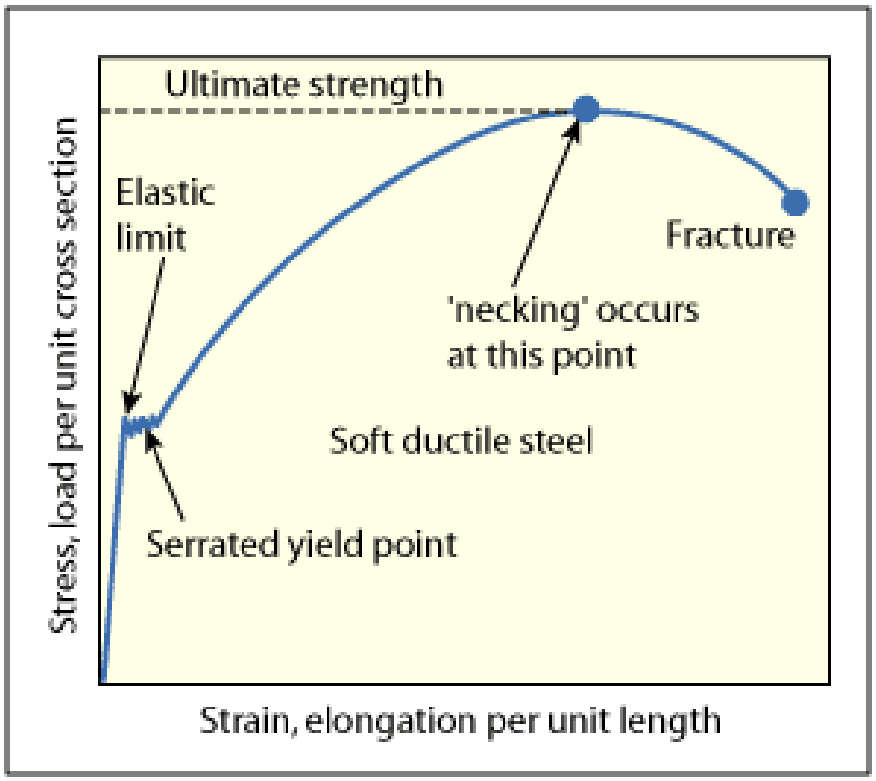


Figure 3; Tensile Curve of soft steel showing clear yield point.

Aluminium on the other hand having a FCC crystal structure does not show the definite yield point in comparison to those of the BCC structure materials, but shows a smooth engineering stress - strain curve. The yield strength [**proof strength**] therefore has to be calculated from the load at 0.2% strain divided by the original cross-sectional area as follows;

$$\sigma_{0.2\%y} = \frac{P_{0.2\%}}{A_o} \qquad \ldots(5)$$

Figure 4 shows how the 0.2% proof strength is determined from the stress – strain diagrams;

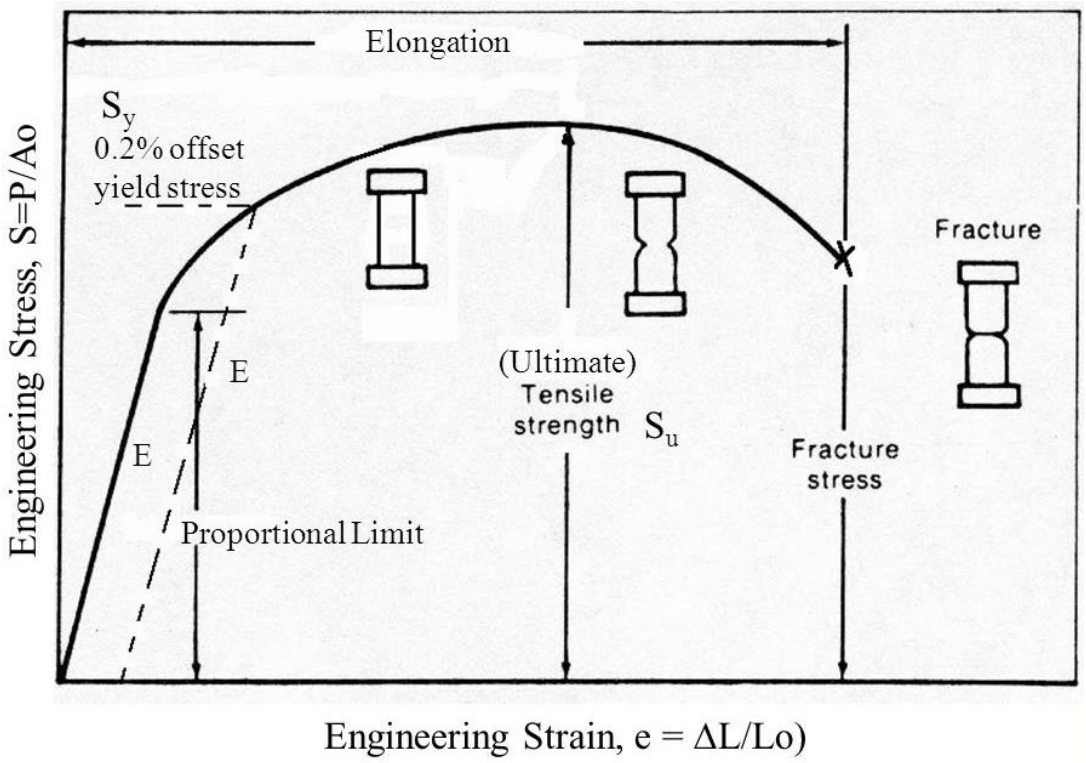


Figure 4; Determination of the Proof strength using 0.2% offset method.

1.2.3 Ultimate Tensile Strength, σ_{TS};

Beyond yielding, continuous loading leads to an increase in the stress required to permanently deform the specimen as shown in the engineering stress-strain curve. At this stage, the specimen is strain hardened or work hardened. The degree of strain hardening depends on the nature of the deformed materials, crystal structure and chemical composition, which affects the dislocation motion. FCC structure materials having a high number of operating slip systems can easily slip and create a high density of dislocations. Tangling of these dislocations requires higher stress to uniformly and plastically deform the specimen, therefore resulting in strain hardening.

If the load is continuously applied, the stress-strain curve will reach the maximum point, which is the ultimate tensile strength (UTS, σ_{TS}). At this point, the specimen can withstand the highest stress before necking takes place. This can be observed by a local reduction in the cross sectional area of the specimen generally observed in the centre of the gauge length as illustrated in figure 5.

$$\sigma_{TS} = \frac{P_{max}}{A_o} \qquad \ldots(6)$$

1.2.4 Tensile ductility;

Tensile ductility of the specimen can be represented as % elongation or % reduction in area as expressed in the equations given below;

$$\%Elongation = \frac{\Delta L}{L_o} \times 100 \qquad \ldots(8)$$

$$\%RA = \frac{A_o - A_f}{A_o} \times 100 = \frac{\Delta A}{A_0} \times 100 \qquad \ldots(9)$$

where A_f is the cross-sectional area of specimen at fracture.

The fracture strain of the specimen can be obtained by drawing a straight line starting at the fracture point of the stress-strain curve parallel to the slope in the linear relation. The interception of the parallel line at the x axis indicates the fracture strain of the specimen being tested.

Questions:

1- Discuss the importance of tensile test;

2- Why do some metals show clear yield point while others do not?

3- What is the effect of temperature on the yield point phenomena?

4- Why do most metals strengthen after the yield point?

5- What is the effect of sample length on the measured ductility?

6- What are extensometers? For what purpose are they used?

7- How many types of extensometers are available? which type is the more accurate?

Experiment No. - 09

Solid state carburizing of steel articles

Aim: Increasing the surface hardness of steel parts by adding more carbon into the surface by solid state carburizing

1- Introduction:

Carburizing is a heat treatment process in which iron or steel absorbs carbon liberated when the metal is heated in the presence of a carbon bearing material, such as charcoal or carbon monoxide, with the intent of making the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content. Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion. When the iron or steel is cooled rapidly by quenching, the higher carbon content on the outer surface becomes hard via the transformation from austenite to martensite, while the core remains soft and tough as a ferritic and/or pearlite microstructure as shown in the following figure.

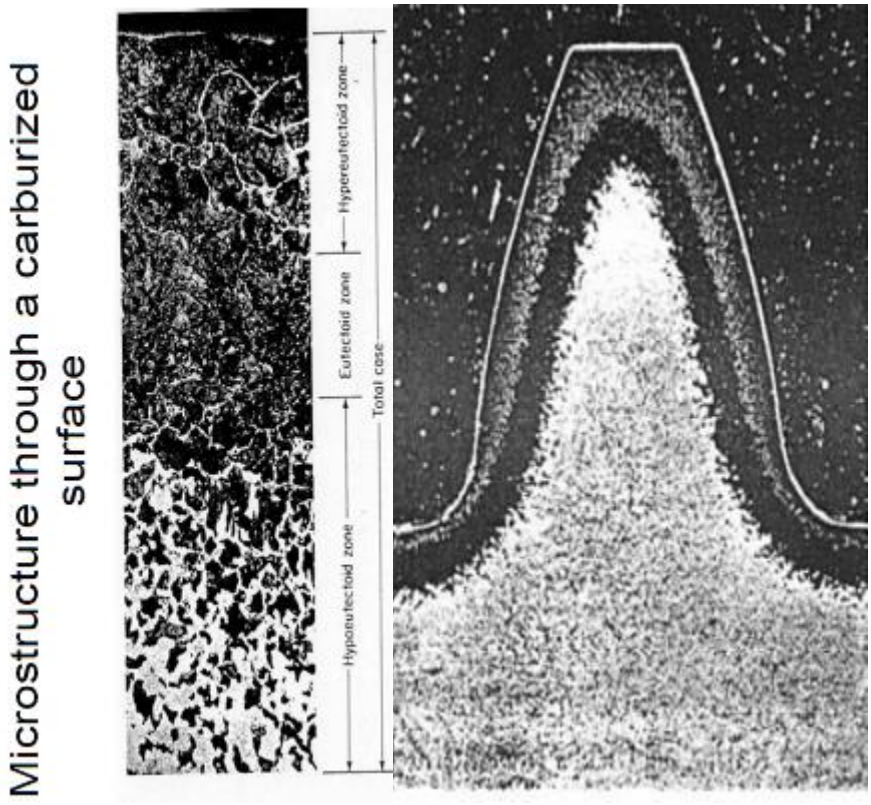


Figure 1; A cross sectional view through a carburized steel gear showing the variation of microstructure as a function of carbon content.

2- Method:

Solid state carburizing also called Pack cementation involves packing the work into heat-resisting steel boxes along with the carburizing material such as charcoal so that a space of approximately 50 mm exists between the components. Then the assembly is heated at about 900°C for some time allowing diffusion to transfer the carbon atoms into the steel surface. A heating period of a few hours might form a high-carbon layer about one millimeter thick

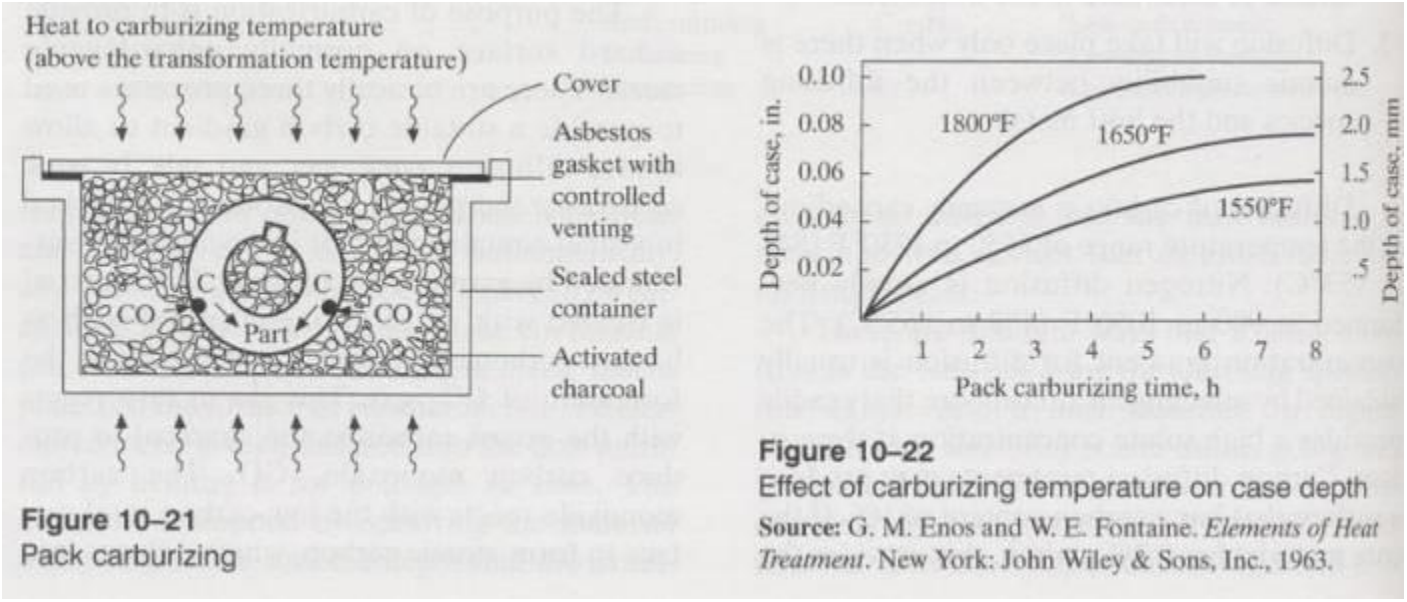


Figure 10–21
Pack carburizing

Figure 10–22
Effect of carburizing temperature on case depth
Source: G. M. Enos and W. E. Fontaine. *Elements of Heat Treatment*. New York: John Wiley & Sons, Inc., 1963.

Figure 2; Solid state or Pack carburizing assembly.

Mechanism (*Pack*): At carburizing temperatures, say 900 °C, the following reactions occur:

$$C + O_2(\text{initial air in charcoal}) \rightarrow CO_2 \qquad CO_2 + C \rightarrow CO \quad . \quad . \quad . \quad . \qquad (1)$$

$$Fe + 2CO \rightarrow Fe(C \text{ in solution}) + CO_2 \qquad CO_2 + C \rightarrow CO \quad . \quad . \quad . \quad . \qquad (2)$$

$$BaCO_3 \rightarrow BaO + CO_2 \qquad CO_2 + C \rightarrow CO \quad . \quad . \quad . \quad . \qquad (3)$$

3- Materials:

The following materials are needed for this process;

1- Electrical furnace capable of reaching about 1000°C of adequate size.

2- Heat resistance steel box of adequate size.

3- Charcoal as a source of carbon.

4- Activator such Barium Carbonate $BaCO_3$

Questions:

1- What other methods of carburizing of steel parts are available? Discuss it.

2- What is the function of $BaCO_3$? are there any other materials that can function the same?

3- Why it's usually necessary to perform post carburizing heat treatment?

4- What kind of diffusion mechanism is involved in this process?

5- What kind of steel parts should be carburized? What is the size limit?

6- What is the max. hardness that can be achieved by this process?