UNIT-I
Syllabus

Materials: Classification of engineering material, Composition of Cast iron and Carbon steels, Iron Carbon diagram. Alloy steels their applications. Mechanical properties like strength, hardness, toughness , ductility, brittleness , malleability etc. of materials , Tensile test- Stress-strain diagram of ductile and brittle materials ,Hooks law and modulus of elasticity, Hardness and Impact testing of materials, BHN etc

What is Material

- A material is any substance that an object is made from..
- Examples: of materials are wood, glass, plastic, metals(copper, aluminum, silver, gold) , steel, stainless steel, paper, rubber, leather, cotton, silk , sand, sugar, wool, nylon, polyester, water, soil etc.

What is Engineering Material

- Materials that are used as raw material for any sort of construction or manufacturing of various products in an organized way of engineering application are known as Engineering Materials. For example, the computer or the pen we use, are manufactured through controlled engineering processes...
- Some examples of engineering materials include steel, concrete, fiberglass, plastics, and rubber etc.

The engineering material can be broadly classified as shown in Fig. 1.1

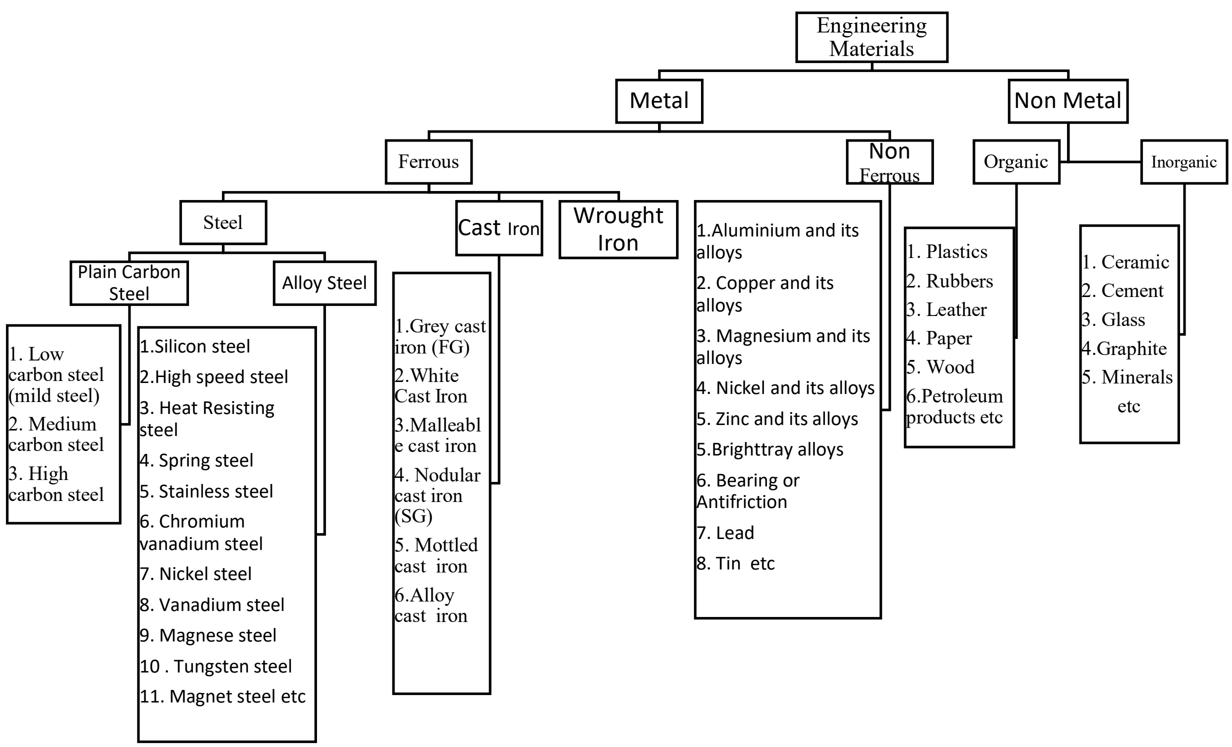


Fig.1.1

Metal
Definition

- Metals are generally composed of an one or more metallic elements (e.g., iron, aluminum, copper, titanium, gold, nickel) which readily gives up electron to form metallic bond and often also nonmetallic elements (e.g., carbon, nitrogen, oxygen) in relatively small amounts. Metals are polycrystalline body consisting of great numbers of fine crystals differently oriented with reference to one another.

Properties of metal

- **Metals generally possess properties like** good thermal and electrical conductivity,hardness, malleable. ductile, plastic deformability, stiffness, rigidity etc

Use of metals

- To make cooking wares, electrical appliances, sheets, electric wire etc.

Alloys: Alloy is *a mixture of two or more metal or metal with non metals.*

Metals may be further subdivided as:

1. Ferrous Metal and its alloy:

- Metals in which chief component is iron are called ferrous metals.The ferrous metals are iron base metals which include all varieties of irons and steels. Properties of ferrous metals: Durable with great tensile strength, generally magnetic, very low resistance to corrosion, recyclable, excellent conductors of electricity
- Uses of ferrous metals: metal ropes, springs, wire, gears, shafts, hammers, drills
- Example of ferrous metals: Steel, cast iron, wrought iron etc

2. Non Ferrous Metal and its alloys

- Metals which do not contain iron are called non-ferrous metals. Properties of non-ferrous metals: light in weight, low resistance to corrosion, non-magnetic etc.
- Uses of non-ferrous metals: Automobiles, utensils, electric cables, electric cells etc.
- Examples of non-ferrous metals: aluminium, zinc, lead, copper

Differentiate between Ferrous and Non-Ferrous Metals:

S.No.	Ferrous Metals	Non-Ferrous Metals
1	High Melting Point	Low Melting Point
2	Higher density	Relatively low density
3	Relatively heavy	Light in weight
4	Higher strength	Lower strength
5	Shrinkage is less	Shrinkage is generally more
6	Less soft	Softness is more
7	Low resistance to corrosion	High resistance to corrosion
8	Highly magnetic due to iron content	Anti magnetic
9	Economical to use	More costly

Table 1.1

Non-Metal

- Non-metallic materials can be defined as any material that does not contain any metallic element in its composition. Non-Metals are generally composed of an one or more non metallic elements (e.g., carbon, nitrogen, oxygen that forms negative ions by accepting or gaining electrons.

Properties of Non-Metals

- High electronegativity,poor thermal conductors,poor electrical conductors, not malleable or ductile, little or no metallic luster, gain electrons easily etc

Uses of Non-metals

- Hydrogen is very useful as rocket fuel.
- Carbon can be used to make pencils when it is in the graphite form.

Examples of Non-Metals

Non-metallic material includes: leather, rubber, plastics, carbon etc.

Non-metals may be subdivided into two categories:

1. Organic Material:

- Organic materials are defined as carbon-based compounds, originally derived from living organisms and plants but now including lab-synthesized versions as well.
- Orgnanic materials are derived directly from carbon. They usually consist of carbon chemicallycombined with hydrogen, oxygen or other non-metallic substances.

Properties of Organic Materials:

- Light in weight
- Combustible
- Soft
- Ductile

Uses of Organic Materials:

- Electric insulation
- Fuel
- Refrigerant
- Lubricant
- Explosive

Examples: rubber, paper, plastics, wood, petroleum products, paints etc.

2. Inorganic Material:

- Material which is not derived from living organisms and contains no organically produced carbon known as inorganic material.
- Inorganic materials are generally derived from non-living sources, such as rocks or minerals.
- Inorganic material composed of matter other than plants or animals.

Properties of Inorganic Materials:

- Very Brittle
- High thermal stability
- High density
- High boiling and melting points etc.

Uses of inorganic material: catalysts, coatings, cooking, electrical circuits etc.

Examples of inorganic materials: carbon monoxide (CO), silicon carbide (SiC), ammonia (NH_3) etc.

Ceramics

- Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides. For example, common ceramic materials include aluminum oxide (or alumina, $Al2O_3$), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the traditional ceramics—those composed of clay minerals (e.g., porcelain), as well as cement and glass.

Important properties of ceramic material

- Brittleness, hardness, stifness, corrosion resistance, high resistance to temperature etc.

Applications of ceramic material

- These materials are used for cookware, cutlery, and even automobile engine parts etc

Wrought Iron: Wrought iron is the mixture of pure iron and 1-3%slag. It also contains traces of carbon, silicon, mangenese, sulphur and phosphorous. First of all the elements (carbon, silicon, mangenese, sulphur and phosphorous) are removed, leaving almost pure iron, then adding slag to pure iron and thoroughly mixed into it. The final mixed is then pressed to remove excess slag and reduced into billets by a rolling.

Propertiess:

- Good ductility, malleability and can be formed into different shapes easily.

Applications:

- Chains, crane hooks, boiler tubes etc.

Cast Iron: It is an alloy of iron and carbon obtained by melting pig iron with coke and limestone in a furnace named Cupola Furnace. It contains 2 to 4% of carbon. It also contains silicon, sulphur, phosphorus and manganese in small quantity. Carbon in cast iron usually exists in two forms.

a) Free Carbon (Graphite)
b) Combined Carbon (Cementite)

Properties of Cast Iron

- Brittle, high compressive strength, good casting characteristics, excellent machinability, wear resistance etc.

Uses

- Piston and piston rings, pressure plate for clutches, brake shoes for ic engine etc.

Types of Cast Iron

1. Grey Cast Iron

- It is basically an alloy of carbon and silicon with iron. Grey cast iron is obtained by allowing the molten cast iron having relatively high carbon euivalen ($C.E = C\% + \frac{Si\%+P\%}{3}$) is cooled and solidified slowly. On solidifying, the solidified cementite breaks up into austenite and graphite flakes. The graphite flakes give the cast iron gray appearance when fractured, hence the name gray cast iron
- Chemical Composition: C =2.5–3.8%; Si = 1.1–2.8% ;Mn = 0.4–1%; P = 0.15% and S = 0.10%., Remaining = Iron.

Properties of Grey Cast Iron.

- It possesses machinability better than steel.
- It possesses high fluidity and hence it can be cast into complex shapes and thin sections.
- It has high resistance to wear.
- It possesses high vibration damping capacity.
- It has low ductility and low impact strength as compared with steel.

Uses

- Manhole covers.
- Gas or water pipes for underground purposes.
- Sanitary works.
- Household appliances.

2. White Cast Iron

- At low value of C.E < 3% (C upto 2.5% and Si < 1.5%) and rapid cooling cementite will not have sufficient time to break into graphite and austenite. As a result the total carbon (maximum) will be in combined form of iron carbide, (Fe_3C).
- Composition: Iron = 94%; Graphite carbon = 0.5%; Combined carbon = 3.5% and the remainder other impurities.

Properties

- Hard, brittle and cannot be machined.
- Highly resistant to wear.
- Tensile strength is good.
- Due to its poor fluidity it does not fill the mould freely.

Uses

- Used for parts subjected to excessive wear e.g. grinding balls
- Agriculture machinery

3. Malleable Cast Iron

- Composition of malleable cast iron: C = 2 – 3%, Si = 0.6 – 1.3%, Mn = 0.2 –0.6%,P = 0.15% , S = 0.10%.,Remaining = Iron.
- The procedure of obtaining malleable cast iron is as follows: The white cast iron casting along with silica is packed in a steel pot in heated ruffle oven or continuous type thermal kiln. The temperature is maintained at 870°C for 60 hours and casting is cooled slowly in the furnace, iron carbide dissociates as $Fe_3C \rightarrow Fe + C$ and thus reduces to malleable cast iron.

Properties

- It can be hammered and rolled to different shapes.
- It has high Young's modulus and low coefficient of thermal expansion.
- It possesses good wear resistance and vibration damping capacity.
- It is soft and easily machined.

Uses

- Brake pedals.
- Tractor springs..
- Washing machine parts.

4. Nodular cast iron (Ductile iron)

- To produce nodular cast iron , the molten metal is first desulphurised .Then the small amount of special alloy containing magnesium are added to molten iron in the ladle causing it, during solidification, to precipitate graphite as amall spherical nodules. It is produced in thicker pieces compared to those of malleable cast iron.
- Composition of Nodular or ductile cast iron: C = 3.2 – 4.2%; Si = 1.1 – 3.5% ;Mn = 0.3 – 0.8% ; P = 0.08% ,S = 0.2%, Remaining = Iron.

Properties

- It possesses very good machinability.
- It possesses excellent castability and wear resistance.
- High fluidity.

Uses

- Hydraulic cylinders
- Power transmission equipment.
- Valves.
- Internal combustion engines.
- Pumps and compressors.

5. Mottled cast iron

- Composition: Iron = 93.5%, Graphite = 1.75%, Combined carbon = 1.75%; the remainder impurities.
- It is mixture of grey and white cast iron in which the outer layers have the structure of white cast iron and the core, that of grey cast iron. It is obtained ny heating cast iron to red hot with the powdered red hematite in an oven.

Properties

- Less tendency to rust than grey variety.
- Fluidity is good.
- Hard and brittle.

Uses

- Also employed for making fire plugs and lamp posts.
- Used for manhole covers and pipes.

6. Alloy cast iron

- Because the cast iron is supposed to be very hard, brittle, lacking in tensile and weak to withstand shocks it is alloyed with other metals to improve its properties.

Effect of alloying element on the properties of cast iron:

1. Carbon: Carbon in cast iron usually exists in two forms: a) Free Carbon (Graphite) b) Combined Carbon (Cementite)

- Carbon lower the melting point and increases fluidity of metal.
- Metal becomes harder and less machinable with the increase in total carbon content.

2. Silicon: When present in small proportions, the Silicon results in precipitation of free carbon and that makes the cast iron soft and ensures better casting. However, when silicon is present in higher proportions it makes the cast iron brittle and more resistance to acid. Silicon is generally present in the cast iron from 1.25 to 3%.

3. Nickel: Nickel is used in cast iron to refine grain structure , increases strength and toughness and increases resistance to corrosion.

4. **Chromium**:Chromium also refines grain structure and increases strength, hardnessand corrosion to resistance. It also increases the wear resistance and heat resistance property of cast iron.

5. Manganese: Manganese is present in cast iron up to 1%

- Hardens the iron by increasing the solubility of carbon in iron
- Stabilizes carbide and that makes the iron more wear resistance

6. Copper: Copper is added to cast iron in amount uptoabout 1.0%. It increases fluidity for improved mould filling ability, imparts corrosion resistance and improves mechanical properties notably toughness and hardness.

Steel:

- Steel is defined as an alloy of iron and carbon in which the carbon content ranges up to 2 percent.
- Steel may be further classified as : a) Plain carbon steel b) Alloy steel

Uses:

- Steel is highly used in the automobile industry. Different types of steels are used in a car body, doors, engine, suspension, and interior
- Most of the household appliances like fridge, TV, oven, sinks etc. are made of steel.
- Steel is used for building construction.

Plain carbon steel:

- Plain carbon steel or carbon steel is an alloy of carbon and iron with varying quantities of unavoidable impurities. It is defined as a steel which has its properties mainly due to the carbon content.
- **Uses:**Its commonly used structurally in buildings and bridges, axles, gears, shafts, rails, pipelines and couplings, cars, fridges and washing machines, used to make cutting tools, blades, punches, dies, springs and high-strength wire etc.

Plain carbon steel can be classified into three categories depending upon the percentage of carbon:

Types of steel	Carbon (%age)	Uses	Properties

Mild Steels (good for welding)	Below 0.1	Galvanised plates, tin plates and wires	1. Soft and easily machinable. 2. Can be easily welded. 3. Hear treatment (hardening and tempering) is ineffective due to low carbon content. 4. Rust prone, get rusted easily. 5. It can be magnetized permanently.
	0.1 to 0.15	Boiler plates, ships plates	
	0.15 to 0.25	Strips of fan blade , machine structure	
	0.25 to 0.35	Hydraulic cylinders, turbine motor shafts	
Medium carbonsteels	0.35 to0.45	Turbine disc, connecting rods, railways	1. It is machinable. 2. The strength of these materials is high but their weldability is comparatively less than mild steel. 3. Due to higher C%, it can be heat treated to get higher hardness.
	0.45 to 0.55	Gear wheels, gun parts	
High carbonsteels	0.55 to 0.65	Gears, tyres	. 1. Can be easily welded. 2. Can be permanently magnetised. 3. Brittle and less ductile. 4. Rusts rapidly. 5. Absorbs shocks.
	0.65 to 0.75	Hammers, crusher rolls	
	0.75 to 0.85	Hand chisels, scissors	
	0.85 to 1.5	Drills, dies, knives	
	1.0 to 1.3	Razors, Drills	

Table 1.2

Alloy steel:

- When certain special properties are desired some elements such as nickel, chromium, manganese, vanadium, tungsten etc. are added to the carbon steels. The steels thus obtained are called alloy steels.

Purposes of alloying:

The alloying elements are added to accomplish one or more of the following:

1. To improve hardness, toughness, elasticity,corrosion, wear resistance, ductility, tensile
2. To improve machinability.
3. To improve high or low temperature stability.
4. To improve cutting ability.

Advantage of alloy steel:

1. Greater ductility at higher strength.
2. Greater hardenability.
3. Greater high temperature strength.
4. Less distortion and cracking.
5. Higher endurance strength

Advantage of alloy steel:

1. High cost.

2. Requires special handling.

The effects of alloying elements:

Metal	Remarks
Nickel	(i) Increases toughness. (ii) Improves elasticity, resistance to fatigue and corrosion
Chromium	(i) It forms complex series of chromium carbide and thus improves the hardenability and increases resistance to abrasion and wear.
Vanadium	(i) Improves response to heat treatment. (ii) It gives strength
Tungsten	(i) Retention of hardness and toughness at high temperatures. (ii) It resist heat
Silicon	(i) Improves oxidation resistance.. (ii) Increases strength without decreasing ductility. (iii) Acts as a deoxidizer.
Copper	(i) In small amounts improves atmospheric corrosion resistance. (ii) Acts as a strengthening agent.
Carbon	(i) Affects melting point. (ii) Affects tensile strength, hardness and machinability.
Molybdenum	(i) Enhances corrosion resistance in stainless steels. (ii) Makes steel usually tough at various hardness levels. (iii) Promotes hardenability of steel.
Manganese	(i) Increases strength and hardness markedly. (ii) Lowers both ductility and malleability if it is present inhigh percentage with high carbon content in steel.
Aluminium	(i) Acts as a de-oxidizer. (ii) If present in an amount of about 1%, it helps promoting nitriding.
Cobalt	(i) Improves heat resistance. (v) Improves mechanical properties such as tensile strength, fatigue strength and hardness.

Table 1.3

Types of alloy steels:

1. Stainless steel:

- Stainless steel is an alloy of iron that is resistant to rusting and corrosion. It contains at least 11% chromium and may contain elements such as carbon, other nonmetals and metals to obtain other desired properties. Stainless steel's resistance to corrosion results from the chromium, which forms a passive film that can protect the material and self-heal in the presence of oxygen.

Properties of Stainless steel

- ;The stainless steel exhibits the properties like luster and corrosion resistance
- Like steel, stainless steels are relatively poor conductors of electricity, with significantly lower electrical conductivities than copper etc.

Uses

- These can be used in cookware, cutlery, surgical instruments etc.

Types of stainless steel

1. Austenitic stainless steel

- Composition: C-0.03 to 0.25%; Mn-2 to 10%; Si-1 to 2%; Cr-16 to 25%; Ni-3.5 to 22%; Mo and Ti are also added in some cases.

Properties

- Owing to ductility, these steels are used for fabrication work.
- These steels are easily weldable, non-magnetic and good corrosion resistant.

Uses

- These steels are used in aircraft, household items etc.

2. Martensitic stainless steel:

- Composition: C-0.15 to 1.2%; Mn-1%; Si-1%; Cr-11.5 to 18%.

Properties

- These steels are magnetic in all conditions and possess the best thermal conductivity of the stainless types.
- These steels can be easily welded and machined
- This steels have good toughness and show good corrosion resistance to wear

Uses

- Springs, screws, nuts, bolts, valves, springs, cutlery, surgical and dental instruments etc.

3. Ferritic stainless steel

- Composition: C-0.08 to 0.20%; Mn-1 to 1.5 %; Si-1%; Cr-11to 27%.

Properties

- These steels are tough, magnetic and have good resistance to corrosion.
- These steels have the good ductility

Uses

- Manufacturing of all types of surgical cutlery, household utensils, components of nuclear power production, etc.

2. High speed steel

- High speed steel, or HSS, is a type of steel that is used in high speed applications, such as in things like drill bits and power saw blades.
- Composition: C=0.7-0.8%, W= 12-20%, Cr=3-5%,V=1-2% and cobalt=5-10%

Properties of high speed steel

- They possess high wear resistance
- It is hard steel and cannot be machined by ordinary method.
- It allows the tool to cut the metal at high speed.

Uses of high speed steel

- Hand tool such as chisels, punches, hammers etc
- For the manufacturing of drills, milling cutters, broaches etc

Types of high speed steel

1. 18-4-1 High Speed Steel

This steel, containing 18% tungsten, 4% chromium, and 1% vanadium with about 0.75% carbon. This steel is extensively used for lathe tools, drills, dies, punches etc**.**

2. Cobalt High Speed Steel

This is known as super high speed steel. This high-speed steel contains 20 %, tungsten, 4 % chromium, 2% vanadium and 12% cobalt. Due to high cost, this steel is used for heavy cutting operations which impose high pressure and temperature on tool.

3. Vanadium High Speed Steel

This steel contains 0.70 %carbon and more than 1 %vanadium. This has excellent abrasive resistance.

4. Molybdenum High Speed Steel

This steel containing 6% molybdenum, 6 % tungsten, 4 % chromium and 2 % vanadium have excellent toughness and cutting ability. It is used for drilling and tapping operations.

Plastics and its properties: Plastic is a of long carbon chains.which can be molded into desired shape and size when soft and can be hardened to produce durable article.Many articles like chairs, tables, buckets, toys, balls, etc are made of plastic material. Plastics are of two types thermoplastics and thermosetting plastic.

1. They are light in weight and are chemically stable.
2. Easily moulded into different shapes and sizes.
3. Good insulation and low thermal conductivity.
4. Impact resistance and they do not rust.
5. Good transparency and wear resistance.
6. Poor dimensional stability and can be easily deformed.
7. Low processing cost.

Stress

Stress is defined as the internal resistance per unit area offered by material against deformation.

$$\text{Stress} = \frac{\text{Internal Resistance Force}}{\text{Area}} = \frac{\textit{External load applied}}{\textit{Area}}$$

SI Unit – N/m^2

Types of Stress

1. Normal Stress: These stresses are produced when a force acts perpendicular (or "normal") to cross-section of an object. It is denoted by σ.
   a) Tensile stress : These stresses are produced when a tensile force alon the axis is acted at CG of cross-section.

$$\sigma t = \frac{\text{Tensile Force}}{\text{Area of cross section}}$$

   b) Compressive stress: These stresses are produced when a compressive force along the axis is acted at CG of cross-section.

$$\sigma t = \frac{\text{Compressive Force}}{\text{Area of cross section}}$$

2. Tangential Stress (Shear Stress): Shear stress is internal resistance per unit area offered offered by material against shearing force.

$$\tau = \frac{\text{Shear force}}{\text{Area of cross section}}$$

Strain

When a body is subjected to some external force, there is some change in dimensions of the body. The ratio of change in dimension of the body to original dimension is known as strain. Strain is a dimensionless quantity.

$$\varepsilon = \frac{\text{Change in dimension}}{\text{Origional dimension}}$$

1. Axial strain (longitudnal strain): Strain in the direction of applied force is known as axial strain.

$$\varepsilon_A = \frac{\text{Change in linear dimension}}{\text{Origional linear dimension}}$$

2. Lateral strain: Strain in the perpendicular direction of applied force is known as axial strain.

$$\varepsilon_L = \frac{\text{Decrease in dimension (length)}}{\text{Origional dimension (length)}} = \frac{dL}{L}$$

3. Shear Strain: Shear strains are angular deformation caused by shearing force.

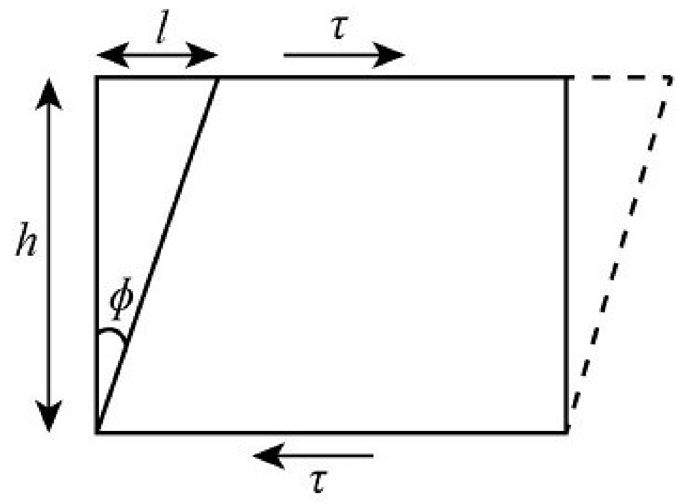


Fig. 1.2

$$\text{Tan } \Phi = \frac{l}{h}$$

For very small angle Φ we can write,

$$\Phi \approx \frac{l}{h}$$

4.Volumetric Strain: Volumetric strain is the ratio of change in volume to the original volume.

$$\varepsilon_V = \frac{\text{Change in volume}}{\text{Origional volume}} = \frac{dV}{V}$$

Poissons's ratio (μ) : It is the ratio of lateral strain to the longitudinal strain is constant when the material is stressed within elastic limit. This ratio is called poisson's ratio.

$$\mu = \frac{lateral\ strain}{longitudnal\ strain}$$

Hooke's Law

Hook's law states that the stress is directly proportional to the strain within proportionality limit.

Stress α Strain

a. Modulus of elasticity: The ratio of tensile or compressive stress to the corresponding strain within proportionality limit is constant. This constant is called young's modulus or modulud of elasticity.

Normal Stress α Strain due to normal stress

$$\sigma \ \alpha \ \varepsilon$$
$$\sigma = E \ \varepsilon$$
$$E = \frac{\sigma}{\varepsilon}$$

Where, E = Modulus of Elasticity or Young's Modulus, N/m^2

The value of E is determined from the stress strain curve by measuring the slope of initial straight line portion of the plot.

b. Modulus of Rigidity: The ratio of shear stress to the corresponding shear strain within proportionality limit is constant. This constant is called modulus of rigidity.

Shear Stress α Shear Strain

$$\tau \ \alpha \ \varphi$$
$$\tau = G \ \varphi$$
$$G = \frac{\tau}{\varphi}$$

Where, G = Modulus of Rigidity, N/m^2

Mechanical Properties of Materials

Knowledge of materials and their properties are great significance for a design engineer. The properties are related with behavior of material under action of forces under different load conditions are called as mechanical properties of material.

Following are the basic mechanical properties of engineering materials.

The properties are related with behavior of material under action of forces under different load conditions are called as mechanical properties of material.

1. Strength: Strength is the ability to bear external forces or load without breaking. Strength of a material depends upon the manner in which the load is applied.

2. Elasticity: When external load is applied on material it undergoes some deformation.

During deformation, internal forces are generated between the molecules of the material, which try to oppose the applied force. This tendency of a material to oppose the action of applied load is called elasticity. Due to elasticity, a material regains its original shape after the external load is removed.

3. Plasticity: Plasticity of a material is its ability to undergo some permanent deformation without rupture. Due to plasticity, material permanently deformed and does not come back to its original shape after removal of force.

4. Ductility: Ductility is the ability of material to undergo plastic deformation under tension forces without rupture. Due to this property material can be converted in form of thin wires.

Examples: Mild steel, copper, aluminium, gold, silver etc.

5. Malleability: Malleability is the ability of material to undergo plastic deformation under compressive forces without rupture.. It is ability of material to be rolled into thin sheets without cracking by rolling or hammering.
Example: Aluminium, copper, tin, lead, gold, silver etc.
Common Metals in order of their ductility and malleability
6. Brittleness: Brittleness is the tendency of a material to fracture without deformation.It is also called lack of ductility in a material.
Example: Cast iron, glass, graphite etc.
7. Toughness: The property which enables the material to absorb without fracture is called toughness
Example: Mild steel, brass, wrought iron etc
8. Hardness: Hardness is property of material with which it is able to resist wear, scratching, abrasion, cutting, machining, penetration and indentation.
Example: Diamond, granite, concrete, tempered steel etc.
9. Stiffness: Stiffness is defined as the resistance of a material to elastic deformation or deflection. It is also called rigidity
10. Resilience: During loading material store elastic strain energy . The total strain energy which can be store in a given volume of the metal and can be released after unloading is called resilience.
11. Creep: At higher temperatures metallic materials have a tendency to undergo continuous deformation even when the applied load is maintained constant. This phenomenon is called creep.
12. Fatigue: When a machine component is subjected to repetitive or variable loading, it fails even when the load is not very high. This phenomenon is called fatigue.
13. Tensile strength: Tensile strength is the ability to bear tensile forces or load without
breaking. It is the ratio of maximum tensile load to original cross-section area.
14. Compressive strength: Tensile strength is the ability to bear compressive forces or load without breaking. It is the ratio of maximum compressive load to original cross-section area.

Material Testing: Materials are tested for one or more of the following purpose:
1. To asses numerically the fundamental mechanical properties of ductility , malleability, toughness etc.
2. To check chemical composition
3. To determine suitability of a material for a particular application.
4. To determine the defects in raw material

Classification of material testing:
1. Destructive: The component or specimen either breaks or remain no longer useful for further use.
2. Non- Destructive: The component or specimen does not breaks and so even after being test it can be used for the purpose for which it was made.

Tensile Testing of Material:

Tensile testing, also known as tension testing is a destructive test process in which a sample is subjected to a controlled tension until failure to determine their suitability for specific engineering application. This test provides information about the tensile strength, yield strength, and ductility of the metallic material. The tensile test is most applied one, of all mechanical tests. The tensile testing is done on the Universal Testing Machine.

Tensile test is performed on a specimen of circular cross-section, having shape like dumb-bell. The specimen is shown in the figure.The parallel portion in the middle of the specimen is known as gauge length.

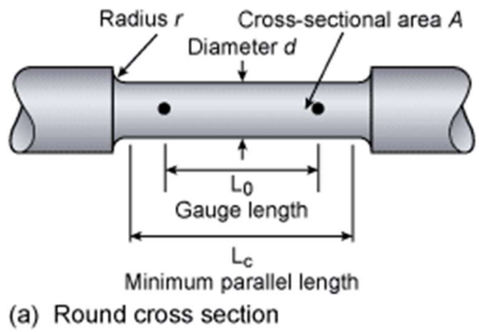


Fig. 1.3

Standard gauge length used most commonly is given by

$$L_o = 5.65 \sqrt{A_o} = 5.0\ d_o$$

Where, L_o= Standard gauge length
A_o = Original cross-section area of gauge length
d_o =Diameter of cross section

Universal Testing Machines. The tensile test for determing the ultimate tensile strength, percentage elongation, yield stress and percentage reduction in area of a given specimen is conducted on UTM. Their primary function is to create the stress- strain curve.

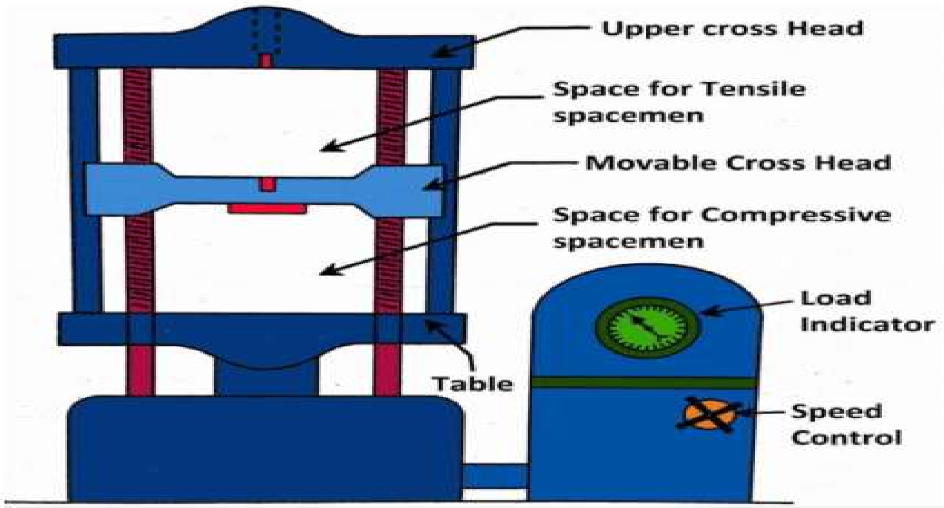


Fig. 1.4

A universal testing machine consists of two main parts loading unit and control unit. The control unit is located on the right and consist of Hydraulic Power Unit (oil sump and a positive displacement pump run by electric motor), Load Measuring and Display Unit (load indicator), Control Devices (control buttons). A right control valve is used to apply load on the specimen. The left control valve is used to release the load application. The loading unit is located on left side consisit of consist of load frame (table and suppots) , upper croshead and lower cross head. The control unit and loading unit are connected by pipes through which oil flow under pressure to the hudraulic cylinder of the loading unit which applies pressure or force on the the test specimen through the movement of crosshead.

Procedure for tensile test:

The dumb-bell shaped ends with the larger diameter of specimen are gripped in the grips of the tensile testing machine. The tensile testing machine has two grips; one fixed grip and other moving. The moving grip is powered hydraulically or by an electric motor or drive. After fixing the specimen in the grips, the specimen is pulled by applying a tensile load on it. The load is increased gradually in suitable steps till the failure of the specimen occur. The load is measured and display continuously on digital display. The elongation is also measured and displayed on the digital display. The stress and strain at each point can be determined using this data. In some machine there is facility to get the graph between stress and strain. By using this various mechanical properties can be determined.

Stress is calculated by dividing load by the original cross-section area of the test specimen. Strain is calculated by dividing the extension of the gauge length by the original length.

$$Stress = \frac{\text{Load}}{\text{Original cross} - \text{sectional area}}$$

$$Strain = \frac{\text{Extension in length (Change in length)}}{\textbf{Original length}}$$

Stress-Strain Curve for Ductile Material

The graph shows the normal stress σ along the y-axis and the strain ε along the x-axis.The stress-strain curve shown below is for ductile material (Mild steel).

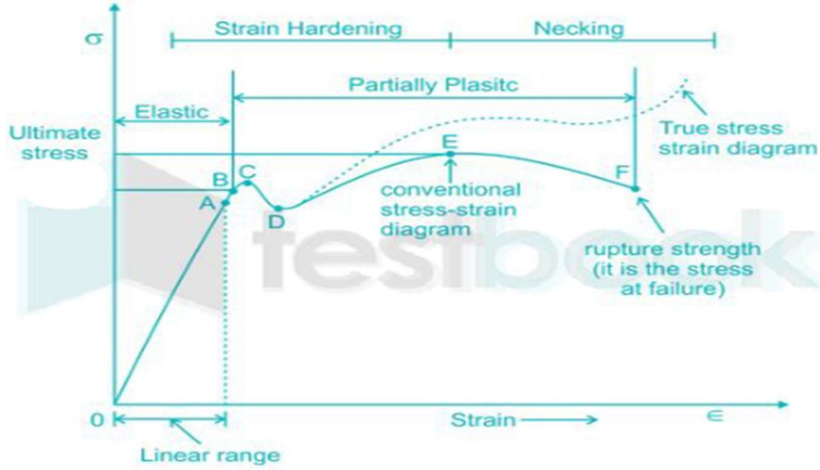


Fig. 1.5

The various important points achieved in this curve are discussed below:

Point A: It is called proportionality limit, the curve OA is linear and hooks law is valid upto this point only.

Point B': The elastic limit is the limit beyond which the material will no longer go back to its original shape when the load is removed, or it is the maximum stress that may be developed such that there is no permanent or residual deformation when the load is entirely removed. Beyond point B the material goes to plastic stage until the material reaches to point C.

Point C and D: Beyond elastic limit, the material shows considerable strain even though there is no or little increase in load or stress.The material becomes inelastic and this begaining of plastic deformation is called the yieldind of material. Yielding exist to a region C-D. Point C represents upper yield point of the material. At this point the cross-sectional area of the material starts decreasing and the stress decreases to a lower point D, called lower yield point. Stress at yield point gives the yields strength of the material.
(Yield point: The first stress in a material, usually less than the maimum attainable stress at which an increase in strain results without increase in stress. If there is decrease in the stress after yielding a distinction is made between upper yield point and lower yield point.)

Point E: It represents the ultimate strength of the material. It is the maximum stress value that material can withstand. It is the point of interest for design engineers. This ultimate strength is referred as the tensile strength of material.

Point F: It represents breaking point. It is the point occurred after maximum deformation. The stress associates with this point known as breaking strength or rupture strength.

Difference between engineering stress strain curve and true stress strain curve

In stress strain curve for ductile material as shown in figure. At point C the cross-sectional area of the material starts decreasing, The tensile load is divided by the reduced cross section area to calculated stress then we obtain the shown by dotted line after the point D. This curve is called true stress strain curve.

Stress-Strain Curve for Brittle Material

a. For brittle materials, yield strength is not present as these materials fail all of a sudden. So, tensile strength is the main important parameter for brittle materials like Cast Iron, glass, and Concrete
b. Fracture takes place at very small strain
c. The ultimate stress is also equal to fracture stress.
d. There is no necking or plastic zone
e. .Failure occurs due to tensile stress on plane perpendicular to the line of action of load at 90^0.

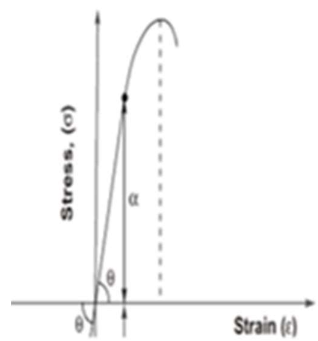


Fig. 1.6

After performing tensile test we obtaine:

1. **Initial Area** $= \frac{\pi}{4}(\boldsymbol{Ininial\ diameter})^2$
2. **Final Area** $= \frac{\pi}{4}(\boldsymbol{Final\ diameter})^2$
3. **Ultimate tensile strength** $= \frac{\boldsymbol{Maximum\ load}}{\boldsymbol{Initial\ area}}$
4. **Yield Strength** $= \frac{\boldsymbol{Yield\ point\ load}}{\boldsymbol{Initial\ area}}$
5. **Percentage elongation** $= \frac{\boldsymbol{Final\ length - Initial\ length}}{\boldsymbol{Initial\ length}}$ **x 100**
6. **Percentage reduction in area** $= \frac{\boldsymbol{Final\ area - Initial\ area}}{\boldsymbol{Initial\ area}}$ **x 100**

Impact Testing

An impact test is used to observe the mechanics that a material will exhibit when it experiences a shock loading that causes the specimen to immediately deform, fracture or rupture completely.

Purpose of impact testing

An impact test signifies the toughness of material that is ability of material to absorb energy during plastic deformation.Several engineering materials have to withstand impact or

suddenly applied load while in service. The impact test measures the energy necessary to fracture a standard notch bar by applying an impulse load.
The principal measurement from the impact test is the energy absorbed in fracturing the specimen (expressed as Joules (J)) which can be read directly from a calibrated dial on the impact tester. The ratio of energy absorbed by the specimen to the cross-sectional area below the notch is known as "Impact Strength". The unit of impact strength is J/mm^2.
The ratio of energy absorbed by the specimen to the volume of the specimen below the notch is known as "Impact Modulus". The unit of impact modulus is J/mm^3.

Procedure: To perform this test the sample is placed into a holding fixture with the geometry and orientation determined by the type of test that is used and then a known weight generally but not always in the shape of a pendulum is released from a known height so that it collides with the specimen with a sudden force. This collision between the weight and specimen generally results in the destruction of the specimen. In a impact test a specially prepared notched specimen is fractured by a single blow from a heavy hammer and energy required being a measure of resistance to impact. Impact load is produced by a swinging of an impact weight W (hammer) from a height h. Release of the weight from the height h swings the weight through the arc of a circle, which strikes the specimen to fracture at the notch. Difference between the initial potential energy and final potential energy of hammer will give the actual energy required to fracture the Specimen.

Impact Testing Machine

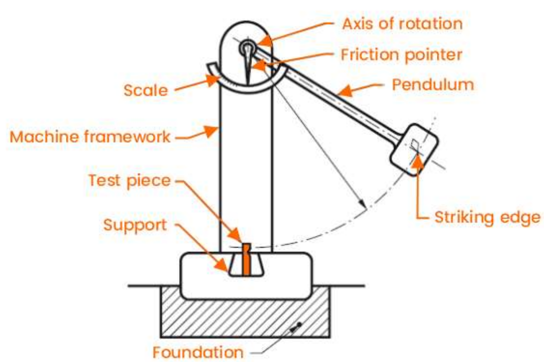


Fig. 1.7

Types of impact tests:

A pendulum type impact testing machine is generally used for conducting notched bar impact tests.the following types of impact tests are performed on this machine:
1. Izod test
2. Charpy test

Izod test: The specimen's cross section is generally square. The dimensions of the specimen are 10mm x 10mm x 75mm (width x thickness x length). The specimen contains V-notch of

45° included angle and depth of notch is 2 mm. The specimen is placed vertically for izod test with lower part fixed. The notch is situated at 28mm from the free end. The specimen is placed such that half of the notch is above meaning that 28 mm free portion is left. The hammer strikes the specimen at 22 mm from lower end of free portion. The angle of release of hammer is 85°' to 90^0.Notch face direction is in the front of striker(pendulam). The striking point is upper tip of specimen.

Fig. 1.8

Charpy test: Specimen of square cross-section 10mm x 10mm and 55mm length, with a V or U notch of included angle 45°, 2mm deep and 0.25mm root radius along the middle of the length. The specimen is kept as a simply supported beam in horizontal position. The angle of drop of hammer is 120^0 to 140^0. Notch face direction is away from striker (pendulam). The striking point is centre of specimen.

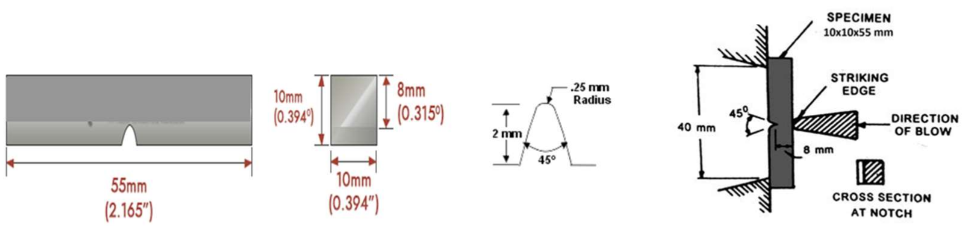


Fig. 1.9

Hardness Testing: Hardness represents the resistance of a material to indentation, penetration and scratching. A hardness test todetermine the hardness can be conducted on Brinell testing m/c, Rockwell hardness m/c or vicker testing m/c. the specimen may be a cylinder, cube, thick or thin metallic sheet. In hardness testing, a define force is mechanically on a test piece for about 15 seconds with the help of indentor. The indentor transmits the load on the test which causes the plastic deformation of the same. piece The indentor may be used are steel hardened ball, a 136° pyramid diamond on a square base or a diamond 120° cone indenter.

Brinell Hardness test:

In Brinell hardness test, a steel ball of diameter (D) is forced under a load (P) on to a surface of the test specimen. Mean diameter (d) of indentation is measured after the removal of the load (P). The Brinell Hardness Number (BHN) is obtained by dividing the applied force P, in kg-F; by the curved surface area of the indentation, which is actually a segment of a sphere.

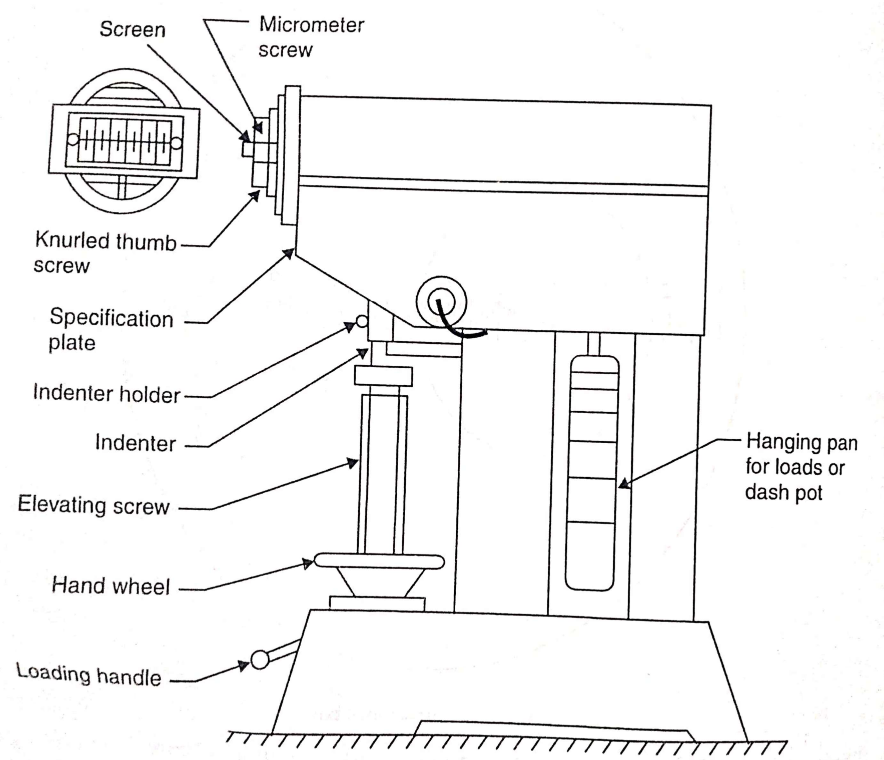


Fig. 1.10

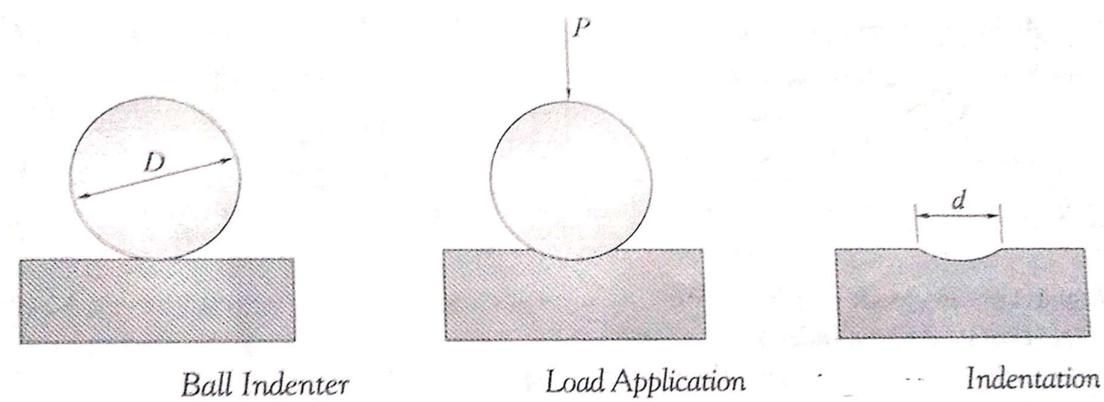
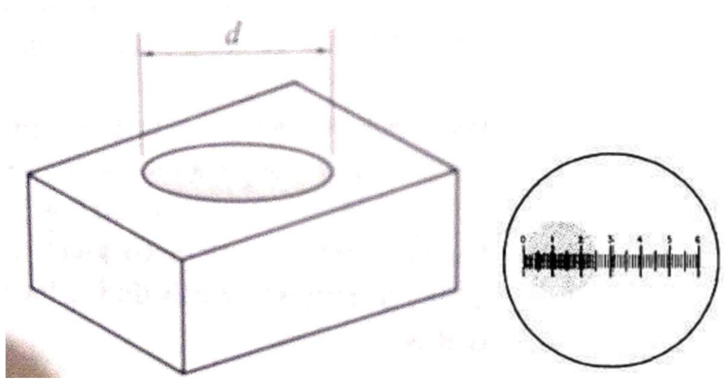


Fig. 1.11



Impression on testpiece

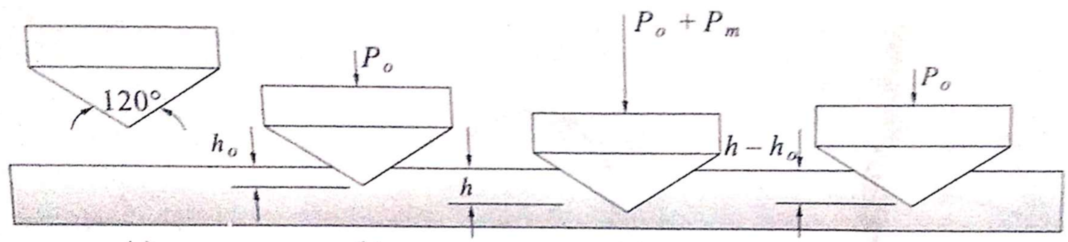
Fig. 1.11

Procedure:
a) Keep the loading and unloading lever at unloading position.
b) Select suitable indentor & weights according to the scale.
c) Place the specimen on testing table anvil.
d) Turn the hand wheel to raise a job until it makes contact with indenter & continue turning till the longer pointer at the dial gauge makes 2 ½ rotations. Then it stops at zero continue turning slowly till the small pointer reaches the red spot.This is automatic zero setting dial gauge.
e) Turn the lever position from unloading to the loading position. So that the total load will act.
f) When the longer pointer of the dial gauge reaches steady position, take back the lever to the unloading position.
g) Remove the job from the platform and note down the diameter of the indentation using Brinell microscope.
h) Using the appropriate formula calculate BHN.

BHN $=\frac{2P}{\pi D[D-\sqrt{D^2+d^2}]}$

The Brinell hardness number is expressed as
D = Diameter of ball indentor in mm
d =mean diameter of indentation in mm
P = Load applied in Kgf
Least countof Brinell Microscope = 0.01mm

Rockwell Hardness test: In this test an indentor is forced into the workpiece which causes a permanent increase in depth of material where the indentation is done. The hardness of a material is measured by the depth of penetration of the indenter. Both ball and diamond cone (angle 120°) type indentor are used in this test. This test gives direct hardness reading on larger dial gauge provided with three scales (A scale,B scale and C scale). The scale used for reading depends upon type of indenter used, the load applied and the material of test piece. Normally two Rockwell scales named B and C are used. The hardness value determined from scale B is reffered to as HRB and from scale C is reffered to as HRC.



Rockwell Hardness Test
(a) Diamond Cone Indenter
(b) Indenter Position when Minor Load is Applied.
(c) Indenter Position when Both Minor and Major Loads are Applied.
(d) Indenter Position when only the Major Load is Removed.

Fig. 1.12

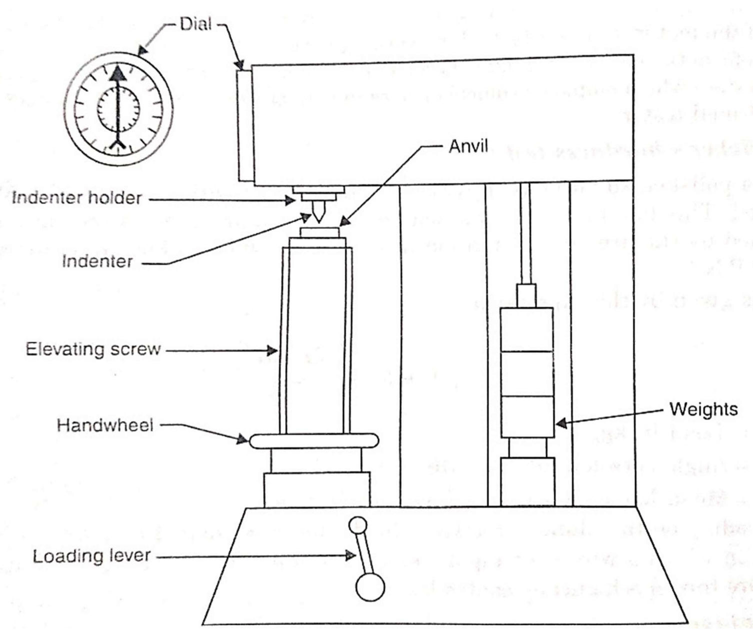


Fig. 1.13

Procedure:
a) Keep the loading and unloading lever at unloading position.
b) Select suitable indentor & weights according to the scale.
c) Place the specimen on testing table anvil.
d) Turn the hand wheel to raise a job until it makes contact with indenter & continue turning till the longer pointer at the dial gauge makes 2 ½ rotations. Then it stops at zero

continue turning slowly till the small pointer reaches the red spot.This is automatic zero setting dial gauge. This will ensure minor load of 10kgf has been applied

e) Turn the lever position from unloading to the loading position. So that the major load will act.

f) When the longer pointer of the dial gauge reaches steady position, take back the lever to the unloading position.This will release major load nor minor load. The pointer will now rotate in the reverse direction .

g) The rockwell hardness number can be read directly from appropriate scale, after the pointer comes to rest.

h) Using the appropriate formula calculate BHN.

Vicker Hardness test: The vicker hardness test utilizes a square base diamond pyramid with an angle of 136 ° between the opposite faces. This tool under gradual load makes an impression on the specimen . Vicker hardness (HV) is obtained by dividing the applied force ; by area of the indentation.

$$HV = \frac{Applied\ load}{Area\ of\ indentation} = \frac{F}{\frac{d^2}{Sin\frac{136}{2}}} = 1.854\frac{F}{d^2}$$

d =mean diameter of indentation in mm
F = Load applied in Kgf

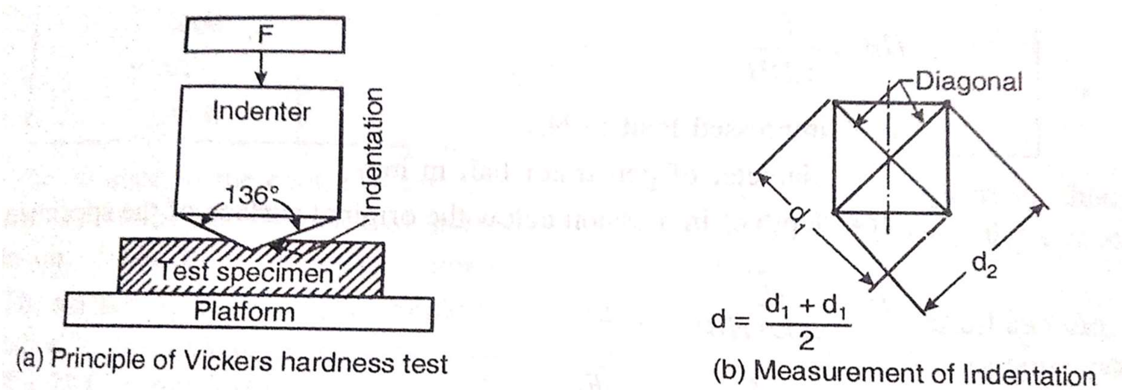


Fig. 1.14

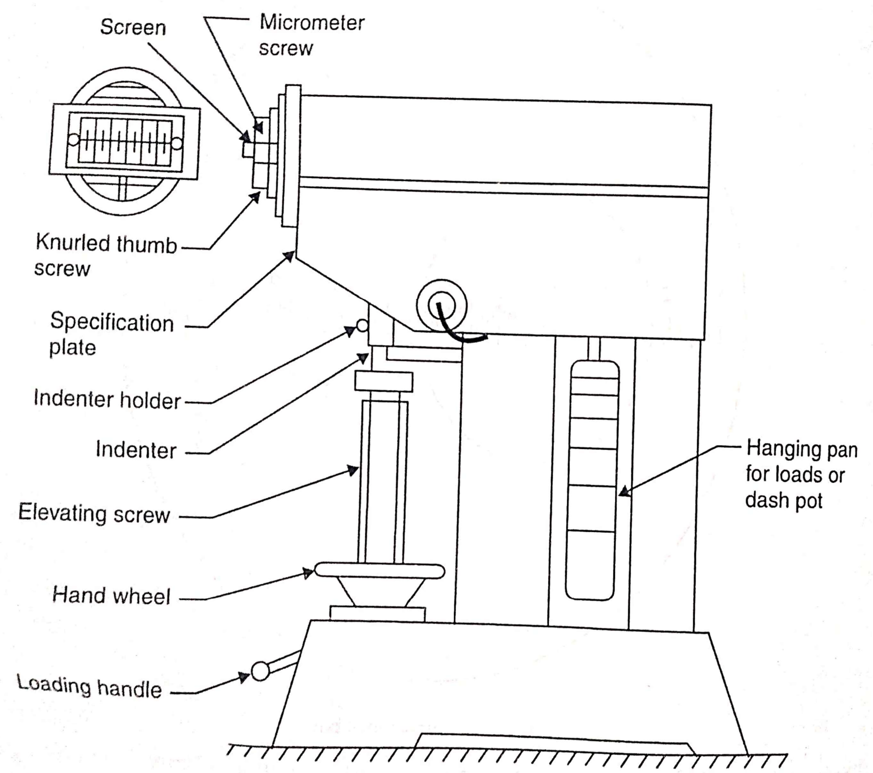


Fig. 1.15

Procedure:
a) Keep the loading and unloading lever at unloading position.
b) Select suitable indentor & weights according to the scale.
c) Place the specimen on testing table anvil.
d) Turn the hand wheel to raise a job until it makes contact with indenter & continue turning till the longer pointer at the dial gauge makes 2 ½ rotations. Then it stops at zero continue turning slowly till the small pointer reaches the red spot.This is automatic zero setting dial gauge.
e) Turn the lever position from unloading to the loading position. So that the total load will act.
f) When the longer pointer of the dial gauge reaches steady position, take back the lever to the unloading position.
g) Remove the job from the platform and note down the diameter of the indentation using microscope.
h) Using the appropriate formula calculate HV.

Cooling curve of iron:

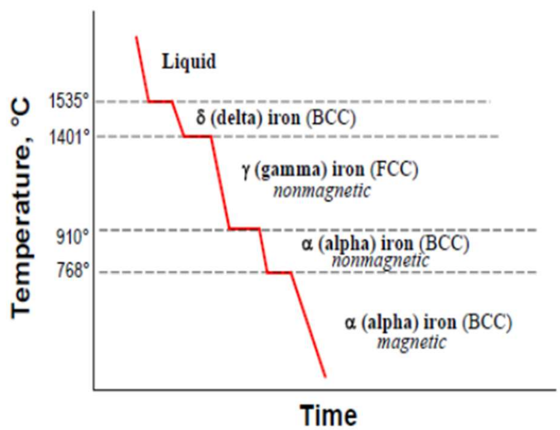


Fig. 1.16

Micro-constituent of iron carbon equilibrium diagram :

1. Ferrite: Iron which contains little or no carbon is called ferrite.This is a BCC iron phase with a very limited solubility,
    a. Delta (δ) solid solution (δ-Ferrite): It is a solid solution of carbon in delta-iron (BCC structure).It is obtained at low percentage carbon and high temperature
    b. Alpha (α) solid solution (α-Ferrite): It is a solid solution of carbon in alpha-iron (BCC structure). It is obtained at low percentage carbon and low temperature.
2. Cementite: This is a carbide of iron and it contains 6.6% carbon and occurs in the form of globular or massive form. Cementite generally increases with the proportion of carbon present.
3. Pearlite: It is the mixture of 87.5% ferrite and 12.5% cementite. Pearlite is eutectoid of steel. Hard steel is mixture of pearlite and cementite.
4. Gamma (γ) solid solution (Austenite): It is a solid solution of carbon in gamma-iron (FCC structure).
5. Ledeburite:Ledeburite is the eutectic mixture of austenite and cementite. It contains 4.3 percent C and is formed at1130°C

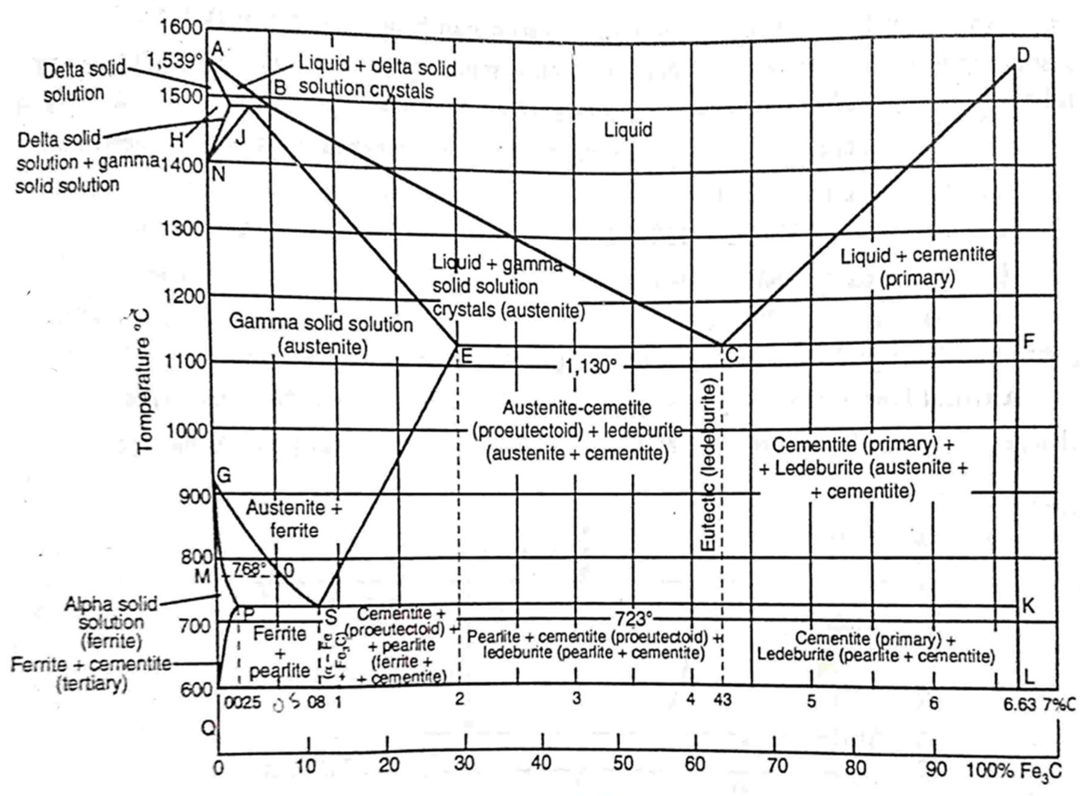


Fig. 1.17 Iron-Crbon equilibrium diagram

Point J indicates peritectic point, point C incdicate eutectic point and point S indicate eutectoid point. At these points following important reaction take place:

a) Peritectic Reaction: The peritectic reaction takes place when iron in molten state and δ-iron in solid phase at 1492˚C give rise to austenite having 0.18% carbon i.e

Liquid (0.5% C) + Solid δ-iron (0.9% C) $\xrightarrow[1493^\circ C]{}$ Single solid phase austenite (00.18% C)

b) Eutectic Reaction: The eutectic reaction takes place when liquid alloy containing 4.3% carbon cools at 1130˚C to a two phase solid called ledeburite, the two phases are austeoite of 2% carbon and cementite of 6.67% carbon that is

Liquid alloy (4.3% C) $\xrightarrow[1130^\circ C]{}$ austenite (2% C) + cementite (6.63% C)

c) Eutectoid Recation: The eutectoid reaction takes place whe solid austeite containing 0.8% carbon is cooled at 723˚C and it decomposes into two solids i.e ferrite and cementite.

Austenite (0.8% C) $\xrightarrow[723^\circ C]{}$ ferrite (0.025) + cementite (6.63% C)

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Iron - Carbon equilibrium diagram is a graphic representation of the effect of temperature and Composition upon the phases present in the alloy. It indicates transformation that takes place in an alloy of iron-Carbon, from pure iron to Cementite (6.63% Carbon). The temperature represented on the vertical axis and Carbon percentage on the horizontal axis.
All the alloys represented by the composition and temperature in the region above ABCD are Completely liquid. The Curve ABCD is called the liquidus. The melting point of pure iron (1539°C) is marked as point A. melting point of iron Carbide (Cementite, 1550°C) is marked by point. D. High temperature transformation (gamma iron ⇌ delta iron) takes place at the upper left hand portion of the diagram. The peritectic reaction HJB represent formation of austenite (solid solution of Carbon in gamma iron). Along the line AB, Crystals of delta iron begains to separate from from the liquid.

As the temperature of the liquid falls along the line ABC, crystals of austenite seperate from the liquid. In the same way crystals of cementite seperate from the liquid along the line CD

The Complete solidification of iron-Carbon alloys proceed along the line HJECF called the solidus. The alloy containing 0.18 to 2% Carbon become solid along the line HFEHJ and those containing Carbon from 2% to 6.63%, become solid along ECF at 1130°C. At point C (4.3% Carbon) austenite & cementite are simultaneously precipitated from the liquid alloy to form the eutectic called Ledeburite.

All the liquid Alloy having carbon between 0.8% Carbon – 2% Carbon will produce austenite after primary solidification & alloy having carbon between 2 – 4.3% will produce austenite + ledeburite & alloy having carbon between 4.3 – 6.62% will produce cementite + ledeburite consider an alloy with 0.3% Carbon is cooled from a temperature abone the line ~~MN~~ GS. Nothing will happen till 800°C, at this temperature decomposition of austenite takes place & ferrite Crystals will form. Point ~~M~~ G at 910°C corresponds to the transformation of gamma iron to alpha iron. The decomposition of austenite into ferrite takes place along ~~MN~~ GS. At point S ~~N~~ (0.8% Carbon) at 723°C a solid phase reaction takes place in which simultaneous separation of ferrite & Comentite forms a new structure called pearlite. Point S is known as eutectoid point. Along ~~NE~~ SE austenite decomposes & comentite is separated

An iron Carbon equilibrium diagram forms a basis for differentiating among iron (0.008% C or less), hypoeutectoid steels (0.08 to 0.8% C), hypereutectoid steel (0.8 to 2.0% C), hypo eutectic castiron (2 to 4.3% C), ~~hypoeutectoid~~ & hyper eutectic cast iron abone 4.3% Carbon