

CHAPTER 1

Materials

Materials: Classification of engineering material, composition of cast iron and carbon steels on iron-carbon diagram and their mechanical properties; Alloy steel and their applications; stress-strain diagram, Hooks law and modulus of elasticity. Tensile, shear, hardness and fatigue testing of materials.

1.1 Engineering Materials

All engineers need to know about materials. Innovation in engineering often means the clever use of a new material for a specific application. For example: plastic containers in place of age-old metallic containers. It is well learnt lesson that engineering disasters are frequently caused by the misuse of materials. So it is vital that the professional engineer should know how to select materials which best fit the demands of the design – economic and aesthetic demands, as well as demands of strength and durability. Beforehand the designer must understand the properties of materials, and their limitations. Thus it is very important that every

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engineer must study and understand the concepts of Materials Science and Engineering. This enables the engineer

- To select a material for a given use based on considerations of cost and performance.
- To understand the limits of materials and the change of their properties with use.
- To be able to create a new material that will have some desirable properties.
- To be able to use the material for different application.

1.2 Classification of Engineering Materials

1.2.1 Metals

Valence electrons are detached from atoms, and spread in an 'electron sea' that "glues" the ions together. Strong, ductile, conduct electricity and heat well, are shiny if polished.

1.2.2 Semiconductors

The bonding is covalent (electrons are shared between atoms). Their electrical properties depend strongly on minute proportions of contaminants. Examples: Si, Ge, GaAs.

1.2.3 Ceramics

Atoms behave like either positive or negative ions, and are bound by Coulomb forces. They are usually combinations of metals or semiconductors with oxygen, nitrogen or carbon (oxides, nitrides, and carbides). They are hard, brittle, and insulators. Examples: glass, porcelain. Examples of ceramic materials are ranging from household and lab products to high performance combustion engines which utilize both metals and ceramics.

Crystalline ceramics (a) and non-crystalline glasses (b) are shown in Fig. 1.1. Open circles represent nonmetallic atoms, solids represent metal atoms.

1.2.4 Polymers

Polymers are bound by covalent forces and also by weak Van der Waals forces, and usually based on C and H. They decompose at moderate temperatures (100–400 °C), and are lightweight. Examples: plastics rubber. Polymers or commercially called "Plastics" need no introduction.

Polymer composite materials and reinforcing glass fibers are in a polymer matrix.

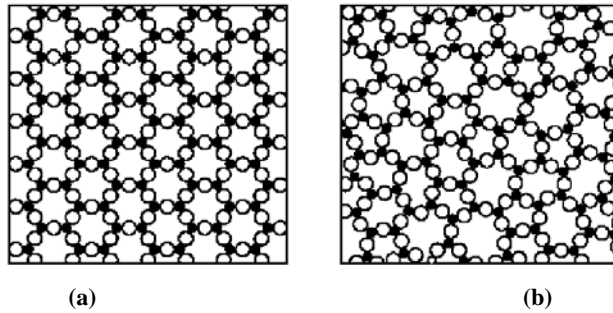


Fig. 1.1 Ceramics and glass

1.2.5 Glasses

Depending on the material structure, the glass can be opaque, transparent, or translucent. Glasses can also be processed to yield high thermal shock resistance.

The Table 1.1 concludes the materials with their applications and properties.

Table 1.1 Properties and Applications of some Engineering Materials.

	Application	Properties
Metals		
Copper	Electrical conductor wire	High electrical conductivity, good formability
Gray cast iron	Automobile engine blocks	Castable, machinable, vibration-damping
Alloy steels	Wrenches	Significantly strengthened by heat treatment
Ceramics		
SiO ₂ -Na ₂ O-CaO	Window glass	Optically useful, thermal insulating
Al ₂ O ₃ , MgO, SiO ₂	Refractories for containing molten metal	Thermal insulating, melt at high temperature, relatively inert to molten metal
Barium titanate	Transducers for audio equipment	Converts sound to electricity (Piezoelectric behaviour)

Table 1.1 Contd...

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	Application	Properties
Polymers		
Polyethylene	Food packaging	Easily formed into thin, flexible airtight film
Epoxy	Encapsulation of integrated circuits	Electrically insulating and moisture-resistant
Phenolics	Adhesives for joining piles in ply wood	Strong, moisture resistant
Semiconductors		
Silicon	Transistors and integrated circuits	Unique electrical behaviour
GaAs	Fiber-optic systems	Converts electrical signals to light
Composites		
Graphite-epoxy	Aircraft components	High strengths-to-weight ratio
Tungsten carbide-cobalt	Carbide cutting tools for machining	High hardness, yet good shock resistance
Titanium-clad steel	Reactor vessels	Has the low cost and high strength of steel, with the corrosion resistance of titanium

1.3 Material Properties

Some of the most important properties of materials are grouped as follows:

1.3.1 Density

It is defined as mass per unit volume. It is expressed as kg/m^3 .

1.3.2 Specific gravity

It is the ratio of density of a material to density of water.

1.3.3 Porosity

The term porosity is used to indicate the degree by which the volume of a material is occupied by pores. It is expressed as a ratio of volume of pores to that of the specimen.

1.3.4 Strength

Strength of a material has been defined as its ability to resist the action of an external force without breaking.

1.3.5 Elasticity

It is the property of a material which enables it to regain its original shape and size after the removal of external load.

1.3.6 Plasticity

It is the property of the material which enables the formation of permanent deformation.

1.3.7 Hardness

It is the property of the material which enables it to resist abrasion, indentation, machining and scratching.

1.3.8 Ductility

It is the property of a material which enables it to be drawn out or elongated to an appreciable extent before rupture occurs.

1.3.9 Brittleness

It is the property of a material, which is opposite to ductility. Material, having very little property of deformation, either elastic or plastic is called Brittle.

1.3.10 Creep

It is the property of the material which enables it under constant load to deform slowly but progressively over a certain period.

1.3.11 Stiffness

It is the property of a material which enables it to resist deformation.

1.3.12 Fatigue

The term fatigue is generally referred to the effect of cyclically repeated stress. Materials response and failure are in form of fracture under constant repeated loading. A material has a tendency to fail at lesser stress level when subjected to repeated loading.

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1.3.13 Impact strength

The impact strength of a material is the quantity of work required to cause its failure per its unit volume. It thus indicates the toughness of a material.

1.3.14 Toughness

It is the property of a material which enables it to be twisted, bent or stretched under a high stress before rupture. Measure of how much force is required to deform the material to breaking point. The area under the stress strain diagram represents the toughness.

1.3.15 Hardness

Resistance of the material to penetration.

1.3.16 Resilience

The ability of the material to absorb energy

1.3.17 Thermal Conductivity

It is the property of a material which allows conduction of heat through its body. It is defined as the amount of heat in kilocalories that will flow through unit area of the material with unit thickness in unit time when difference of temperature on its faces is also unity.

1.3.18 Corrosion Resistance

It is the property of a material to withstand the action of acids, alkalis gases etc., which tend to corrode (or oxidize).

1.4 Cast Iron

Cast iron is a very popular material for machine construction because of its castability, machinability, cheapness and good damping capacity. These are alloys of iron and carbon but contain large proportions of silicon, sulphur, manganese, phosphorus. Iron-carbon alloys containing more than 2 percent carbon are called cast irons.

Composition: All cast irons contain iron, carbon, silicon, manganese, phosphorus and sulphur. Cast iron is iron containing 2 to 4 % carbon.

1.4.1 Properties of cast Iron

The properties of cast iron are given below:

- It is the least expensive casting material. All the raw materials used are relatively cheap – pig iron, cast iron scrap, steel scrap, lime stone, coke and iron ore.
- Cast iron has a lower melting point temperature (1140 to 1200) degrees Celsius than steel (1380-1500) degrees Celsius.
- It possesses high casting properties such as, high fluidity, low shrinkage, casting soundness, ease of production, and a higher yield.
- Cast iron can provide a very wide range of metallic properties ranging from a high yield strength to high ductility and toughness
- They possess a very high compressive strength, about 3 to 4 times that of its tensile strength.
- Cast irons can be machined easily.
- They provide high wear and hardness resistance.
- An important characteristic of cast iron is its high damping capacity. It is that property which permits a material to absorb vibrational stresses.

1.4.2 Applications

The few applications of cast iron are as:

- cast iron can be used for production of complex shapes i.e., machinery parts,
- piston rings,
- frames for electric motors,
- machine tool structure,
- cylinder blocks and head of I.C engine,
- household appliances,
- crank shaft,
- pumps and compressors,
- pipes,
- chain links,
- farm implements and tractors,
- used as excellent vibration damper in machines.

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Depending upon the structure and form of the carbon present, cast-irons can be classified into different groups such, as white cast iron, grey iron, Nodular and malleable iron. The properties of the cast iron are affected by the following factors:

- Chemical composition of the iron.
- Rate of cooling of the casting in the mould (which depends on the section thickness in the casting).
- Type of graphite formed (if any).

1.4.3 Types of cast iron

Fig. 1.2 classifies the cast iron on the basis of structure and form of the carbon present.

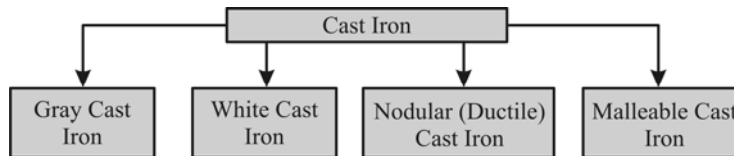


Fig. 1.2 Types of cast iron

- (i) **Gray Cast Iron:** Gray cast iron is by far the oldest and most common form of cast iron. The flake-like shape of graphite in Gray iron, see Fig. 1.3 and 1.4, exerts a dominant influence on its mechanical properties. The graphite flakes act as stress raisers which may prematurely cause localized plastic flow at low stresses, and initiate fracture in the matrix at higher stresses. As a result, Gray iron exhibits no elastic behavior but excellent damping characteristics, and fails in tension without significant plastic deformation. The presence of graphite flakes also gives gray iron excellent machinability and self-lubricating properties.

Properties of Gray Cast Iron:

- Graphite acts as a chip breaker and a tool lubricant.
- Very high damping capacity.
- Good dry bearing qualities due to graphite.
- After formation of protective scales, it resists corrosion in many common engineering environments.
- Brittle (low impact strength) which severely limits use for critical applications.

- Graphite acts as a void and reduces strength. Maximum recommended design stress is 1/4 of the ultimate tensile strength. Maximum fatigue loading limit is 1/3 of fatigue strength.
- Changes in section size will cause variations in machining characteristics due to variation in microstructure.
- Higher strength gray cast irons are more expensive to produce.

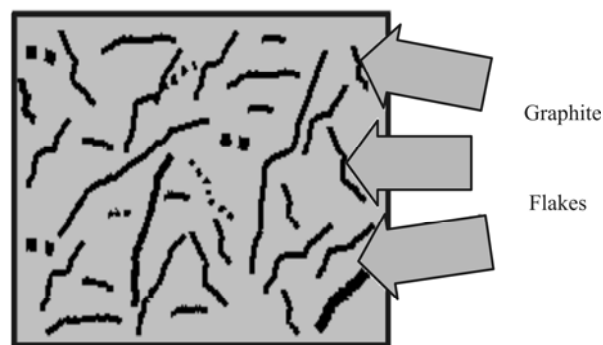


Fig. 1.3 Graphite flakes in gray cast iron



Fig. 1.4 Photomicrograph of gray cast iron

Applications:

- It is used in clutch plates and brake drums.
- It is widely used for bases or beds for machine tools.
- It is used in heat shock applications such as ingot or pig-moulds.
- It is used in elevator counterweights, industrial counter weights etc.

- It is used as cylinders, pistons and engine frames.
 - It is used for gear housings, enclosures for electrical equipments, pump housings etc.
- (ii) **White Cast Iron:** White cast iron is unique in that it is the only member of the cast iron family in which carbon is present only as carbide. Due to the absence of graphite, it has a light appearance. The presence of different carbides, depending on the alloy content, makes white cast irons extremely hard and abrasion resistant but very brittle (Fig. 1.5). An improved form of white cast iron is the chilled cast iron. When localized area of a gray cast iron is cooled very rapidly from the melt, cast iron is formed at the place that has been cooled. This type of white cast iron is called chilled iron.

Properties of white cast iron:

- Chromium is used in small amounts to control chill depth.
- Because of the formation of chromium carbides, chromium is used in amount of 1 to 4 percent in chilled iron to increase hardness and improve abrasion resistance.
- When added in amounts of 12 to 35 percent, chromium will impart resistance to corrosion and oxidation at elevated temperatures.
- If alloys such as nickel, chromium, or molybdenum are added, much of the austenite transforms to martensite instead of Pearlite.
- The hardness of chilled cast iron is generally due to the formation of martensite.

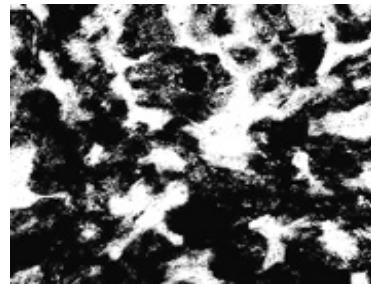


Fig. 1.5 White cast iron

Applications:

- railway-car wheels,
- crushing rolls,
- stamp shoes and dies, and
- Heavy-duty machinery parts.

(iii) **Ductile Cast Iron (Nodular Cast Iron):** This structure is developed from the melt. The carbon forms into spheres when cerium, magnesium, sodium, or other elements are added to a melt of iron with a very low sulfur content that will inhibit carbon from forming. The control of the heat-treating process can yield pearlitic, ferritic, martensitic matrices into which the carbon spheres are embedded. Figure 1.6 and 1.7 shows the structure of ductile (nodular) cast iron.

Properties:

- The advantages of ductile cast iron which have led to its success are numerous, but they can be summarized easily – versatility and high performance at low cost. In addition to cost advantages offered by all castings, ductile cast iron, when compared to steel and malleable cast iron, also offers further cost savings. Like most commercial cast metal, steel and malleable cast iron decrease in volume during solidification, and as a result, require feeders and risers to offset the shrinkage and prevent the formation of internal or external shrinkage defects.
- In other cases, it requires feeders that are much smaller than those used for malleable cast iron and steel. This reduced requirement for feed metal, increases the productivity of ductile cast iron and reduces its material and energy requirements, resulting in substantial cost savings.
- The use of the most common grades of ductile cast iron "as-cast" eliminates heat treatment costs, offering a further advantage.

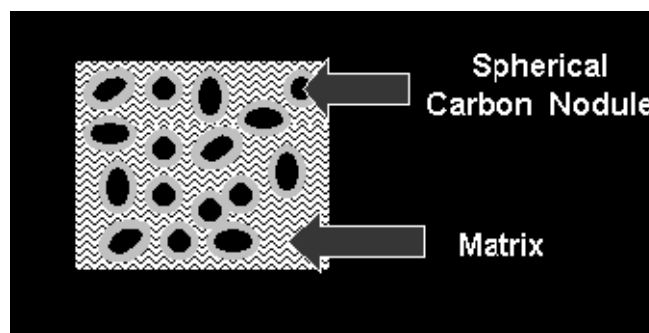


Fig. 1.6 Nodular (Ductile) cast iron and the spherical carbon embedded into the matrix

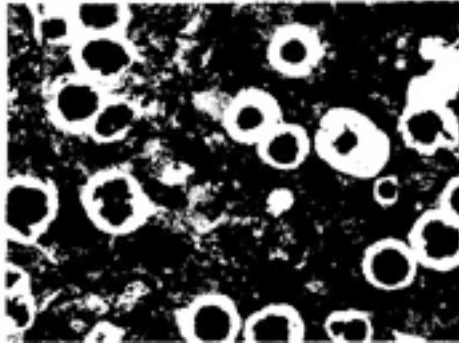


Fig. 1.7 Photomicrograph of nodular cast iron

Applications:

- Ductile cast iron is used for many structural applications, particularly those requiring strength and toughness combined with good machinability and low cost.
 - The automotive and agricultural industries are the major users of ductile iron castings.
 - Because of economic advantage and high reliability, ductile iron is used for such critical automotive parts as crankshafts, engine connecting rods, idler arms, wheel hubs, truck axles, front wheel spindle supports, disk brake calipers, Suspension system parts, power transmission yokes.
 - High temperature applications for turbo housing and manifolds.
 - High security valves for many applications.
 - The cast iron pipe industry is another major user of ductile iron.
- (iv) **Malleable Cast Iron:** If cast iron is cooled rapidly, the graphite flakes needed for gray cast iron do not get a chance to form. Instead, white cast iron forms. This white cast iron is reheated to about 1700°F for long periods of time in the presence of materials containing oxygen, such as iron oxide. At the elevated temperatures cementite (Fe_3C) decomposes into ferrite and free carbon. Upon cooling, the combined carbon further decomposes to small compact particles of graphite (instead of flake-like graphite seen in gray cast iron). If the cooling is very slow, more free carbon is released. This free carbon is referred to as temper carbon and the process is called malleableizing (Fig.1.8).

Properties:

- It has excellent machinability
- It has significant ductility
- It has good shock resistance properties.
- The major disadvantage is shrinkage. Malleable cast iron decreases in volume during solidification, and as a result, requires attached reservoirs (feeders and risers) of liquid metal to offset the shrinkage and prevent the formation of internal or external shrinkage defects.

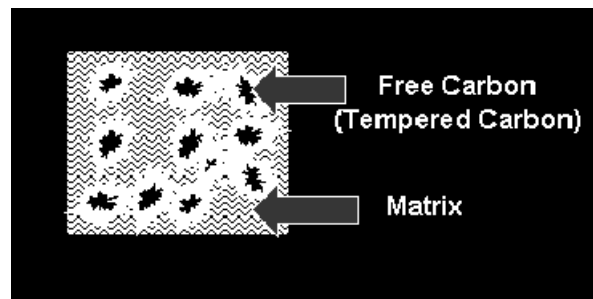


Fig. 1.8 Malleable cast iron

Figure 1.9 shows the ferritic malleable cast iron, which has a ferritic matrix and the tempered carbon particles are embedded into the matrix.

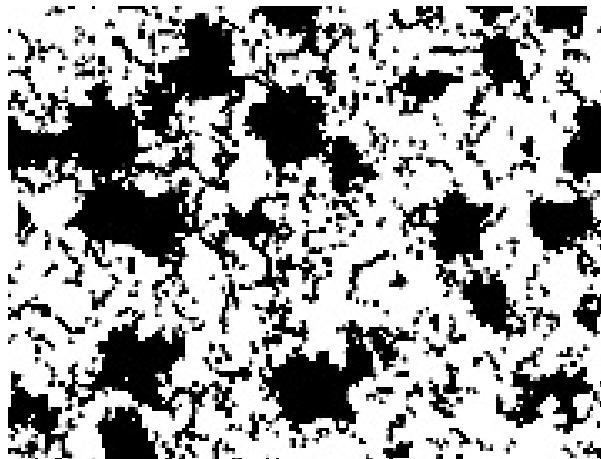


Fig. 1.9. Ferritic Malleable Cast Iron

Figure 1.10 shows the pearlitic malleable cast iron, which has a pearlitic matrix. By adding manganese to the structure, carbon is retained in the form of cementite.

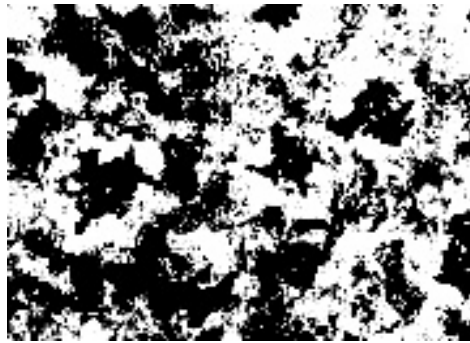


Fig. 1.10 Pearlitic Malleable Cast Iron

Applications: Malleable cast iron is used for:

- Connecting rods and universal joint yokes.
- Transmission gears.
- Differential cases and certain gears.
- Compressor crankshafts and hubs, flanges.
- Pipe fittings and valve parts for railroad.
- Marine and other heavy-duty applications.

1.5 Carbon Steel

Steel is an alloy of iron, carbon and several other elements. It is an iron-carbon alloy which contains up to 2 percent carbon, the amount of carbon in steels has a marked effect on the properties. In addition to carbon, steels generally contain small amounts of silicon, sulphur, phosphorus and manganese. Manganese & silicon is an important constituent because of its ability to increase the hardness and strength of the steel. Steel is the most widely used engineering material because of its relative advantages over materials.

1.5.1 Properties of plain carbon steels

- It is cheap and readily available.
- It can provide a very wide range of mechanical properties, from a very soft condition to a very hard condition.

- Properties of steel can be improved easily by addition of small amounts of other elements known as alloying elements.
- Due to phase transformations which take place in steel, it responds to heat-treatment. Any desired combination of strength and ductility can be obtained by different heat treatments.
- Steel possesses good machinability and weldability.

1.5.2 Classification of steels

- | | |
|-----------------------------------|-------------------|
| (i) Low carbon steel (Mild steel) | less than 0.30% C |
| (ii) Medium carbon steel | 0.30 to 0.70% C |
| (iii) High carbon steel | 0.70 to 2.0% C |

1.5.3 Low Carbon/Mild Steel

Mild steel is the commonest steel with a range of 0.05 to 0.30% carbon. Further it is classified into three types:

- (i) Dead mild steel- C 0.05 to 0.15%
- (ii) Mild steel - C 0.15 to 0.20%
- (iii) Mild steel – C 0.20 to 0.30%

Properties:

- (i) Bright fibrous structure.
- (ii) Can be readily forged and welded.
- (iii) Can be permanently magnetized.
- (iv) Rusts rapidly.
- (v) Can be hardened and tempered but not easily.

Applications:

- (i) Wires.
- (ii) Structural shapes.
- (iii) Screw machine parts such as screws, nuts and bolts, storage tanks, automobile frames, galvanizes steel valves, sheet.

These steels are soft, very ductile, easily machined. Since the carbon content is low so heat treatment process is ineffective.

1.5.4 Medium Carbon Steel

These are used for rails, axels, gears and parts requiring high strength. Medium steel is containing carbon from 0.30 to 0.70%.

1.5.5 High Carbon Steels

Steels containing 0.70 to 2.0% carbon is called high carbon steel. Carbon is the most important alloying element in steel. Plain-carbon steels are very satisfactory where strength and other properties are not too severe. They are also used successfully at ordinary temperatures. It was also noticed that at high temperatures the plain carbon steel softens. This behaviour restricts the applicability. Alloying elements are added to overcome the limitations. They are mainly silicon, manganese, chromium and other elements added in very small proportions.

Composition: In high carbon steel the following elements are present in the following compositions:

Carbon	-	0.7 to 2%
Silicon	-	0.2 to 0.6%
Manganese	-	0.2 to 0.8%
Phosphorus	-	0.05 to 0.15%
Chromium	-	0.12 to 0.2%
Sulphur	-	0.005 to 0.05%

Properties:

- (i) it has fine granular structure,
- (ii) tough and more elastic than mild steel,
- (iii) can be hardened and tempered readily,
- (iv) cannot be easily forged and welded,
- (v) can be permanently magnetized,
- (vi) brittle and less ductile than mild steel,
- (vii) rusts rapidly, absorbs shocks.

Applications: High carbon steels are widely used in:

- (i) Cutting tools such as: knives, drills, taps, hand tools, reamers and for abrasion-resisting properties.
- (ii) This steel is also used for making products having edges on cutlery, chisels, and shear blades and also for spring wire, wire rope.

1.5.6 Alloy steels

When elements like nickel, chromium, vanadium, molybdenum, tungsten are present in sufficient quantity, the steel is called “**alloy steel**”. In order to obtain special characteristics like high hardenability, high temperature

properties, corrosion resistance etc., generally steel has to be alloyed with other alloying elements. Different alloying elements give rise to enhancing of different physical and mechanical properties.

Effect of alloying elements in steel:

Element	Effects
Carbon	Increases hardness, strength, decreases ductility
Nickel	Increases hardness, toughness, corrosion resistance
Chromium	Increases corrosion resistance and elastic limit
Tungsten and molybdenum	Increases strength and toughness for high speed cutting tools

Alloy steels are generally classified into two major types depending on the structural classification:

Low alloy steels: These possess similar microstructure and heat treatment as that of plain carbon steels. These generally contain up to 3-4 % of one or more alloying elements for purpose of increasing strength, toughness and hardenability. The applications of low alloy steels are similar to those of plain carbon steels of similar carbon contents. Low alloy steels containing nickel are particularly suitable for applications requiring resistance to fatigue.

High alloy steels: Those steels that possess structures, and require heat treatments, that differ considerably from those of plain carbon steels. A few examples of high alloy steels are given below:

- (i) **High-speed tool steels:** Tungsten and chromium form very hard and stable carbides. Both elements also raise the critical temperatures and, also, cause an increase in softening temperatures. High carbon steels rich in these elements provide hard wearing metal-cutting tools, which retain their high hardness at temperature up to 600°C. A widely used high-speed tool steel composition is containing 18% of tungsten, 4% of chromium, 1% of vanadium and 0.8% of carbon. This high alloy content enables them to be used as cutting tools at high cutting speed.
- (ii) **Stainless steels:** When chromium is present in amounts in excess of 12%, the steel becomes highly resistance to corrosion, owing to protective film of chromium oxide that forms on the metal surface. Chromium also raises the transformation temperature of iron, and tends to stabilize ferrite in the structure.

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There are several types of stainless steels, and these are summarized below:

- (a) Ferritic stainless steels contain between 12-25% of chromium and less than 0.1% of carbon.
 - (b) Martensitic stainless steels contain between 12-18 % of chromium, together with carbon contents ranging from 0.1 to 1.5 %.
 - (c) Austenitic steels contain both chromium and nickel. When nickel is present, the tendency of nickel to lower the critical temperatures over-rides the opposite effect of chromium, and the structure may become wholly austenitic.
- (iii) *Maraging steels*: These are very high-strength materials that can be hardened to give tensile strengths up to 1900 MN/m². They contain 18% of nickel, 7% of cobalt and small amounts of other elements such as titanium, and the carbon content is low, generally less than 0.05%. A major advantage of maraging steels is that after the solution treatment they are soft enough to be worked and machined with comparative ease.

Applications:

- (i) General machinery parts
- (ii) Aircraft
- (iii) Taps
- (iv) Hand tools, cutting tools
- (v) Drills
- (vi) Knives

So the most used elements with the alloy steel and with their amount as a percentage of:

- 2 % Manganese (Mn)
- 0.5 % Chrome (Cr) or Nickel (Ni)
- 0.3 % Tungsten (W) or Cobalt
- 0.1 % Molybdenum (Mo) or Vanadium
- Different amount of Aluminum (Al), Copper (Cu) and Silicon (Si).

Type 304 Stainless Steel: Type 304 stainless steel (containing 18%-20% chromium and 8%-10.5% nickel) is used in the tritium production reactor tanks, process water piping, and original process heat exchangers. This alloy resists most types of corrosion.

1.6 Steel and Iron Carbon Diagram

Steel is basically an alloy of iron and carbon, but several elements are used in various proportions and combinations to produce different types. Carbon is by far the most important element in steel: By definition, steel has a maximum carbon content of 2.0%. Structural steels normally contain less than 0.30% carbon, however, and in terms of chemical composition can be classified as either plain carbon or low-alloy steels. The chemical composition of steel is very important since it has a significant effect on the microstructure of the material and hence on its mechanical behavior and properties.

The changes in composition (cementite or iron carbide [Fe₃C] content), microstructure (pearlite content), and mechanical properties (strength and ductility, in particular) resulting from changes in the carbon content in annealed plain carbon steels are shown very clearly in Fig. 1.11. In the range of carbon contents shown in Fig. 1.11, a significant increase in strength and decrease in ductility are produced by an increase in the carbon content in the steel. In their simplest form, steels are alloys of Iron (Fe) and Carbon (C). The Fe-C phase diagram is a fairly complex one, but we will only consider the steel part of the diagram, up to around 7% Carbon.

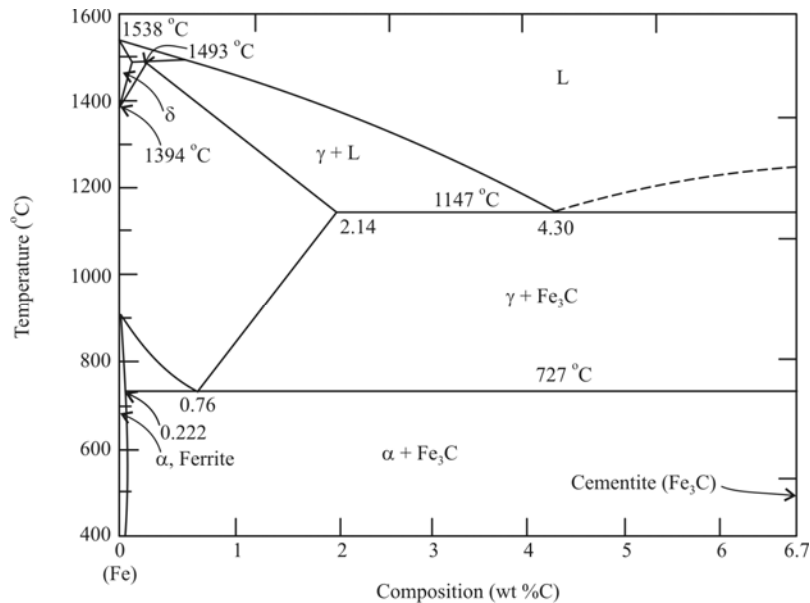
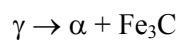


Fig. 1.11 Iron carbon diagram

The following features should be noted in the iron-cementite, Fe-Fe₃C, phase diagram

- (i) Iron goes through two allotropic transformations during heating or cooling: On continued cooling from a liquid melt, it first forms a body-centered cubic (BCC) structure, then a face-centered cubic (FCC) structure, and finally another BCC structure. All three allotropes will form interstitial solid solutions with carbon, identified as delta iron (δ), austenite (γ), and ferrite (α), respectively. A greater number of carbon atoms can be accommodated in the austenite than in the other two phases, since the interstitial holes in the FCC lattice are somewhat larger than those in the BCC lattices. Hence the maximum solubility of carbon in austenite is 2.0%, while it is much lower in delta iron (0.10%) and ferrite (0.025%). These solid solutions are relatively soft and ductile, but stronger than pure iron due to solid solution strengthening by the interstitial carbon atoms.
- (ii) Cementite, or iron carbide, Fe₃C, is a stoichiometric intermetallic compound formed when the solubility of carbon in solid iron is exceeded. This compound contains 6.67% C, is extremely hard and brittle, and is present in all commercial steels. The degree of dispersion strengthening and the properties of the steel are hence controlled by properly regulating the amount, size, and shape of the Fe₃C phase.
- (iii) A eutectoid reaction occurs as the austenite (γ) cools below 727°C. That is,



Since the two phases that form has different compositions, atoms must diffuse during the reaction: Most of the carbon in the austenite diffuses to the Fe₃C, and most of the iron to the ferrite (α). Since this redistribution of atoms is easiest if the diffusion distances are short, the α and Fe₃C grow as thin lamellae, or plates, forming a structure called pearlite. The various phases and its description are shown in Table 1.2.

Table 1.2 Phases in the Fe-Fe₃C System

Phase	Atomic packing	Description and comments
Liquid (iron)	d.r.p (densely random packing)	Liquid solution of C (carbon) in Fe
δ (also called delta iron)	b.c.c (body- centered cubic)	Random interstitial solid solution of C in b.c.c. Fe
γ (also called austenite)	f.c.c (face- centered cubic)	Random interstitial solid solution of C in f.c.c. Fe. Maximum solubility is 2 wt% at 1147 ^o C. It is normally not stable at room temperature.
α (also called ferrite)	b.c.c	Random interstitial solid solution of C in b.c.c. Fe. Maximum solubility is 0.02 wt% at 723 ^o C. It is the softest structure appears on the diagram.
Fe ₃ C (also called iron carbide or cementite)	orthorhombic	A hard and brittle interstitial compound of Fe and C containing 25 atomic % (6.7 wt%) C.
(α + Fe ₃ C) Pearlite	-	It is very fine platelike or lamellar eutectoid mixture of ferrite and cementite containing 0.8 wt% C and formed at 723 ^o C on very slow cooling

1.6.1 Martensite

It is a supersaturated solid solution of carbon in b.c.t (body-centered tetragonal) iron. This meta-stable phase is formed under very rapid cooling.

1.6.2 Ferrite

Ferrite is practically pure iron containing only 0.06 percent carbon at room temperature. The name “ferrite” comes from the Latin word, ‘ferum’, which means iron. It is also called as alpha iron. Ferrite is relatively soft and ductile phase. It can undergo extensive cold working. Ferrite is strongly magnetic at room temperature and becomes paramagnetic at 770 degrees Celsius.

1.6.3 Austenite

Austenite is a solid solution of carbon in gamma iron and, it can dissolve up to two percent of carbon at 1148 degrees Celsius. Austenite is also a

soft and ductile phase but stronger and less ductile than ferrite. It is a non-magnetic (paramagnetic) phase and exists at temperature above 727 degrees Celsius.

1.6.4 Cementite

Cementite is an interstitial compound of iron containing 6.67 per cent of carbon. It is an extremely hard and brittle phase. Cementite is a magnetic phase at room temperature and becomes paramagnetic above 210 degrees Celsius. It is also known as iron-carbide.

1.6.5 Pearlite

Pearlite is an intimate mixture of ferrite and Cementite. It has a distinct lamellar structure and consists of alternate layers of ferrite and Cementite. Pearlite is so called because of the lustrous, mother-of-pearl appearance it presents in the microscope. Due to its distinct appearance under a microscope, Pearlite is called as micro constituent. Pearlite contains 88.5 percent ferrite and 11.5 percent Cementite. It is obtained from austenite, when the later is cooled slowly below 727 degrees Celsius. Pearlite has a variable hardness depending upon its fineness.

1.6.6 Ledeburite

Ledeburite is also a micro constituent consisting of a mixture of two phases, austenite and Cementite. It is obtained when the liquid alloy containing 4.3 percent carbon is cooled below 1148 degrees Celsius. Below 727 degrees Celsius austenite of Ledeburite changes to Pearlite giving it a characteristic appearance under microscope.

1.7 Stress vs Strain

1.7.1 Stress

The internal resistance of the material to counteract the applied load is called stress. Stress (σ) can be equated to the load per unit area or the force (F) applied per cross-sectional area (A) perpendicular to the force.

$$\text{Stress} = \sigma = \frac{F}{A}$$

where,

σ = stress (N/m²);

F = applied force (N);

A = cross-sectional area (m²)

Stress intensity within the body of a component is expressed as one of three basic types of internal load. They are known as tensile, compressive, and shear. Fig. 1.12 illustrates the different types of stress. As illustrated in Fig. 1.12, the plane of a tensile or compressive stress lies perpendicular to the axis of operation of the force from which it originates. The plane of a shear stress lies in the plane of the force system from which it originates.

1.7.2 Types of stresses

Tensile stress: force acts to pull materials apart;

Compressive stress: the force squeezes material;

Shear stress: the force causes one part to slide on another part

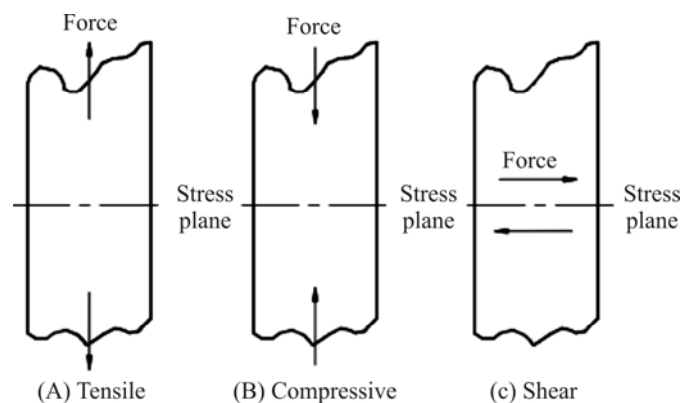


Fig. 1.12 Types of applied stress

- (i) **Tensile stress:** Tensile stress is that type of stress in which the two sections of material on either side of a stress plane tend to pull apart or elongate as illustrated in Fig. 1.12(A).
- (ii) **Compressive stress:** Compressive stress is the reverse of tensile stress. Adjacent parts of the material tend to press against each other through a typical stress plane as illustrated in Fig. 1.12(B).
- (iii) **Shear stress:** Shear stress exists when two parts of a material tend to slide across each other in any typical plane of shear upon application of force parallel to that plane as illustrated in Fig. 1.12(C).

1.7.3 Strain

Strain is defined as change in length over original length of the member under tensile or compressive load. If L stands for original length, and ΔL represents change in length, then the change in length divided by the original length will give us the strain in the material.

$$\epsilon = \text{Lateral/Linear Strain} = \text{change in length/Original length}$$

$\epsilon = \Delta L/L$ [Unit of Length/Unit of Length] and therefore it is a dimensionless quantity.

1.7.4 Stress-Strain Diagram

The stress-strain diagram is a diagram with values of stress (load) as ordinate and strain (elongation, compression, deflection, twist etc.) as abscissa. Mechanical properties depend upon the crystal structure, its bonding forces, and the imperfections which exist within the crystal. The various mechanical properties can be defined or understood with the help of the above diagram. This is drawn with data obtained from a test on Universal Testing Machine (UTM). To establish a relationship between stress and strain, we can perform tests on a given specimen, one such test is the tensile test, where the specimen is loaded in tension in a machine (Tensile Test Machine) and the stress and strain are recorded.

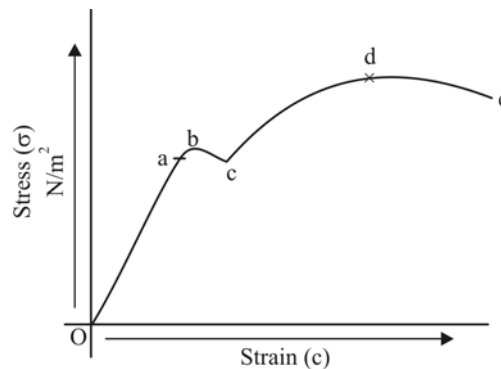


Fig. 1.13 Stress-strain diagram for steel

The stress-strain diagram for steel is shown in Fig. 1.13. The salient points are:

Point a: Limit of proportionality, O-a is a straight line and stress is proportional to strain. The slope of the line gives the value of Young's Modulus of Elasticity; E .

Point b: gives the yield point of the material and is called the elastic limit. This is the greatest stress that the material can endure without taking up permanent set after load is removed.

Point c: is called lower yield point.

Point d: gives the maximum or ultimate stress.

Point e: is called the breaking point and material fails.

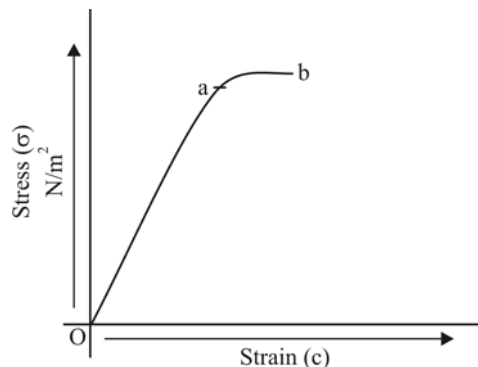


Fig. 1.14 Stress-strain diagram for brittle materials (Cast Iron)

The stress-strain ($\sigma - \epsilon$) diagram for high carbon steel, cast iron and other brittle materials are shown in Fig.1.14.

Point a is the limit of proportionality and

Point b is the breaking point.

The curve does not have a yield point. Looking at a typical stress strain curve, when the specimen is loaded, it will deform and elongate in a linear fashion with a slope up to the proportional limit. At this point the material if loaded further will start to yield. If unloaded, the specimen will return to its origin O. (Approximately, with a 0.2% offset). After the yield the material is in plastic region and if unloaded the material will not return to its original length and will have what is called a permanent deformation or permanent set. The stronger the material the greater the slope of stress-strain curve.

1.7.5 Definition related to stress strain curve

- (i) **Ultimate Stress** (determined while testing): The highest point in stress strain curve before fracture. Maximum stress the specimen can be subjected to under testing. The point on the stress strain diagram after which the material elongates without further additional load and elongates until fracture.

- (ii) **Ultimate Strength** determined by applying a factor of safety depends on the loading condition and type of member being loaded and importance of the member in structural stability, axial load on column, bending moment or shear in beam.
- (iii) **Elastic Range:** Range on the stress strain curve up to the elastic or proportional limit.
- (iv) **Elastic Limit/Proportional Limit:** Point on the stress strain curve up to which if load is removed, the material will return back to its original length and shape.
- (v) **Yield Point:** The point on the stress strain curve after which the specimen/material will not return to its original length and shape. The crystal structure of the specimen/material begins to change up to plastic limit.
- (vi) **Plastic-Strain hardening Range:** Range between Yield and Ultimate Stress.
- (vii) **Plastic limit:** In the plastic range, the specimen will be able to take additional load – 1.2 times the yield strength.
- (viii) **Young’s Modulus (or) Modulus of Elasticity (E):** The slope of the stress strain curve is termed the Modulus of Elasticity or Young’s Modulus.
- (ix) **Hooke’s Law:** There exists a linear relationship between stress and Strain (elongation) of a bar in tension within the elastic limit.
- (x) **True Stress and Strain:** If the results of tensile testing are to be used to predict how a metal will behave under other forms of loading, it is desirable to plot the data in terms of true stress and true strain. True stress, σ , is defined as

$$\sigma = F/A \quad \dots(1.1)$$

where A is the cross-sectional area at the time that the applied force is F. Up to the point at which necking starts, true strain, e , is defined as

$$e = \ln (L/L_0) \quad \dots(1.2)$$

This definition arises from taking an increment of true strain, $d\epsilon$, as the incremental change in length, dL , divided by the length, L , at the time, $d\epsilon = dL/L$, and integrating. As long as the deformation is uniform along the gage section, the true stress and strain can be calculated from the engineering quantities. With constant volume and uniform deformation, $LA = L_0A_0$:

$$A_0 / A = L/L_0 \quad \dots(1.3)$$

Thus, according to, $A_0/A = 1 + e$

Eq. 1 can be rewritten as

$$\sigma = (F/A_0) (A_0/A)$$

and, with substitution for A_0/A and F/A_0 , as

$$\sigma = s (1 + e) \quad \dots(1.4)$$

Substitution of $L/L_0 = 1 + e$ into the expression for true strain (Eq 2) gives

$$e = \ln (1 + e) \quad \dots(1.5)$$

At very low strains, the differences between true and engineering stress and strain are very small. It does not really matter whether Young's modulus is defined in terms of engineering or true stress strain.

It must be emphasized that these expressions are valid only as long as the deformation is uniform. Once necking starts, Eq. 1.1 for true stress is still valid, but the cross-sectional area at the base of the neck must be measured directly rather than being inferred from the length measurements. Because the true stress, thus calculated, is the true stress at the base of the neck, the corresponding true strain should also be at the base of the neck. Eq. 1.2 could still be used if the L and L_0 values were known for an extremely short gage section centered on the middle of the neck (one so short that variations of area along it would be negligible). Of course, there will be no such gage section, but if there were, Eq. 1.3 would be valid. Thus the true strain can be calculated as

$$\epsilon = \ln (A_0/A) \quad \dots(1.6)$$

1.8 Testing of Materials

Materials are tested for one or more of the following purposes:

- (i) To assure mechanical properties of materials like ductility, malleability, toughness etc.
- (ii) To determine suitability of a material for a particular application.
- (iii) To determine the surface or surface defects in raw materials or processed parts.
- (iv) To check chemical composition.

The various test and its applications are summarized in Table 1.3.

Table 1.3 Various Test and Application

S. No	Name of the test	Properties measured
1.	Tensile test	Tensile strength, yield point, elastic limit, Young's modulus, ductility, toughness, etc,
2.	Impact test	Toughness of a material under shock loading condition.
3.	Hardness test	Wear resistance, indentation resistance, scratch resistance or cutting ability of material.
4.	Fatigue test	Behaviour of material under repeated applied stress and its endurance limit.
5.	Creep test	Behaviour of material under a steady load over long period of time and creep limit of material.

1.8.1 Tensile Testing

Tensile testing involves the stretching of a piece of material, or putting it under strain, and examining how it behaves under test. The ductility of a metal can be found by tensile testing using an *extensometer*, which is an instrument for measuring the amount that a specimen stretches or extends during a test. These specimens may be rectangular or circular but must have a specified cross sectional area (CSA) as shown in Fig. 1.15.

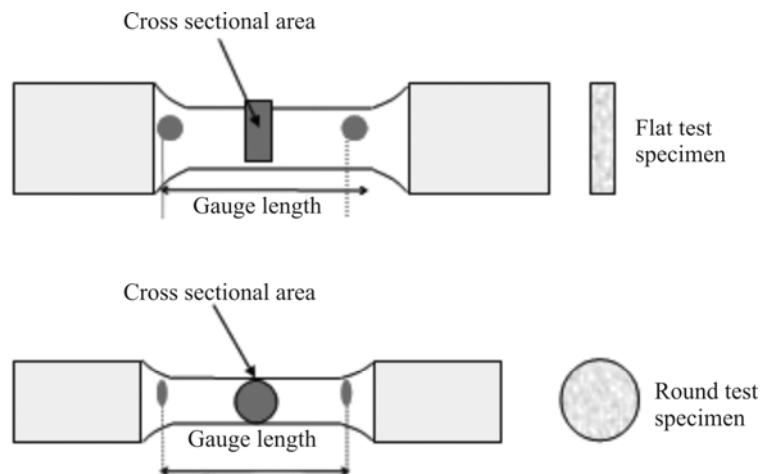


Fig. 1.15 Tensile test specimens

A material that returns to its original length has elasticity. Repeated tests are carried out making the load greater each time. While the material under test has elasticity, the extension or stretch is directly proportional to the load. This is known as *Hookes Law*. Metals are elastic in the early stage of tensile testing, plastics are not. When a material fails to return to its original length which means it has reached its *elastic limit* or the *limit of proportionality*. After the elastic limit the loads produce much larger extensions of the specimen. This is called the plastic region. At the end of this stage, the extension is even greater and a *yield point* is reached.

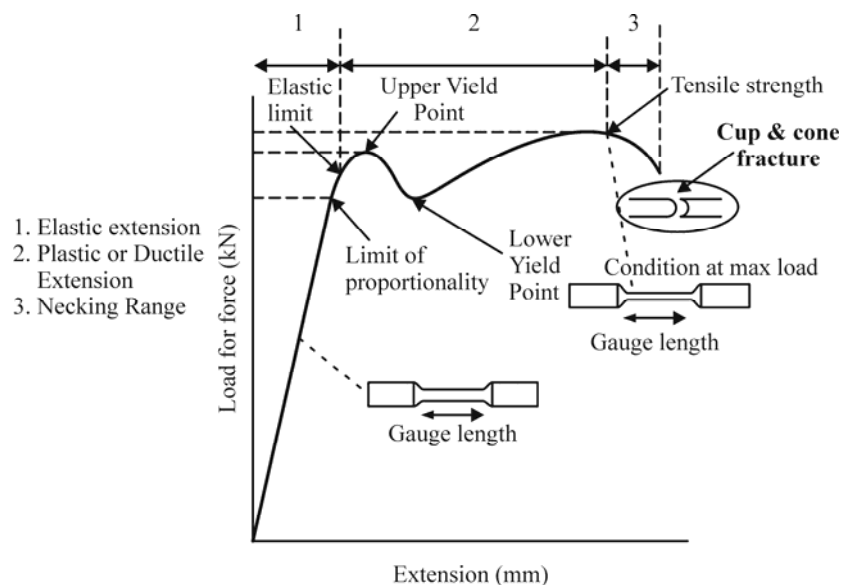


Fig. 1.16 Stress strain for material under tensile test

A further increase in the load causes the specimen to thin uniformly and then to *neck*. After necking the specimen will break or fracture. When the fracture occurs one side of the specimen has a rough cone shape and the other has a rough cup shape. This is known as a *cup and cone* fracture. Fig. 1.16 shows the stress-strain plot for a material under tensile test.

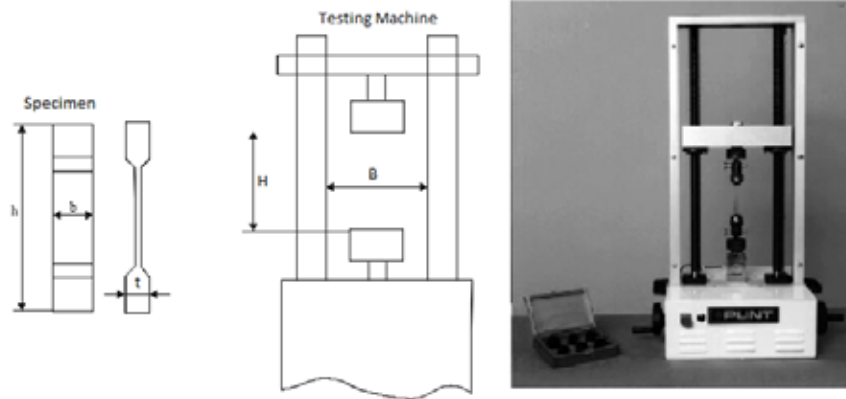


Fig. 1.17 Specimen and universal testing machine

The Test Procedure

- The specimen is set up in the tensile testing machine, the extensometer.
- One end is held in a vice and the other in a holding system.
- A controlled load, measured in newtons (N), is applied.

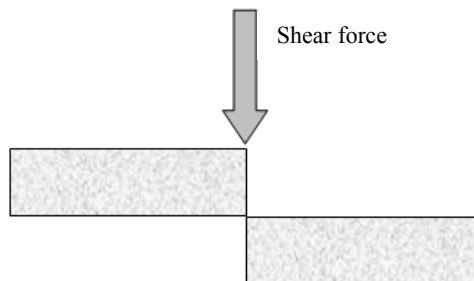
The amount of stretch or extension that this force causes is measured. Universal testing machine is used for performing shear, compression and tension. Fig. 1.17 shows the sketch and pictorial view of Universal Testing Machine (UTM)

There are two types of UTM.

- (i) Screw type
- (ii) Hydraulic type.

1.8.2 Shear testing

A shear force tends to shear the material into two parts. Shear force is used in cutting with scissors, tinsnips and guillotine.



In actual practice when a beam is loaded the shear force at a section always comes to play along with bending moment. It has been observed that the effect of shearing stress as compared to bending stress is quite negligible. But sometimes, the shearing stress at a section assumes much importance in design calculations.

Details of UTM:

Capacity : 400 KN.

Range : 0 – 400 KN.

Working Procedure:

1. Measure the diameter of the hole accurately.
2. Insert the specimen in position and grip one end of the attachment in the upper portion and the other end in the lower portion.
3. Switch on the main switch on the universal testing machine.
4. Bring the drag indicator in contact with the main indicator.
5. Gradually move the head control lever in left hand direction till the specimen shears.
6. Note down the load at which specimen shears.
7. Stop the machine and remove the specimen.

Model Observation:

Diameter of the specimen (d)= ----- mm

Cross sectional area in double shear , (A) = $2 \times \pi d^2/4 \text{ mm}^2$

Shear Load taken by specimen at the time of failure (P) = ----- KN.

Shear strength = $\frac{\text{Maximum shear force}}{\text{Area of the specimen}}$

Shear strength of the given material = ----- N / mm²

1.8.3 Parameters measured using UTM

- (i) **Stress:** Stress can be defined as the amount of load or force carried by a unit area. It is normally written as Newtons per millimetre square, (N/mm²).

$$\text{Stress} = \frac{\text{Load}}{\text{Cross sectional Area (CSA)}}$$

Example: If a bar, 15 mm wide × 8 mm deep, is pulled with a force of 360 kN, the stress is found as follows.

$$\begin{aligned} \text{Force} &= 360 \text{ kN} \\ \text{Cross Sectional Area (CSA)} &= 120 \text{ mm}^2 (15 \times 8) \\ \text{Stress} &= \frac{360 \text{ kN}}{120 \text{ mm}^2} = \mathbf{3 \text{ kN/mm}^2} \end{aligned}$$

- (ii) **Strain:** Stress is the ratio of extension and original length. It is dimensionless quantity.

$$\text{Strain} = \frac{\text{Extension}}{\text{Original Length}}$$

Example: The extension is the amount by which the length changes and in a tensile tests the original length is the gauge length. If the bar in the previous example measures 2 metres before the force is applied, and 2.05 metres when the force is applied then the strain can be found as follows

$$\text{Strain} = \frac{05(2.05 - 2.0 \text{ extension})}{(\text{Original length})} = \mathbf{0.025}$$

- (iii) **Young's Modulus of Elasticity:** In the elastic range of a material, stress is directly proportional to strain, which is another way of stating *Hooke's Law*. This is called Young's Modulus, is represented by 'E' and measured in kN/mm².

$$\text{Youngs Modulus of Elasticity (E)} = \frac{\text{Stress}}{\text{Strain}}$$

- (iv) **Tensile Strength:** Tensile strength is the maximum force of load, in Newtons, applied to the specimen before it fractures divided by the original cross sectional area.

$$\text{Tensile Strength} = \frac{\text{Max Load}}{\text{Original CSA}}$$

- (v) **Proof Stress:** Some materials do not have a well defined yield point or an indication at what stress, yield occurs. To overcome this, a value of stress, known as proof stress is used.

Reading 0.1% Proof Stress from a stress-strain graph

Proof stress is much easier to find from a stress-strain graph. Proof stress is read almost directly from this type of graph as shown in Fig.1.18. If the 0.1% proof stress is required, then a line is drawn from 0.001 strain, parallel to the straight part of the graph.

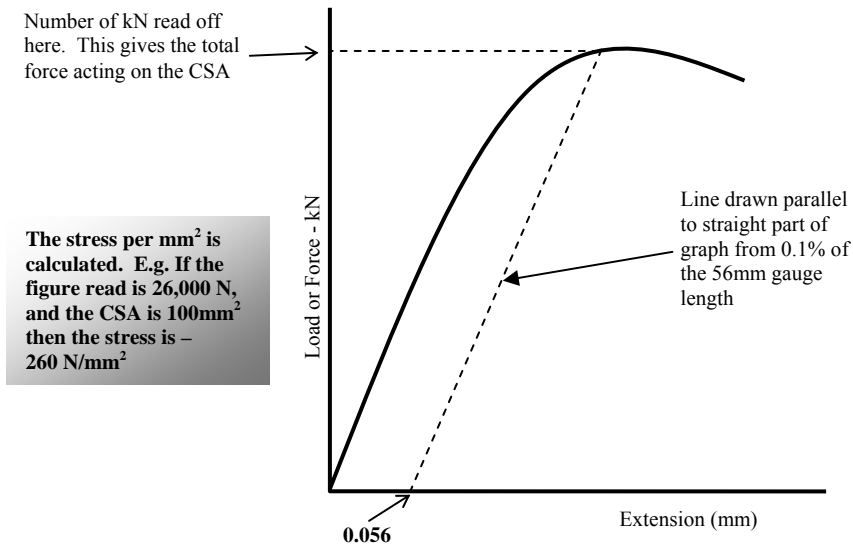


Fig. 1.18 Proof stress from a stress-strain graph

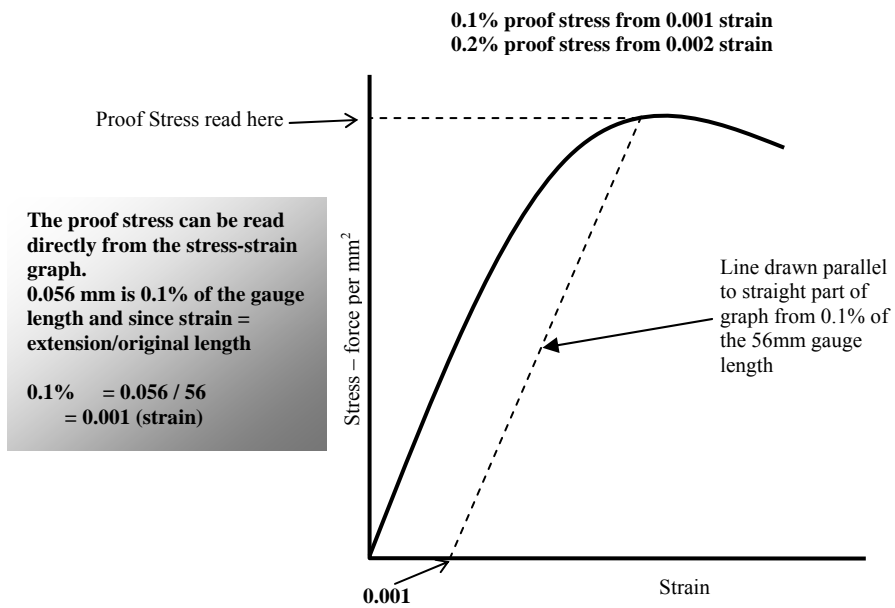
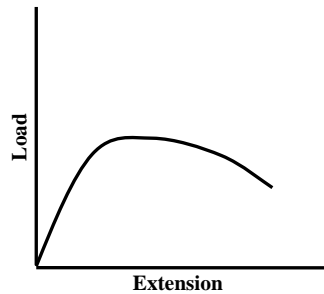


Fig. 1.19 Proof stress from a load vs extension

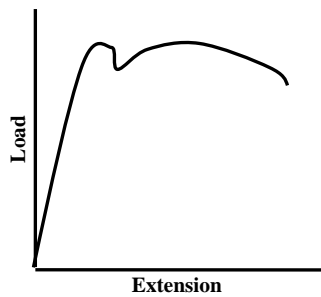
Reading 0.1% Proof Stress from a force-extension graph

A distance equal to 0.1% of the gauge length, from the origin, is located. If the gauge length is 56 mm, then the distance from the origin for 0.1% proof stress is 0.056 mm. A line, parallel to the straight part of the graph is drawn from the 0.056 mm mark until it cuts the graph line as shown in Fig. 1.19. The stress at that point is the 0.1% proof stress.

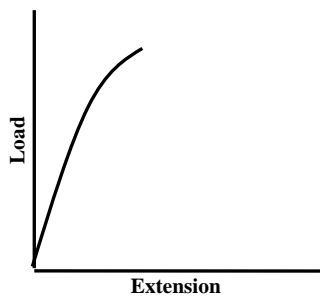
Load vs Extension Graph: The shape of the load vs extension diagram is useful in determining the properties of materials as shown in Fig.1.20.



- Very ductile material
- Little increase in load
- Example of material - copper



- Good ductility
- Definite elastic limit
- Example of material – low carbon steel



- Small amounts of elasticity
- No ductility
- A brittle material
- Example of material – cast iron

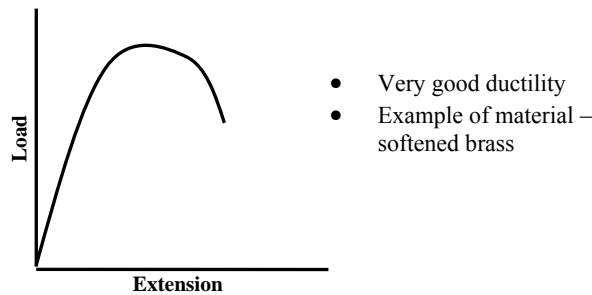


Fig. 1.20 Load Vs extension graph results

1.9 Hardness Testing

Hardness is tested by measuring the material’s resistance to indentation or scratching of its surface. Hardness in metals may vary or can be changed by heat treatment.

A hard piece of metal, called the indenter, is pressed against the surface of the material being tested. The force used is measured and the indentation caused, is read directly. The softer the material, the deeper the indentation will be. The principle parts and picture of hardness testing machine is shown in Fig.1.21. There are three main types of hardness tests

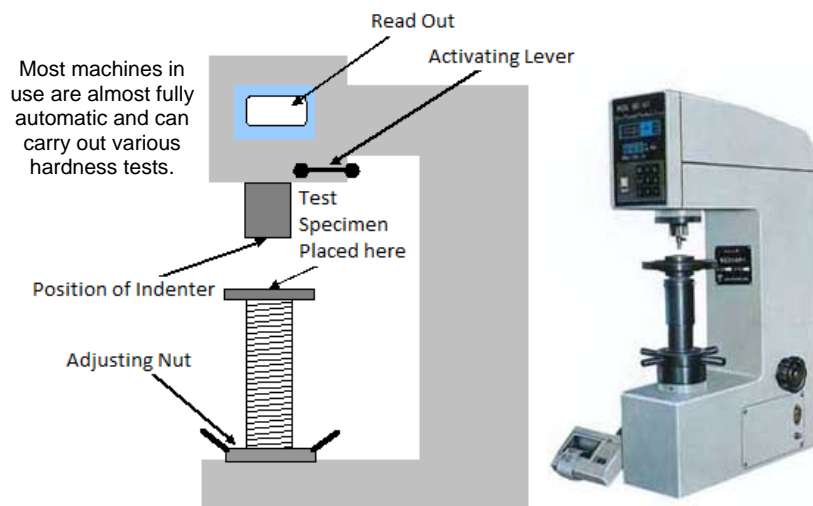


Fig. 1.21 The principal parts of a basic hardness testing machine

- (i) *The Brinell Test*, which uses a ball indenter.
- (ii) *The Vickers Test*, which uses a diamond, square based pyramid indenter.
- (iii) *The Rockwell Test*, which uses a steel ball for soft materials and a diamond cone for hard materials.

(i) **The Brinell Test** [Refer Fig. 1.22]

Indenter: Hardened steel or Tungsten Carbide ball

Procedure: Ball indenter forced into the surface of the test piece by a suitable load. Diameter of indentation is measured and converted into a Brinell hardness number. The test piece must be 8 times thicker than the depth of the impression to prevent the table of the test machine absorbing the indenting force.

Uses: Used on iron castings and drop forgings.

Disadvantages: Cannot be used on thin material specimens.

Ball deforms with very hard material specimens.

Ball indents too much with soft material specimens.

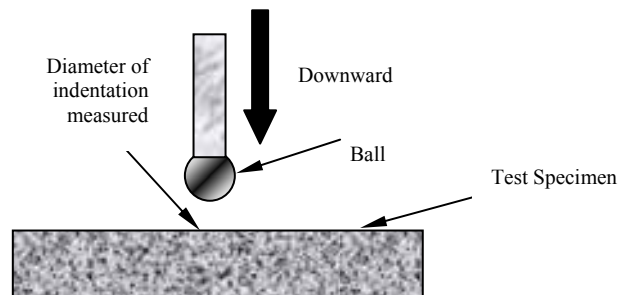


Fig. 1.22 Brinell test procedure

(ii) **The Vickers Test**

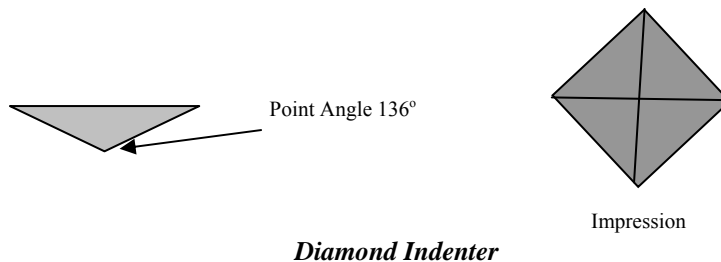
Indenter: Diamond, square based pyramid – point angle of 136°

Procedure: Diamond indenter forced into the surface of the material being tested making a square shaped impression. The diamond pyramid is less likely to distort under high forces than the steel ball.

The diagonal length of the impression is measured and this measurement is converted into a Vickers hardness number.

The test piece must be 5 times thicker than the depth of penetration required.

Uses: Used for very hard materials, gives a more accurate reading than Brinell. Easier to use. A smoother surface is required on test pieces which makes this method ideal for finished components.



Diamond Indenter

(iii) The Rockwell Test

Indenter: The two most common indenters are the Ball and Cone.



Ball and Cone Indenter

Procedure: Similar to the Vickers process.

Rockwell system has a large range of hardness scales.

Each scale has its own type and size of indenter, as well as a specified indenting force.

‘C’ scale indicates that a Cone was used and ‘B’ scale indicates that a Ball was used. The ball is used for soft materials and the cone is used for hard materials.

Uses: Particularly useful for rapid routine testing of finished components, as the hardness number is directly read from the dial. No preparation of the test piece is required.

Note: Both the Brinell and Vickers hardness tests measure the surface areas that the indenters make, to determine the hardness numbers but the Rockwell test measures how far the indenter moves into the material tested.

1.10 Toughness Testing

Toughness testing can also be called *Impact Testing* or *Notched Bar Testing*. The Fig. 1.23 shows the Impact testing machine. The two common methods of Impact Testing are

- The Izod Test
- The Charpy Test

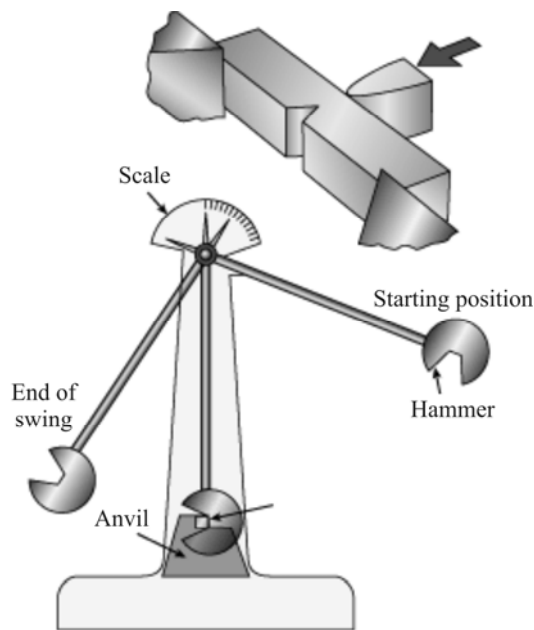


Fig. 1.23 Diagram of impact testing machine

Procedure: Notched specimens are held in a vice and are struck by a weighted pendulum. The energy absorbed in breaking the test piece is measured and a value for toughness is given. The height that the pendulum swings to after breaking the specimen indicates how much energy was absorbed.

The Izod Test [Refer Fig. 1.24]

- Specimen is held vertically
 - Notch is facing the pendulum
 - Striking energy of 167 Joules
- ‘I’ for Izod and the specimen stands in the vice like an ‘I’.

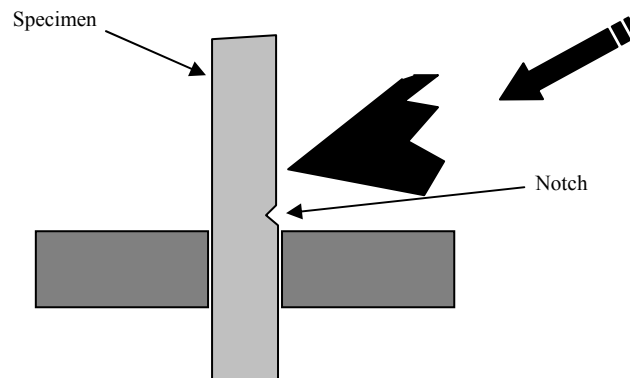


Fig. 1.24 Izod test

The Charpy Test [Refer Fig. 1.25]

- Specimen is held horizontally
- Notch is facing away from the pendulum
- Striking energy of 300 Joules – greater than the Izod because the pendulum is released from a higher position
- A different striker is fitted for this test – a knife edge striker

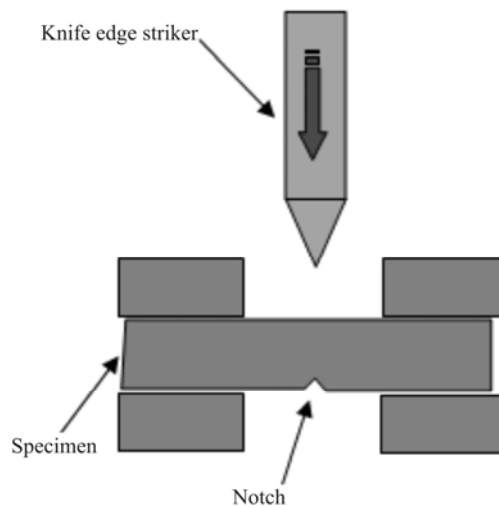


Fig. 1.25 Charpy test

1.11 Creep

Creep is the continuous slow deformation over time in materials subjected to steady persistent stress. The slow and continuous elongation of a material with time at constant stress and high temperature below elastic limit is called creep. In general, the higher the melting point of a metal, the higher its resistance to creep. Factors that affect creep in metals are length of time, size of load and temperature. At high temperatures, stresses even below the elastic limit can cause some permanent deformation on stress-strain diagram.

1.11.1 Stages of creep

Creep test is carried out at high temperature (Fig. 1.26). A creep curve (Fig. 1.27) is a plot of elongation of a tensile specimen versus time, for a given temperature and under constant stress. Tests are carried out for a period of a few days to many years. The test can be carried out on Universal Testing Machine with special attachments.

In the first stage the material elongates rapidly but at a decreasing rate. In the second stage, the rate of elongation is constant. In third stage, the rate of elongation increases rapidly until the material fails. The stress for a specified rate of strain at a constant temperature is called creep strength.

Creep curve shows four stages of elongation:

- (a) Instantaneous elongation on application of load.
- (b) Primary creep: Work hardening decreases and recovery is slow.
- (c) Secondary creep: Rate of work hardening and recovery processes is equal.
- (d) Tertiary Creep: Grain boundary cracks. Necking reduces the cross-sectional area of the test specimen.

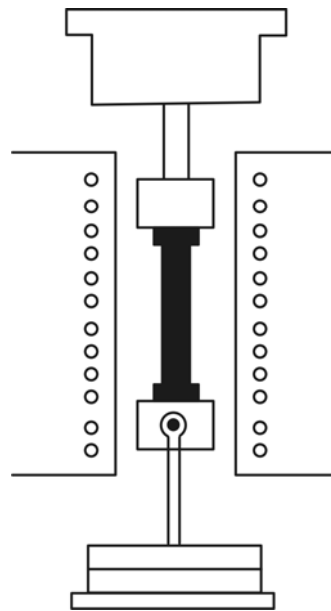


Fig. 1.26 Creep test design

The creep strength is used for the design of blades and other parts of steam and gas turbines working at high temperatures.

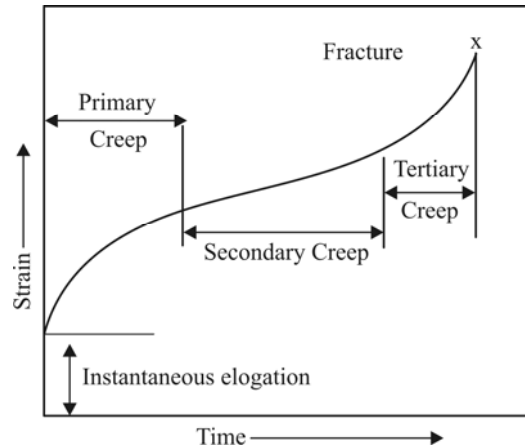


Fig. 1.27 Creep test curve

1.12 Fatigue and Fatigue Test

A material may become fatigued after it has been subjected to many small and alternating stresses over a period of time. Fatigue may start as a little crack on the surface of the component. Slowly the crack increases and moves across the section of the component until it fractures. Fatigue testing is often carried out by means of the Cantilever Beam Test. The fatigue strength of a material is the maximum stress at which failure may occur after a certain number of cyclic load applications. A component is designed to give a certain length of service under a specified loading cycle. Many components of high speed aero and turbine engines are designed for fatigue strength. The fatigue strength or endurance limit of material is used in the design of parts subjected to repeated alternating stresses over an extended period of time. Specimens are tested to failure using different loads. The number of cycles is noted for each load. The results of such tests are plotted as graphs of applied stress against the logarithm of the number of cycles of failure. The curve is known as S-N curve. The tests are carried out on special fatigue testing machines.

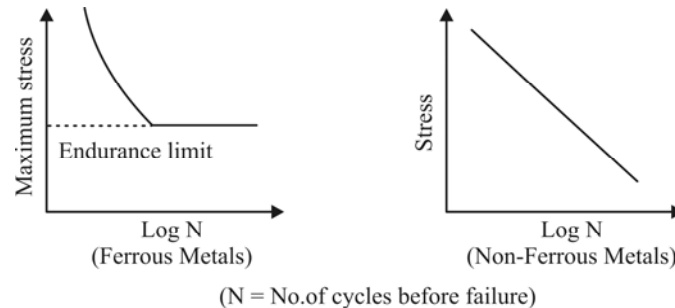


Fig. 1.28 Fatigue (S-N) curves

Many components are subjected to alternating or fluctuating loading cycles during service, and failure by fatigue is a fairly common occurrence. When a metal is tested to determine its fatigue characteristics, the test conditions usually involve the application of an alternating stress cycle with a mean stress value of zero. The results are plotted in the form of an S-N curve (Fig. 1.28), where S is the maximum stress in the cycle, and N is the number of cycles to failure. Most steels show an S-N curve of type (i), with a very definite fatigue limit, or endurance strength. This means that if the maximum stress in the stress cycles is less than this fatigue limit, fatigue failure should never occur. Many non-ferrous materials show S-N curves of type (ii) with no definite fatigue limit with these materials it is only possible to design for a limited life, and a limit of 10^6 or 10^7 cycles is often used.

Solved Numerical Examples

Example 1: A Force of 500 N acts on an area of 10 m^2 . Determine the stress if the area is increased to 20 m^2

Solution:

Stress will be equal to $500/10 = 50 \text{ N/m}^2$

Increasing the area to 20 m^2 will decrease the stress to

$$500/20 = 25 \text{ N/m}^2$$

If area is doubled the stress will be halved.

Example 2: A cylindrical rod of copper ($E = 110 \text{ GPa}$) having a yield strength of 240 MPa is to be subjected to a load of 6660 N). If the length of the rod is 380 mm, what must be the diameter to allow an elongation of 0.50 mm

Solution:

Assuming that deformation is entirely elastic and employing the following equations

$$\sigma = \frac{F}{A_0} = \frac{F}{\pi \left(\frac{d_0^2}{4} \right)} = E \frac{\Delta l}{l_0}$$

Or, solving for d_0

$$d_0 = \sqrt{\frac{4 l_0 F}{\pi E \Delta l}}$$

$$= \sqrt{\frac{(4)(380 \times 10^{-3} \text{ m})(6660 \text{ N})}{(\pi)(110 \times 10^9 \text{ N/m}^2)(0.50 \times 10^{-3} \text{ m})}}$$

$$= 7.65 \times 10^{-3} \text{ m} = 7.65 \text{ mm}$$

Example 3: A 3.0 m length of copper wire of diameter 0.4 mm is suspended from the ceiling. When a 0.5 kg mass is suspended from the bottom of the wire it extends by 0.9 mm. Calculate the strain and Stress in the wire. Also calculate the value of the Young modulus for copper.

Solution:

$$\text{Strain} = \frac{\text{Extension}}{\text{Length}} = \frac{0.9 \times 10^{-3} \text{ m}}{3.0 \text{ m}} = 3.0 \times 10^{-4}$$

$$\text{Stress} = \frac{\text{Load}}{\text{Cross sectional area}} = \frac{5.0 \text{ N}}{\pi(0.2 \times 10^{-3} \text{ m})^2} = 4.0 \times 10^7 \text{ Pa}$$

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{4.0 \times 10^7 \text{ Pa}}{3.0 \times 10^{-4}} = 1.3 \times 10^{11} \text{ Pa}$$

Example 4: A long strip of rubber whose cross section measures 12 mm by 0.25 mm is pulled with a force of 3.0 N. What is the tensile stress in the rubber? Another strip of rubber originally 90 mm long is stretched until it is 120 mm long. What is the tensile strain?

Solution:

$$\text{Stress} = \frac{\text{Load}}{A} = \frac{3 \text{ N}}{12 \times 10^{-3} \text{ mm} \times 0.25 \times 10^{-3} \text{ mm}} = 1 \times 10^6 \text{ Pa}$$

$$\text{Strain} = \frac{\text{Extension}}{\text{Length}} = \frac{120 \text{ mm} - 90 \text{ mm}}{90 \text{ mm}} = 0.33$$

Review Questions

1. What is meant by mechanical properties of materials? State their importance in the design of a machine or structural element.
2. Explain the difference between malleability and ductility. Toughness, stiffness and strength.
3. Explain the term 'fatigue'. Also explain the term fatigue strength and fatigue limit related to fatigue.
4. Explain the difference between hardness and brittleness, strength and stiffness, elasticity and creep, malleability and ductility.
5. What do you understand from the term "Mechanical Properties of Materials"? On which factors does these properties mainly depend?
6. Explain the following in brief:
 - (i) Impact strength (ii) Plasticity
 - (iii) Fatigue (iv) Elasticity
7. Draw a typical "creep test" curve, showing different stages of elongation for a long time, high temperature creep test. State how the information is useful to the design engineers.
8. Differentiate between:
 - (a) Hardness and impact resistance
 - (b) Hardness and toughness
9. Explain: Brittleness, Stiffness and Ductility.
10. What property is dependent on time and temperature?
11. On what factors does the hardness of steel depend?
12. Briefly explain what do you understand by: Toughness, Fatigue, Creep, Hardness
13. Differentiate among strength, stiffness and toughness.
14. Explain (i) Elasticity (ii) Plasticity (iii) Toughness. (iv) Malleability
15. Discuss the factors that are taken into considerations in selecting materials for engineering design.
16. Mention the list of important physical properties of building material.

17. Describe the important mechanical properties of building materials.
18. Explain the following terms.
 - (a) Hardness
 - (b) Chemical resistance
 - (c) Bulk density
 - (d) Impact strength
 - (e) Thermal resistance
 - (f) Elasticity
 - (g) Strength
 - (h) Durability
 - (i) Creep
 - (j) porosity
19. Differentiate between the following
 - (a) Density and bulk density
 - (b) Elasticity and plasticity
 - (c) Ductile materials and Brittle materials
 - (d) Hardness and impact strength

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