**CHAPTER – 1 - INTRODUCTION**

**TOPIC – 1 – Introduction to Machine Elements**

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**1.1 Definition**

The subject Machine Design is the creation of newand better machines and improving the existing ones. Anew or better machine is one which is more economical inthe overall cost of production and operation. The processof design is a long and time consuming one. From the studyof existing ideas, a new idea has to be conceived. The ideais then studied keeping in mind its commercial success andgiven shape and form in the form of drawings. In thepreparation of these drawings, care must be taken of theavailability of resources in money, in men and in materialsrequired for the successful completion of the new idea intoan actual reality. In designing a machine component, it isnecessary to have a good knowledge of many subjects suchas Mathematics, Engineering Mechanics, Strength ofMaterials, Theory of Machines, Workshop Processes andEngineering Drawing.

**1.2 Classifications of Machine Design**

The machine design may be classified as follows:

**1. Adaptive design:**

In most cases, the designer’s work is concerned with adaptation of existingdesigns. This type of design needs no special knowledge or skill and can be attempted by designers ofordinary technical training. The designer only makes minor alternation or modification in the existingdesigns of the product.

**2. Development design:**

This type of design needs considerable scientific training and designability in order to modify the existing designs into a new idea by adopting a new material or differentmethod of manufacture. In this case, though the designer starts from the existing design, but the finalproduct may differ quite markedly from the original product.

**3. New design:**

This type of design needs lot of research, technical ability and creative thinking.Only those designers who have personal qualities of a sufficientlyhigh order can take up theworkof a new design.

The designs, depending upon the methods used, may be classified as follows:

**(a) Rational design:**This type of design depends upon mathematical formulae of principle ofmechanics.

**(b) Empirical design:** This type of design depends upon empirical formulae based on the practiceand past experience.

**(c) Industrial design:** This type of design depends upon the production aspects to manufactureany machine component in the industry.

**(d) Optimum design:** It is the best design for the given objective function under the specifiedconstraints. It may be achieved by minimising the undesirable effects.

**(e) System design:**It is the design of any complex mechanical system like a motor car.

**(f) Element design:**It is the design of any element of the mechanical system like piston,crankshaft, connecting rod, etc.

**(g) Computer aided design:**This type of design depends upon the use of computer systems toassist in the creation, modification, analysis and optimisation of a design.

**1.3 General Considerations in Machine Design**

Following are the general considerations in designing a machine component:

**1. Type of load and stresses caused by the load.**

The load, on a machine component, may actin several ways due to which the internal stresses are set up.

**2. Motion of the parts or kinematics of the machine.**

The successful operation of any machinedepends largelyupon the simplest arrangement of the parts which will give the motion required.

Themotion of the parts may be:

(a) Rectilinear motion which includes unidirectional and reciprocating motions.

(b) Curvilinear motion which includes rotary, oscillatory and simple harmonic.

(c) Constant velocity.

(d) Constant or variable acceleration.

**3. Selection of materials.**

It is essential that a designer should have a thorough knowledge ofthe properties of the materials and their behaviour under working conditions. Some of theimportantcharacteristics of materials are: strength, durability, flexibility, weight, resistance to heat and corrosion,ability to cast, welded or hardened, machinability,electrical conductivity,etc.

**4. Form and size of the parts.**

The form and size are based on judgement. The smallest practicablecross-section may be used, but it may be checked that the stresses induced in the designedcross-sectionare reasonably safe. In order to design any machine part for form and size, it is necessaryto know the forces which the part must sustain. It is also important to anticipate any suddenlyappliedor impact load which may cause failure.

**5. Frictional resistance and lubrication.**

There is always a loss of power due to frictionalresistance and it should be noted that the friction of starting is higher than that of running friction. Itis, therefore, essential that a careful attention must be given to the matter of lubrication of all surfaceswhich move in contact with others, whether in rotating, sliding, or rolling bearings.

**6. Convenient and economical features.**

In designing, the operating features of the machineshould be carefully studied. The starting, controlling and stopping levers should be located on thebasis of convenient handling. The adjustment for wear must be provided employing the various takeupdevices and arranging them so that the alignment of parts is preserved. If parts are to be changedfordifferentproducts or replaced on account of wear or breakage, easy access should be providedandthe necessity of removing other parts to accomplish this should be avoided if possible.The economical operation of a machine which is to be used for production, or for the processingof material should be studied, in order to learn whether it has the maximum capacity consistent withthe production of good work.

**7. Use of standard parts.**

Theuse of standard parts is closely relatedto cost, because the cost of standardor stock parts is only a fraction of thecost of similar parts made to order.The standard or stock partsshould be used whenever possible; parts for which patterns are alreadyin existence such as gears, pulleys andbearings and parts which may beselected from regular shop stock suchas screws, nuts and pins. Bolts andstuds should be as few as possible toavoid the delay caused by changingdrills, reamers and taps and also to decrease the number of wrenches required.

**8. Safety of operation.**

Some machines are dangerous to operate, especially those which arespeeded up to insure production at a maximum rate. Therefore, any moving part of a machine whichis within the zone of a worker is considered an accident hazard and may be the cause of an injury. Itis, therefore, necessary that a designer should always provide safety devices for the safety of theoperator. The safety appliances should in no way interfere with operation of the machine.

**9. Workshop facilities.**

A design engineer should be familiar with the limitations of hisemployer’s workshop, in order to avoid the necessity of having work done in some other workshop.It is sometimes necessary to plan and supervise the workshop operations and to draft methods forcasting, handling and machining special parts.

**10. Number of machines to be manufactured.**

The number of articles or machines to be manufactured affects the design in a number of ways. The engineering and shop costs which are calledfixedchargesor overhead expenses are distributed over the number of articles to be manufactured. Ifonlya few articles are to be made, extra expenses are not justified unless the machine is largeor ofsomespecial design. An order calling for small number of the product will not permit any undueexpense in the workshop processes, so that the designer should restrict his specification to standardparts as much as possible.

**11. Cost of construction.**

The cost of construction of an article is the most important considerationinvolved in design. In some cases, it is quite possible that the high cost of an article may immediatelybar it from further considerations. If an article has been invented and tests of handmade samples haveshown that it has commercial value, it is then possible to justify the expenditure of a considerable sumof money in the design and development of automatic machines to produce the article, especially if itcan be sold in large numbers. The aimof design engineer under allconditions, should be to reduce themanufacturing cost to the minimum.

**12. Assembling.**

Everymachine or structure must beassembled as a unit before it canfunction. Large units must often beassembled in the shop, tested andthen taken to be transported to theirplace of service. The final locationof any machine is important and thedesign engineer must anticipate theexact location and the local facilitiesfor erection.

**1.4 General Procedure in Machine Design**

In designing a machine component, there is no rigid rule. Theproblem may be attempted in several ways. However, the generalprocedure to solve a design problem is as follows:

**1. Recognition of Need.**

First of all, make a complete statementof the problem, indicating the need, aim or purpose for which themachine is to be designed.

**2. Synthesis (Mechanisms).**

Select the possible mechanism orgroup of mechanisms which will give the desired motion.

**3. Analysis of Forces.**

Find the forces acting on each memberof the machine and the energy transmitted by each member.

**4. Material selection.**

Select the material best suited for eachmember of the machine.

**5. Design of elements (Size and Stresses).**

Find the size ofeach member of the machine by considering the force acting on the member and the permissible stresses for the material used. It shouldbe kept in mind that each member should not deflect or deform thanthe permissible limit.

**6. Modification.**

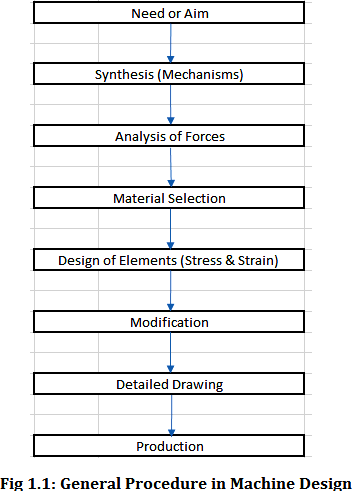
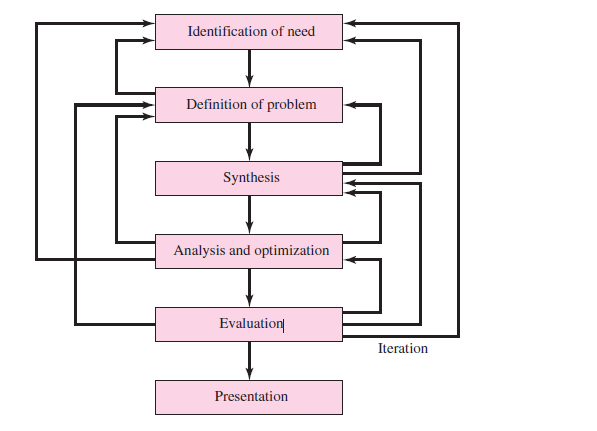
Modify the size of the member to agree withthe past experience and judgment to facilitate manufacture. Themodification may also be necessary by consideration of manufacturingto reduce overall cost.

**7. Detailed drawing.**

Draw the detailed drawing of each component and the assembly of themachine with complete specification for the manufacturing processes suggested.

**8. Production.**

The component, as per the drawing, is manufactured in the workshop.

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**1.5 Units**

**Fundamental Units.**

The measurement of physical quantities is one of the most important operations in engineering.Every quantity is measured in terms of some arbitrary, but internationally accepted units, calledfundamental units.

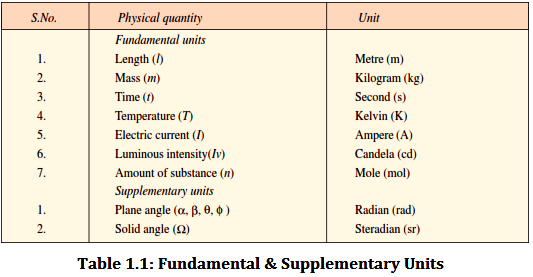
**Derived Units.**

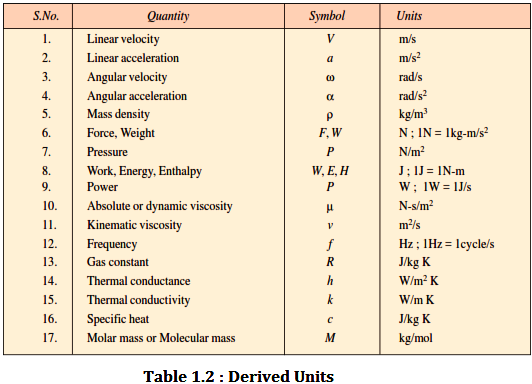
Some units are expressed in terms of other units, which are derived from fundamental units, areknown as derived units e.g. the unit of area, velocity, acceleration, pressure, etc.

**System of Units.**

There are only four systems of units, which are commonly used and universally recognised.These are known as:

1. C.G.S. units, 2. F.P.S. units, 3. M.K.S. units, and 4. S.I. units.





**1.6 Mass and Weight**

**Mass.**

It is the amount of matter contained in a given body and does not vary with the change inits position on the earth’s surface.

**Weight.**

It is the amount of pull, which the earth exerts upon a given body. Since the pull varieswith the distance of the body from the centre of the earth, therefore, the weight of the body will varywith its position on the earth’s surface (say latitude and elevation). It is thus obvious, that the weightis a force.

W =m\*g and Units are Newtons.

**1.7 Inertia**

It is that property of a matter, by virtue of which a body cannot move of itself nor change themotion imparted to it.

**1.8 Laws of Motion**

**1. Newton’s First Law of Motion.**

It states, “Everybody continues in its state of rest or ofuniform motion in a straight line, unless acted upon by some external force”. This is also known asLaw of Inertia.

**2. Newton’s Second Law of Motion.**

It states, “The rate of change of momentum is directlyproportional to the impressed force and takes place in the same direction in which the force acts”.

**3. Newton’s Third Law of Motion.**

It states, “To every action, there is always an equal andopposite reaction”.

**1.9 Force**

It is an agent which produces or tends to produce, destroy or tends to destroy motion.

According to Newton’s Second Law of Motion, the applied force or impressed force is directlyproportional to the rate of change of momentum.

We know thatMomentum = Mass × Velocity

Let m = Mass of the body,

u = Initial velocity of the body,

v = Final velocity of the body,

a = Constant acceleration, and

t = Time required to change velocity from u to v.

∴ Change of momentum = mv – mu

&rate of change of momentum = = =

Or

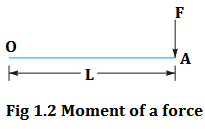
**1.10 Moment of a force**

It is the turning effect produced by a force, on the body, on which it acts. The moment of a forceis equal to the product of the force and the perpendicular distance of the point, about which themoment is required, and the line of action of the force.

Mathematically,Moment of a force = F × L

Where F = Force acting on the body, and

L = Perpendicular distance of the point and the line of action ofthe force (F) as shown in Fig. 1.2.

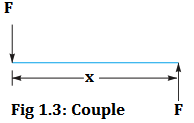
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**1.11 Couple**

The two equal and opposite parallel forces, whose lines of action are different form a couple, asshown in Fig. 1.3.

The perpendicular distance (x) between the lines of action of two equal and opposite parallelforces is known as arm of the couple.

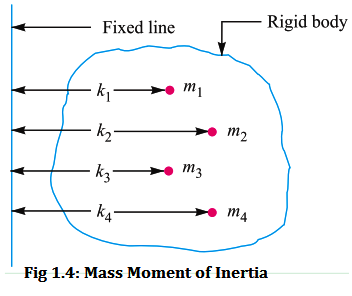
The magnitude of the couple (i.e. moment of a couple) is theproduct of one of the forces and the arm of the couple. Mathematically,Moment of a couple = F × x

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**1.12 Mass moment of Inertia**

It has been established since long that a rigid bodyis composed of small particles. If the mass of everyparticle of a body is multiplied by the square of its perpendicular distance from a fixed line, then the sumof these quantities (for the whole body) is known asmass moment of inertia of the body. It is denoted by I.

Consider a body of total mass m. Let it becomposed of small particles of masses. Ifare the distance from a fixed line, as shown in the fig 1.4. Then the mass moment of inertia of the whole body is given by



If the total mass of a body may be assumed to concentrate at one point (known as centre of massor centre of gravity), at a distance k from the given axis, such that

Then I = where k is called the **radius of gyration**. It may be defined as the distance, from a givenreference, where the whole mass of body is assumed to be concentrated to give the same value ofI.

The unit of mass moment of inertia in S.I. units is kg-m².

**1.13 Angular Momentum**

It is the product of the mass moment of inertia and the angular velocity of the body.

Mathematically, Angular momentum = I.ω

Where I = Mass moment of inertia, and

ω = Angular velocity of the body.

**1.14 Torque**

It may be defined as the product of force and theperpendicular distance of its line of action from thegiven point or axis.

Where α is called angular acceleration.

**1.15 Work**

Whenever a force acts on a body and the body undergoes a displacement in the direction of theforce, then work is said to be done. For example, if a force F acting on a body causes a displacementx of the body in the direction of the force, then

Work done = Force × Displacement = F × x Units of work is N-m.

**1.16 Power**

It may be defined as the rate of doing work or work done per unit time. Mathematically,

Power, P =

* The ratio of the power output to power input is known as efficiency of a machine. It is always less thanunity and is represented as percentage. It is denoted by a Greek letter eta (η), Mathematically,

**1.17 Energy**

It may be defined as **the capacity to do work.**

The energy exists in many forms e.g. mechanical,electrical, chemical, heat, light, etc. But we aremainly concerned with mechanical energy.

The mechanical energy is equal to thework done on a body in altering either itsposition or its velocity.

The following three typesof mechanical energies are important from thesubject point of view:

**1. Potential energy.**

It is the energy possessedby a body, for doing work, by virtue of its position.

For example, a body raised to some height abovethe ground level possesses potential energy, becauseit can do some work by falling on earth’s surface.

Let W = Weight of the Body

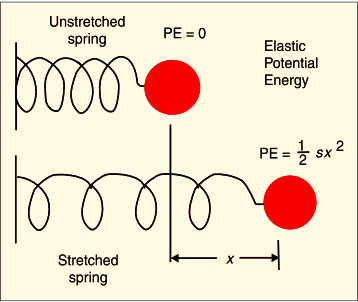
m = mass of the Body&

h = Distance through which the body falls.

**2. Strain energy.**

It is the potential energy stored by an elastic body when deformed. Acompressed spring possesses this type of energy, because it can do some work in recovering itsoriginal shape. Thus, if a compressed spring of stiffness (s) N per unit deformation (i.e. extension orcompression) is deformed through a distance x by a weight W, then

Strain Energy = work done =



**3. Kinetic energy.**

It is the energy possessed by a body, for doing work, by virtue of its massand velocity of motion.

If a body of mass m attains a velocity v from rest in time t, under the influenceof a force F and moves a distance s, then

Work done = F.s = m.a.s

**Notes:**

* When a body of mass moment of inertia I (about a given axis) is rotated about that axis, with anangular velocity ω, then it possesses some kinetic energy. In this case,

Kinetic Energy of rotation KE =

* When a body has both linear and angular motions, e.g. wheels of a moving car, then the total kineticenergy of the body is equal to the sum of linear and angular kinetic energies.
* The energy can neither be created nor destroyed, though it can be transformed from one form into anyof the forms, in which energy can exist. This statement is known as ‘**Law of Conservation of Energy’**.

**TOPIC – 2 - Engineering Materials**

**2.1 Introduction**

**2.2 Classification of Engineering Materials**

**2.3 Selection of Materials for Engineering Purposes**

**2.4 Physical Properties of Metals**

**2.5 Mechanical Properties of Metals**

**2.6 Ferrous Metals**

**2.7 Cast Iron**

**2.8 Types of Cast Iron**

**2.9 Alloy Iron**

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**2.15 Heat Resisting Steel**

**2.16 High Speed Tool Steels**

**2.17 Spring Steels**

**2.18 Heat Treatment of Steels**

**2.19 Non-ferrous Metals**

**2.20 Bearing Metals**

**2.21 Nickel Base Alloys**

**2.22 Non-metallic Materials**

**2.1 Introduction:**

The knowledge of materials and their properties is of great significance for a design engineer. The machine elements should be made of such a material which has properties suitable for the conditions of operation. In addition to this, a design engineer must be familiar with the effects which the manufacturing processes and heat treatment have on the properties of the materials.

**2.2 Classification of Engineering Materials:**

The engineering materials are mainly classified as:

1. Metals and their alloys, such as iron, steel, copper, aluminium, etc.

2. Non-metals, such as glass, rubber, plastic, etc.

The metals may be further classified as:

(a) Ferrous metals, and (b) Non-ferrous metals.

The ferrous metals are those which have the **iron** as their main constituent, such as cast iron,wrought iron and steel.

The non-ferrous metals are those which have a metal other than iron as their main constituent,such as copper, aluminium, brass, tin, zinc, etc.

**2.3 Selection of Materials for Engineering Purposes:**

The following factors should be consideredwhile selecting the material:

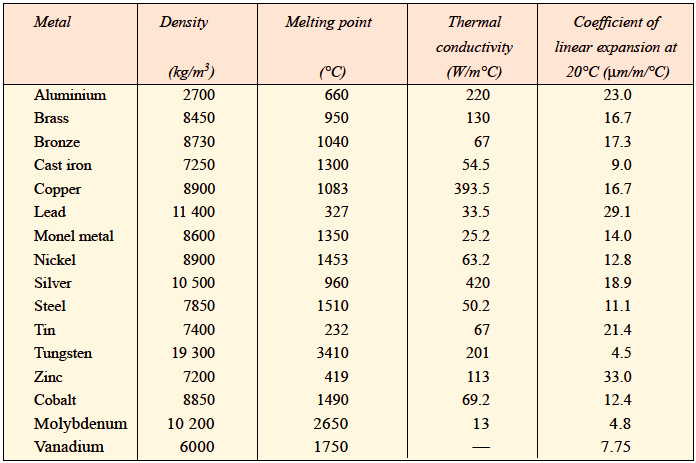
1. Availability of the materials,

2. Suitability of the materials for the workingconditions in service, and

3. The cost of the materials.

**2.4 Physical Properties of Metals**

The physical properties of the metals include luster, colour, size and shape, density, electric andthermal conductivity, and melting point. The following table shows the important physical propertiesof some pure metals.



**2.5 Mechanical Properties of Metals**

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness.

**1. Strength:** It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called stress.

**2. Stiffness:** It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

**3. Elasticity:** It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber

**4. Plasticity:** It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

**5. Ductility:** It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper, aluminum, nickel, zinc, tin and lead.

**6. Brittleness:** It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads snap off without giving any sensible elongation. Cast iron is a brittle material.

**7. Malleability:** It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are lead, soft steel, wrought iron, copper and aluminum.

**8. Toughness:** It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed up to the point of fracture. This property is desirable in parts subjected to shock and impact loads.

**9. Machinability:** It is the property of a material which refers to a relative case with which a material can be cut. The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. It may be noted that brass can be easily machined than steel.

**10. Resilience:** It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

**11. Creep:** When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called creep. This property is considered in designing internal combustion engines, boilers and turbines.

**12. Fatigue:** When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as fatigue. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.

**13. Hardness:** It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal.

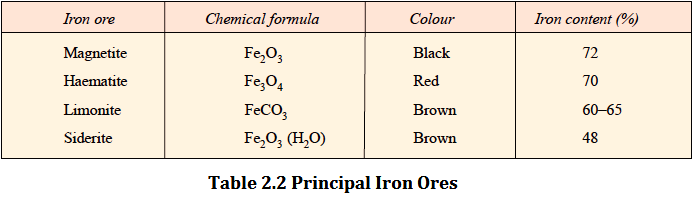
The hardness is usually expressed in numbers which are dependent on the method of making the test. The hardness of a metal may be determined by the following tests:

(a) Brinell hardness test, (b) Rockwell hardness test,

(c) Vickers hardness (Diamond Pyramid) test (d) Shore scleroscope.

**2.6 Ferrous Metals**

We have already discussed that the ferrous metals are those which have iron as theirmain constituent. The ferrous metals commonly used in engineering practice are cast iron, wroughtiron, steels and alloy steels. The principal raw material for all ferrous metals is pig iron which isobtained by smelting iron ore with coke and limestone, in the blast furnace. The principal iron oreswith their metallic contents are shown in the following table:



**2.7 Cast Iron**

The cast iron is obtained by re-melting pig ironwith coke and limestone in a furnace known as cupola.It is primarily an alloy of iron and carbon. The carboncontent in cast iron varies from 1.7 % to 4.5 %. It also contains small amounts of silicon,manganese, phosphorous and sulphur. The carbon in acast iron is present in either of the following two forms:1. Free carbon or graphite, and 2. Combined carbonor cementite.

Since the cast iron is a brittle material, therefore,it cannot be used in those parts of machines which aresubjected to shocks. The properties of cast iron whichmake it a valuable material for engineering purposesare its low cost, good casting characteristics, highcompressive strength, wear resistance and excellentmachinability. The compressive strength of cast iron ismuch greater than the tensile strength.

**2.8 Types of Cast Iron**

1. **Grey Cast Iron**

It is an ordinary commercial iron having the following compositions:

Carbon = 3 to 3.5%; Silicon = 1 to 2.75%; Manganese = 0.40 to 1.0%; Phosphorous = 0.15 to 1%; Sulphur = 0.02 to 0.15%; and the remaining is iron.

The grey colour is due to the fact that the carbon ispresent in the form of free graphite. It has a low tensilestrength, high compressive strength and no ductility. It canbe easily machined. A very good property of grey cast ironis that the free graphite in its structure acts as a lubricant. Due to this reason, it is very suitable forthose parts where sliding action is desired. The grey iron castings are widely used for machine toolbodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agriculturalimplements.

1. **White Cast Iron**

The white cast iron shows a white fracture and has the following approximatecompositions:

Carbon = 1.75 to 2.3%; Silicon = 0.85 to 1.2%; Manganese = less than 0.4%; Phosphorus= less than 0.2%; Sulphur = less than 0.12%, and the remaining is iron.

The white colour is due to fact that it has no graphite and whole of the carbon is in the form ofcarbide (known as cementite) which is the hardest constituent of iron. The white cast iron has a hightensile strength and a low compressive strength. Since it is hard, therefore, it cannot be machined withordinary cutting tools but requires grinding as shaping process. The white cast iron may be producedby casting against metal chills or by regulating analysis. The chills are used when a hard, wear resistingsurface is desired for such products as for car wheels, rolls for crushing grains and jaw crusher plates.

Other types of CAST IRON are chilled Cast Iron, Mottled Cast Iron, Malleable cast Iron, Nodular or spheroidal graphite cast iron.

**2.9 Alloy Iron**

The cast irons contain small percentages of other constituents likesilicon, manganese, sulphur and phosphorus. These cast irons may be called as **plain cast irons**. Thealloy cast iron is produced by adding alloying elements like nickel, chromium, molybdenum, copperand manganese in sufficient quantities. These alloying elements give more strength and result inimprovement of properties. The alloy cast iron has special properties like increased strength, highwear resistance, corrosion resistance or heat resistance. The alloy cast irons are extensively used for gears, automobile parts like cylinders, pistons, piston rings, crank cases, crankshafts, camshafts, sprockets,wheels, pulleys, brake drums and shoes, parts of crushing and grinding machinery etc.

**2.10 Wrought Iron**

It is the purest iron which contains at least 99.5% iron but may contain upto 99.9% iron. Thetypical composition of a wrought iron isCarbon = 0.020%, Silicon = 0.120%, Sulphur = 0.018%, Phosphorus = 0.020%, Slag = 0.070%,and the remaining is iron.

The wrought iron is produced from pig iron by remelting it in the puddling furnace ofreverberatory type. The molten metal free from impurities is removed from the furnace as a pastymass of iron and slag. The balls of this pasty mass, each about 45 to 65 kg are formed. These ballsare then mechanically worked both to squeeze out the slag and to form it into some commercialshape.

The wrought iron is a tough, malleable and ductile material. It cannot stand sudden and excessiveshocks. Its ultimate tensile strength is 250 MPa to 500 MPa and the ultimate compressive strength is300 MPa.It can be easily forged or welded. It is used for chains, crane hooks, railway couplings, and waterand steam pipes.

**2.11 Steel**

It is an alloy of iron and carbon, with carbon content up to a maximum of 1.5%. The carbonoccurs in the form of iron carbide, because of its ability to increase the hardness and strength of thesteel. Other elements e.g. silicon, sulphur, phosphorus and manganese are also present to greater orlesser amount to impart certain desired properties to it. Most of the steel produced now-a-days isplain carbon steel or simply carbon steel.

Carbon steel is defined as steel which has its propertiesmainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese.

The plain carbon steels varying from 0.06% carbon to 1.5% carbon are divided into the followingtypes depending upon the carbon content.

1. Dead mild steel — up to 0.15% carbon

2. Low carbon or mild steel — 0.15% to 0.45% carbon

3. Medium carbon steel — 0.45% to 0.8% carbon

4. High carbon steel — 0.8% to 1.5% carbon

**2.12 Free cutting Steels**

The free cutting steels contain sulphur and phosphorus. These steels have higher sulphur contentthan other carbon steels. In general, the carbon content of such steels varies from 0.1 to 0.45 per centand sulphur from 0.08 to 0.3 per cent.

These steels are used where rapid machining is the primerequirement. It may be noted that the presence of sulphur and phosphorus causes long chips in machiningto be easily broken and thus prevent clogging of machines. Now a days, lead is used from 0.05 to 0.2per cent instead of sulphur, because lead also greatly improves the machinability of steel without theloss of toughness.

**2.13 Alloy Steel**

An alloy steel may be defined as a steel to which elements other than carbon are added insufficient amount to produce an improvement in properties. The alloying is done for specific purposesto increase wearing resistance, corrosion resistance and to improve electrical and magnetic properties,which cannot be obtained in plain carbon steels. The chief alloying elements used in steel are nickel,chromium, molybdenum, cobalt, vanadium, manganese, silicon and tungsten. Each of these elementsconfers certain qualities upon the steel to which it is added. These elements may be used separately orin combination to produce the desired characteristic in steel. Following are the effects of alloyingelements on steel:

1. **Nickel.**

It increases the strength and toughness of the steel. These steels contain 2 to 5%nickel and from 0.1 to 0.5% carbon. In this range, nickel contributes great strength and hardness withhigh elastic limit, good ductility and good resistance to corrosion. An alloy containing 25% nickelpossesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning athigh temperature. It has proved to be of advantage in the manufacture of boiler tubes, valves for usewith superheated steam, valves for I.C. engines and spark plugs for petrol engines.

A nickel steelalloy containing **36%** of nickel is known as **invar**. It has nearly zero coefficient of expansion. So it isin great demand for measuring instruments and standards of lengths for everyday use.

1. **Chromium.**

It is used in steels as an alloying element to combine hardness with high strengthand high elastic limit. It also imparts corrosion-resisting properties to steel. The most common chromesteels contains from 0.5 to 2% chromium and 0.1 to 1.5% carbon. The chrome steel is used for balls,rollers and races for bearings. A nickel chrome steel containing 3.25% nickel, 1.5% chromium and0.25% carbon is much used for armour plates. Chrome nickel steel is extensively used for motor carcrankshafts, axles and gears requiring great strength and hardness.

1. **Vanadium.**

It aids in obtaining a finegrain structure in tool steel. The addition of a verysmall amount of vanadium (less than 0.2%)produces a marked increase in tensile strength andelastic limit in low and medium carbon steelswithout a loss of ductility.

The chrome-vanadiumsteel containing about 0.5 to 1.5% chromium, 0.15to 0.3% vanadium and 0.13 to 1.1% carbon haveextremely good tensile strength, elastic limit,endurance limit and ductility. These steels arefrequently used for parts such as springs, shafts,gears, pins and many drop forged parts.

1. **Manganese.**

It improves the strength ofthe steel in both the hot rolled and heat treated condition. The manganese alloy steels containing over1.5% manganese with a carbon range of 0.40 to 0.55% are used extensively in gears, axles, shafts andother parts where high strength combined with fair ductility is required. The principal uses of manganesesteel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.

1. **Silicon.**

The silicon steels behave like nickel steels. These steels have a high elastic limit ascompared to ordinary carbon steel. Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4%carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springsand corrosion resisting materials.

**2.14 Stainless Steel**

It is defined as that steel which when correctlyheat treated and finished, resists oxidation andcorrosive attack from most corrosive media.

Thedifferent types of stainless steels are discussedbelow:

1. **Martensitic stainless steel.**

* The chromiumsteels containing 12 to 14 per cent chromium and 0.12to 0.35 per cent carbon are the first stainless steelsdeveloped. Since these steels possess martensiticstructure, therefore, they are called martensiticstainless steels.
* These steels are magnetic and maybe hardened by suitable heat treatment and thehardness obtainable depends upon the carbon content.
* These steels can be easily welded and machined.
* Whenformability, softness, etc. are required in fabrication,steel having 0.12 per cent maximum carbon is oftenused in soft condition.
* With increasing carbon, it ispossible by hardening and tempering to obtain tensilestrength in the range of 600 to 900 N/mm², combinedwith reasonable toughness and ductility. In thiscondition, these steels find many useful generalapplications where mild corrosion resistance isrequired. Also, with the higher carbon range in thehardened and lightly tempered condition, tensilestrength of about 1600 N/mm² may be developed withlowered ductility.
* These steels may be used where the corrosion conditions are not too severe, such as for hydraulic, steam and oil pumps, valves and other engineering components.
* However, these steels are not suitable for shafts and parts working in contact with non-ferrous metals (i.e. brass, bronze or gun metal bearings) and with graphite packings, because electrolytic corrosion is likely to occur.
* After hardening and light tempering, these steels develop good cutting properties. Therefore, they are used for cutlery, springs, surgical and dental instruments.

1. **Ferritic stainless steel.**

* The steels containing greater amount of chromium (from 16 to 18%) and about 0.12 % carbon are called ferritic stainless steels.
* These steels have bettercorrosion resistant property than martensiticstainless steels. But, such steels have little capacity forhardening by heat treatment.
* However, in the softened condition, they possess good ductility and aremainly used as sheet or strip for cold forming and pressing operations for purposes where moderatecorrosion resistance is required.
* They may be cold worked or hot worked. They are Ferro-magnetic,usually undergo excessive grain growth during prolonged exposure to elevated temperatures, andmay develop brittleness after electric arc resistance or gas welding.
* These steels have lower strength at elevated temperatures than martensitic steels. However, resistance to scaling and corrosion atelevated temperatures are usually better. The machinability is good and they show no tendency tointercrystalline corrosion.

1. **Austenitic stainless steel.**

* The steel containing high content of both chromium and nickelare called austenitic stainless steels.
* There are many variations in chemical composition of thesesteels, but the most widely used steel contain 18 per cent chromium and 8 per cent nickel with carboncontent as low as possible. Such a steel is commonly known as **18/8 steel.**
* These steels cannot behardened by quenching, in fact they are softened by rapid cooling from about 1000°C.
* They are nonmagneticand possess greatest resistance to corrosion and good mechanical properties at elevatedtemperature.
* These steels are very tough and can be forged and rolled but offer great difficulty in machining.
* They can be easily welded, but after welding, it is susceptible to corrosive attack in an area adjacentto the weld. This susceptibility to corrosion (called intercrystalline corrosion or weld decay) may beremoved by softening after welding by heating to about 1100°C and cooling rapidly.
* These steels areused in the manufacture of pump shafts, rail road car frames and sheathing, screws, nuts and bolts andsmall springs. Since 18/8 steel provide excellent resistance to attack by many chemicals, therefore, itis extensively used in chemical, food, paper making and dyeing industries.

**2.15 Heat Resisting Steel**

The steels which can resist creep and oxidation at high temperatures and retain sufficient strengthare called heat resisting steels.

A number of heat resisting steels have been developed as discussed below:

**1. Low alloy steels.**

* These steels contain 0.5 per cent molybdenum.
* The main application of these steels are for super heater tubes and pipes in steam plants, where service temperatures are in the range of 400°C to 500°C.

**2. Valve steels.**

* The chromium-silicon steels such as silchrome (0.4% C, 8% Cr, and 3.5% Si) andVolmax (0.5% C, 8% Cr, 3.5% Si, and 0.5% Mo) are used for automobile valves.
* They possess goodresistance to scaling at dull red heat, although their strength at elevated temperatures is relatively low.
* For aeroplane engines and marine diesel engine valves, 13/13/3 nickel-chromium-tungsten valvesteel is usually used.

**3. Plain chromium steel.**

* The plain chromium steel consists of(a) Martensitic chromium steel with 12–13% Cr, and(b) Ferritic chromium steels with 18–30% Cr.
* These steels are very good for oxidation resistance at high temperatures as compared to theirstrength which is not high at such conditions.
* The maximum operating temperature for martensiticsteels is about 750°C, whereas for ferritic steels it is about 1000 – 1150°C.

**4. Austenitic chromium-nickel steels.**

* These steels have good mechanical properties at hightemperatures with good scaling resistance.
* These alloys contain a minimum of 18 per cent chromiumand 8 per cent nickel stabilised with titanium or niobium.
* Other carbide forming elements such asmolybdenum or tungsten may also be added in order to improve creep strength. Such alloys aresuitable for use up to 1100°C and are used for gas turbine discs and blades.

**2.16 High Speed Tool Steels**

These steels are used for cutting metals at a much higher cutting speed than ordinary carbontool steels. The carbon steel cutting tools do not retain their sharp cutting edges under heavier loadsand higher speeds. This is due tothe fact that at high speeds,sufficient heat may be developedduring the cutting operation andcauses the temperature of thecutting edge of the tool to reacha red heat. This temperaturewould soften the carbon tool steeland thus the tool will not workefficiently for a longer period.The high speed steels have thevaluable property of retainingtheir hardness even when heatedto red heat.

Most of the highspeed steels contain tungsten asthe chief alloying element, but other elements like cobalt, chromium, vanadium, etc. may be presentin some proportion. Following are the different types of high speed steels:

**1. 18-4-1 High Speed Steel.**

* This steel, on an average, contains 18 % tungsten, 4% chromium and 1 % vanadium.
* It is considered to be one of the best of all purpose tool steels. Itis widely used for drills, lathe, planer and shaper tools, milling cutters, reamers, broaches, threadingdies, punches, etc.

**2. Molybdenum High Speed Steel.**

* This steel, on an average, contains 6 % tungsten, 6 % molybdenum, 4 % chromium and 2 % vanadium.
* It has excellent toughness andcutting ability. The molybdenum high speed steels are better and cheaper than other types of steels.
* Itis particularly used for drilling and tapping operations.

**3. Super High Speed Steel.**

* This steel is also called cobalt high speed steel because cobalt isadded from 2 to 15 %, in order to increase the cutting efficiency especially at high temperatures.
* This steel, on an average, contains 20 % tungsten, 4 % chromium, 2 % vanadiumand 12 % cobalt.
* Since the cost of this steel is more, therefore, it is principally used for heavycutting operations which impose high pressure and temperatures on the tool.

**2.17 Spring Steels**

The most suitable material for springs are those which can store up the maximum amount ofwork or energy in a given weight or volume of spring material, without permanent deformation.These steels should have a high elastic limit as well as high deflection value. The spring steel, foraircraft and automobile purposes should possess maximum strength against fatigue effects and shocks.

The steels most commonly used for making springs are as follows:

**1. High Carbon Steels.**

* These steels contain 0.6 to 1.1 % carbon, 0.2 to 0.5 % silicon and 0.6 to 1 % manganese.
* These steels are heated to 780 – 850°C according to the composition and quenched in oil or water. It is then tempered at 200 – 500°C to suit the particular application.
* These steels are used for laminated springs for locomotives, carriages, wagons, and for heavy road vehicles. The higher carbon content oil hardening steels are used for volute, spiral and conical springs and for certain types of petrol engine inlet valve springs.

**2. Chrome-vanadium steels.**

* These are high quality spring steels and contain 0.45 to 0.55 % carbon, 0.9 to 1.2 % chromium, 0.15 to 0.20 % vanadium, 0.3 to 0.5 % silicon and 0.5 to 0.8 % manganese.
* These steels have high elastic limit, resistance to fatigue and impact stresses.
* Moreover, these steels can be machined without difficulty and can be given a smooth surface free from tool marks.
* These are hardened by oil quenching at 850 – 870°C and tempered at 470 – 510°C for vehicle and other spring purposes.
* These steels are used for motor car laminated and coil springs for suspension purposes, automobile and aircraft engine valve springs.

**3. Silicon-manganese steels.**

* These steels contain 1.8 to 2.0 % silicon, 0.5 to 0.6 % carbon and 0.8 to 1 % manganese.
* These steels have high fatigue strength, resistance andtoughness.
* These are hardened by quenching in oil at 850 – 900°C and tempered at 475 – 525°C.
* These are the usual standard quality modern spring materials and are much used for many engineeringpurposes.

**2.18 Heat Treatment of Steels**

The term heat treatment may be defined as an operation or a combination of operations, involvingthe heating and cooling of a metal or an alloy in the solid state for the purpose of obtaining certaindesirable conditions or properties without change in chemical composition. The aim of heat treatmentis to achieve one or more of the following objects:

1. To increase the hardness of metals.

2. To relieve the stresses set up in the material after hot or cold working.

3. To improve machinability and to soften the metal.

4. To modify the structure of the material to improve its electrical and magnetic properties.

5. To change the grain size.

6. To increase the qualities of a metal to provide better resistance to heat, corrosion andwear.

Following are the various heat treatment processes commonly employed in engineering practice:

**1. Normalising:** The main objects of normalising are:

1. To refine the grain structure of the steel to improve machinability, tensile strength andstructure of weld.

2. To remove strains caused by cold working processes like hammering, rolling, bending,etc., which makes the metal brittle and unreliable.

3. To remove dislocations caused in the internal structure of the steel due to hot working.

4. To improve certain mechanical and electrical properties.

* The process of normalising consists of heating the steel from 30 to 50°C above its upper critical temperature (for hypoeutectoid steels) or Acm line (for hypereutectoid steels).
* It is held at this temperature for about fifteen minutes and then allowed to cool down in still air.
* This process provides a homogeneous structure consisting of ferrite and pearlite for hypoeutectoid steels, and pearlite and cementite for hypereutectoid steels.
* The homogeneous structure provides a higher yield point, ultimate tensile strength and impact strength with lower ductility to steels.
* The process of normalising is frequently applied to castings and forgings, etc. The alloy steels may also be normalised but they should be held for two hours at a specified temperature and then cooling in the furnace.

Notes: (a) The upper critical temperature for a steel depends upon its carbon content. It is 900°C for pure iron,860°C for steels with 2.2% carbon, 723°C for steel with 0.8% carbon and 1130°C for steel with 1.8% carbon.

(b) Steel containing 0.8% carbon is known as eutectoid steel, steel containing less than 0.8% carbon iscalled hypoeutectoid steel and steel containing above 0.8% carbon is called hypereutectoid steel.

**2. Annealing.** The main objects of normalising are:

1. To soften the steel so that it may be easily machined or cold worked.

2. To refine the grain size and structure to improve mechanical properties like strengthand ductility.

3. To relieve internal stresses which may have been caused by hot or cold working or byunequal contraction in casting.

4. To alter electrical, magnetic or other physical properties.

5. To remove gases trapped in the metal during initial casting.

The annealing process is of the following two types:

**(a) Full annealing.**

The purpose of full annealing is to soften the metal to refine the grainstructure, to relieve the stresses and to remove trapped gases in the metal. The process consists of

(i) Heating the steel from 30 to 50°C above the upper critical temperature for hypoeutectoidsteel and by the same temperature above the lower critical temperature i.e. 723°C forhypereutectoid steels.

(ii) Holding it at this temperature for some time to enable the internal changes to take place.The time allowed is approximately 3 to 4 minutes for each millimetre of thickness of thelargest section, and

(iii) Cooling slowly in the furnace. The rate of cooling varies from 30 to 200°C per hourdepending upon the composition of steel.

In order to avoid decarburisation of the steel during annealing, the steel is packed in a cast ironbox containing a mixture of cast iron borings, charcoal, lime, sand or ground mica. The box alongwith its contents is allowed to cool slowly in the furnace after proper heating has been completed.

**(b) Process annealing.**

The process annealing is used for relieving the internal stresses previouslyset up in the metal and for increasing the machinability of the steel. In this process, steel is heated toa temperature below or close to the lower critical temperature, held at this temperature for some timeand then cooled slowly. This cause’s complete recrystallization in steels which have been severelycold worked and a new grain structure is formed. The process annealing is commonly used in thesheet and wire industries.

**3. Spheroidising:**

* It is another form of annealing in which cementite in the granular form is produced in the structure of steel. This is usually applied to high carbon tool steels which are difficult to machine.
* The operation consists of heating the steel to a temperature slightly above the lower critical temperature (730 to 770°C). It is held at this temperature for some time and then cooled slowly to a temperature of 600°C. The rate of cooling is from 25 to 30°C per hour.
* The Spheroidising improves the machinability of steels, but lowers the hardness and tensile strength. These steels have better elongation properties than the normally annealed steel.

**4. Hardening:** The main objects of hardening are:

1. To increase the hardness of the metal so that itcan resist wear.

2. To enable it to cut other metals i.e. to make itsuitable for cutting tools.

The process of hardening consists of

(a) Heating the metal to a temperature from 30 to 50°C above the upper critical point forhypoeutectoid steels and by the same temperature above the lower critical point forhypereutectoid steels.

(b) Keeping the metal at this temperature for a considerable time, depending upon its thickness.

(c) Quenching (cooling suddenly) in a suitable cooling medium like water, oil or brine.

It may be noted that the low carbon steels cannot be hardened appreciably, because of thepresence of ferrite which is soft and is not changed by the treatment. As the carbon content goes onincreasing, the possible obtainable hardness also increases.

Notes: 1. The greater the rate of quenching, the harder is the resulting structure of steel.

2. For hardening alloy steels and high speed steels, they are heated from 1100°C to 1300°C followed bycooling in a current of air.

**5. Tempering:**

The steel hardened by rapid quenching is very hard and brittle. It also containsinternal stresses which are severe and unequally distributed to cause cracks or even rupture of hardenedsteel. The tempering (also known as drawing) is, therefore, done for the following reasons:

1. To reduce brittleness of the hardened steel and thus to increase ductility.

2. To remove the internal stresses caused by rapid cooling of steel.

3. To make steel tough to resist shock and fatigue.

The tempering process consists of reheating the hardened steel to some temperature below thelower critical temperature, followed by any desired rate of cooling. The exact tempering temperaturedepends upon the purpose for which the article or tool is to be used.

**6. Surface hardening or case hardening:**

In many engineering applications, it is desirable thatsteel being used should have a hardened surface to resist wear and tear. At the same time, it shouldhave soft and tough interior or core so that it is able to absorb any shocks, etc. This is achieved byhardening the surface layers of the article while the rest of it is left as such. This type of treatment isapplied to gears, ball bearings, railway wheels, etc.

Following are the various surfaces or case hardening processes by means of which the surfacelayer is hardened:

1. Carburising, 2. Cyaniding, 3. Nitriding, 4. Induction hardening and 5. Flame hardening.

**2.19 Non-ferrous Metals**

We have already discussed that the non-ferrous metals are those which contain a metal otherthan iron as their chief constituent. The non-ferrous metals are usually employed in industry due tothe following characteristics:

1. Ease of fabrication (casting, rolling, forging, welding and machining),

2. Resistance to corrosion,

3. Electrical & thermal conductivity and weight.

The various non-ferrous metals used in engineering practice are aluminium, copper,lead, tin,zinc, nickel, etc. and their alloys.

1. **Aluminium**

It is white metal produced by electrical processes from its oxide (alumina), which is preparedfrom clayey mineral called bauxite. It is a light metal having specific gravity 2.7 and melting point658°C. The tensile strength of the metal varies from 90 MPa to 150 MPa.

* In its pure state, the metal would be weak and soft for most purposes, but when mixed with small amounts of other alloys, it becomes hard and rigid. So, it may be blanked, formed, drawn, turned, cast, forged and die cast.
* Its good electrical conductivity is an important property and is widely used for overhead cables.
* The high resistance to corrosion and its non-toxicity makes it a useful metal for cooking utensils under ordinary condition and thin foils are used for wrapping food items.
* It is extensively used in aircraft and automobile components where saving of weight is an advantage.

**Aluminium Alloys:**The aluminium may be alloyed with one or more other elements like copper, magnesium,manganese, silicon and nickel. The addition of small quantities of alloying elements converts the softand weak metal into hard and strong metal, while still retaining its light weight. The main aluminiumalloys are discussed below:

1. **Duralumin:**

It is an important and interesting wrought alloy. Its composition is as follows:

* Copper = 3.5 – 4.5%; Manganese = 0.4 – 0.7%; Magnesium = 0.4 – 0.7%, and the remainder isaluminium.
* This alloy possesses maximum tensile strength (up to 400 MPa) after heat treatment and agehardening. After working, if the metal is allowed to age for 3 or 4 days, it will be hardened. Thisphenomenon is known as age hardening.
* It is widely used in wrought conditions for forging, stamping, bars, sheets, tubes and rivets.
* Itcan be worked in hot condition at a temperature of 500°C. However, after forging and annealing, itcan also be cold worked.
* Due to its high strength and light weight, this alloy may be used in automobileand aircraft components. It is also used in manufacturing connecting rods, bars, rivets, pulleys, etc.

1. **Y-alloy:**

* It is also called copper-aluminium alloy. The addition of copper to pure aluminiumincreases its strength and machinability.
* The composition of this alloy is as follows :

Copper = 3.5 – 4.5%; Manganese = 1.2 – 1.7%; Nickel = 1.8 – 2.3%; Silicon, Magnesium, Iron= 0.6% each; and the remainder is aluminium.

* This alloy is heat treated and age hardened like duralumin. The ageing process is carried out atroom temperature for about five days.
* It is mainly used for cast purposes, but it can also be used for forged components like duralumin.Since Y-alloy has better strength (than duralumin) at high temperature, therefore, it is much used inaircraft engines for cylinder heads and pistons.

1. **Magnalium:**

* It is made by melting the aluminium with 2 to 10% magnesium in a vacuumand then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres. It also contains about1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraftand automobile components.

1. **Copper**

* It is one of the most widely used non-ferrous metals in industry.
* It is a soft, malleable and ductile material with a reddish-brown appearance.
* Its specific gravity is 8.9 and melting point is 1083°C. The tensile strength varies from 150 MPa to 400 MPa under different conditions.
* It is a good conductor of electricity. It is largely used in making electric cables and wires for electric machinery and appliances, in electrotyping and electroplating, in making coins and household utensils.
* It may be cast, forged, rolled and drawn into wires.
* It is non-corrosive under ordinary conditions and resists weather very effectively.
* Copper in the form of tubes is used widely in mechanical engineering. It is also used for making ammunitions. It is used for making useful alloys with tin, zinc, nickel and aluminium.

**Copper Alloys:**

The copper alloys are broadly classified into thefollowing two groups:

**1. Copper-zinc alloys (Brass):**

* The most widely used copper-zinc alloy is brass.
* There are various types of brasses, depending upon the proportions of copper and zinc. This is fundamentally a binary alloy of copper with zinc each 50%. By adding small quantities of other elements, the properties of brass may be greatly changed.
* For example, the addition of lead (1 to 2%) improves the machining quality of brass. It has a greater strength than that of copper, but have a lower thermal and electrical conductivity.
* Brasses are very resistant to atmospheric corrosion and can be easily soldered. They can be easily fabricated by processes like spinning and can also be electroplated with metals like nickel and chromium.

**2. Copper-tin alloys (Bronze):**

* The alloys of copper and tin are usually termed as bronzes.
* Theuseful range of composition is 75 to 95% copper and 5 to 25% tin.
* The metal is comparatively hard,resists surface wear and can be shaped or rolled into wires, rods and sheets very easily.
* In corrosionresistant properties, bronzes are superior to brasses. Some of the common types of bronzes are asfollows:

**(a) Phosphor bronze.**

* When bronze contains phosphorus, it is called phosphor bronze.
* Phosphorus increases the strength, ductility and soundness of castings.
* The tensile strengthof this alloy when cast varies from 215 MPa to 280 MPa but increases upto 2300 MPawhen rolled or drawn.
* This alloy possesses good wearing qualities and high elasticity.
* Themetal is resistant to salt water corrosion. The composition of the metal varies according towhether it is to be forged, wrought or made into castings.
* It is used for bearings, worm wheels, gears, nuts for machine lead screws, pump parts,linings and for many other purposes. It is also suitable for making springs.

**(b) Silicon bronze.**

* It contains 96% copper, 3% silicon and 1% manganese or zinc.
* It hasgood general corrosion resistance of copper combined with higher strength.
* It can be cast,rolled, stamped, forged and pressed either hot or cold and it can be welded by all the usualmethods.
* It is widely used for boilers, tanks, stoves or where high strength and good corrosionresistance is required.

**(c) Beryllium bronze.**

* It is a copper base alloy containing about 97.75% copper and 2.25%beryllium.
* It has high yield point, high fatigue limit and excellent cold and hot corrosionresistance.
* It is particularly suitable material for springs, heavy duty electrical switches,cams and bushings. Since the wear resistance of beryllium copper is five times that ofphosphor bronze, therefore, it may be used as a bearing metal in place of phosphor bronze.
* It has a film forming and a soft lubricating property, which makes it more suitable as abearing metal.

**(d) Manganese bronze.**

* It is an alloy of copper, zinc and little percentage of manganese.
* Theusual composition of this bronze is as follows:Copper = 60%, Zinc = 35%, and Manganese = 5%.
* This metal is highly resistant to corrosion. It is harder and stronger than phosphor bronze.
* It is generally used for bushes, plungers, feed pumps, rods etc. Worm gears are frequentlymade from this bronze.

**(e) Aluminium bronze.**

* It is an alloy of copper and aluminium.
* The aluminium bronze with6–8% aluminium has valuable cold working properties.
* The maximum tensile strength ofthis alloy is 450 MPa with 11% of aluminium.
* They are most suitable for makingcomponents exposed to severe corrosion conditions.
* When iron is added to these bronzes,the mechanical properties are improved by refining the grain size and improving theductility.
* Aluminium bronzes are widely used for making gears, propellers, condenser bolts, pumpcomponents, tubes, air pumps, slide valves and bushings, etc. Cams and rollers are alsomade from this alloy.
* The 6% aluminium alloy has a fine gold colour which is used forimitation jewellery and decorative purposes.

1. **Tin**

* It is brightly shining white metal.
* It is soft, malleable and ductile. It can be rolled into very thin sheets.
* It is used for making important alloys, fine solder, as a protective coating for iron and steel sheets and for making tin foil used as moisture proof packing.
* A tin base alloy containing 88% tin, 8% antimony and 4% copper is called **Babbitt metal**. It is a soft material with a low coefficient of friction and has little strength.
* It is the most common bearing metal used with cast iron boxes where the bearings are subjected to high pressure and load.

Note: Those alloys in which lead and tin are predominating are designated as **white metal bearing alloys**. Thisalloy is used for lining bearings subjected to high speeds like the bearings of aero-engines.

**2.20 Bearing Metals**

The following are the widely used bearing metals:

1. Copper-base alloys 2. Lead-base alloys, 3. Tin-base alloys and 4. Cadmium-base alloys

* The copper base alloys are the most important bearing alloys. These alloys are harder and stronger than the white metals (lead base and tin base alloys) and are used for bearings subjected to heavy pressures.
* The cadmium base alloys contain 95% cadmium and 5% silver. It is used for medium loaded bearings subjected to high temperature.

The selection of a particular type of bearing metal depends upon the conditions under which itis to be used. It involves factors relating to bearing pressures, rubbing speeds, temperatures, lubrication,etc. A bearing material should have the following properties:

1. It should have low coefficient of friction.

2. It should have good wearing qualities.

3. It should have ability to withstand bearing pressures.

4. It should have ability to operate satisfactorily with suitable lubrication means at the maximumrubbing speeds.

5. It should have a sufficient melting point.

6. It should have high thermal conductivity.

7. It should have good casting qualities.

8. It should have minimum shrinkage after casting.

9. It should have non-corrosive properties.

10. It should be economical in cost.

**2.21 Nickel Base Alloys**

The nickel base alloys are widely used in engineering industry onaccount of their high mechanical strength properties, corrosion resistance,etc. The most important nickel base alloys are discussed below:

**1. Monel metal**:

* It is an important alloy of nickel and copper.
* It contains 68% nickel, 29% copper and 3% other constituents like iron, manganese, silicon and carbon.
* Its specific gravity is 8.87 and melting point 1360°C.
* It has a tensile strength from 390 MPa to 460 MPa.
* It resembles nickel in appearance and is strong, ductile and tough.
* It is superior to brass and bronze in corrosion resisting properties. It is used for making propellers, pump fittings, condenser tubes, steam turbine blades, sea water exposed parts, tanks and chemical and food handling plants.

**2. Inconel:**

* It consists of 80% nickel, 14% chromium, and 6% iron.
* Its specific gravity is 8.55 and melting point 1395°C.
* This alloy has excellent mechanical properties at ordinary and elevated temperatures.
* It can be cast, rolled and cold drawn.
* It is used for making springs which have to withstand high temperatures and are exposed to corrosive action. It is also used for exhaust manifolds of aircraft engines.

**3. Nichrome:**

* It consists of 65% nickel, 15% chromium and 20% iron.
* It has high heat and oxidation resistance. It is used in making electrical resistance wire for electric furnaces and heating elements.

**4. Nimonic**:

* It consists of 80% nickel and 20% chromium.
* It has high strength and ability to operate under intermittent heating and cooling conditions. It is widely used in gas turbine engines.

**2.22 Non-metallic Materials**

The non-metallic materials are used in engineering practice due to their low density, low cost,flexibility, resistant to heat and electricity. Though there are many non-metallic materials, yet thefollowing are important from the subject point of view.

**1. Plastics.**

The plastics are synthetic materialswhich are moulded into shape under pressure with orwithout the application of heat. These can also be cast,rolled, extruded, laminated and machined. Following arethe two types of plastics:

(a) Thermosetting plastics (b) Thermoplastic.

The thermosetting plastics are those which areformed into shape under heat and pressure and results ina permanently hard product. The heat first softens thematerial, but as additional heat and pressure is applied, itbecomes hard by a chemical change known as phenol formaldehyde(Bakelite), phenol-furfural (Durite), urea formaldehyde(Plaskon), etc.

The thermoplastic materials do not become hard withthe application of heat and pressure and no chemical changeoccurs. They remain soft at elevated temperatures untilthey are hardened by cooling. These can be remelted repeatedly by successive application of heat. Someof the common thermoplastics are cellulose nitrate (Celluloid), polythene, polyvinyl acetate, polyvinylchloride (P.V.C.), etc.

The plastics are extremely resistant to corrosion and have a high dimensional stability. They aremostly used in the manufacture of aeroplane and automobile parts. They are also used for makingsafety glasses, laminated gears, pulleys, self-lubricating bearing, etc. due to their resilience and strength.

**2. Rubber.**

It is one of the most important natural plastics. It resists abrasion, heat, strongalkalis and fairly strong acids. Soft rubber is used for electrical insulations. It is also used for powertransmission belting, being applied to woven cotton or cotton cords as a base. The hard rubber is usedfor piping and as lining for pickling tanks.

**3. Leather.**

It is very flexible and can withstand considerable wear under suitable conditions. Itis extensively used for power transmission belting and as a packing or as washers.

**4.** **Ferrodo.**

It is a trade name given to asbestos lined with lead oxide. It is generally

used as afriction lining for clutches and brakes.

**TOPIC – 3 - Stresses & Safety Factor**

**3.1 Introduction**

**3.2 Load**

**3.3 Stress**

**3.4 Strain**

**3.5 Tensile Stress and Strain**

**3.6 Compressive Stress and Strain**

**3.7 Young's Modulus or Modulus of Elasticity**

**3.8 Shear Stress and Strain**

**3.9 Shear Modulus or Modulus of Rigidity**

**3.10 Stress-strain Diagram**

**3.11 Working Stress**

**3.12 Factor of Safety**

**3.13 Selection of Factor of Safety**

**3.14 Stresses in Composite Bars**

**3.15 Stresses due to Change in Temperature—Thermal Stresses**

**3.16 Linear & Lateral Strain**

**3.17 Poisson's Ratio**

**3.19 Bulk Modulus**

**3.20 Resilience**

**3.1 Introduction**

In engineering practice, the machine parts are subjected to various forces which may be due to either one or more of the following:

1. Energy transmitted, 2. Weight of machine,

3. Frictional resistances, 4. Inertia of reciprocating parts,

5. Change of temperature, 6. Lack of balance of moving parts

The different forces acting on a machine part produces various types of stresses, which will be discussed in this chapter.

**3.2 Load**

It is defined as **any external force acting upon a machine part***.*

The following four types of the load are important from the subject point of view:

**1. Dead or steady load:** A load is said to be a dead or steady load, when it does not change inmagnitude or direction.

**2. Live or variable load:**A load is said to be a live or variable load, when it changes continually.

**3. Suddenly applied or shock loads.** A load is said to be a suddenly applied or shock load, whenit is suddenly applied or removed.

**4. Impact load:** A load is said to be an impact load, when it is applied with some initial velocity.

**3.3 Stress**

When some external system of forces or loads acts on a body, the internal forces (equal andopposite) are set up at various sections of the body, which resist the external forces. This internalforce per unit area at any section of the body is known as unit stress or simply a stress. It is denotedby a Greek letter sigma (σ).

Mathematically, Stress, σ = P/A

Where P = Force or load acting on a body, andA = Cross-sectional area of the body.

In S.I. units, the stress is usually expressed in Pascal (Pa) such that 1 Pa = 1 N/m².

In actualpractice, we use bigger units of stress i.e. mega Pascal (MPa) and Gigapaschal (GPa), such that 1 MPa = 1 × 106 N/m² = 1 N/mm²

1 GPa = 1 × 109 N/m² = 1 kN/mm²

**3.4 Strain**

When a system of forces or loads acts on a body, it undergoes some deformation. This deformationper unit length is known as unit strain or simply a strain. It is denoted by a Greek letter epsilon (ε).

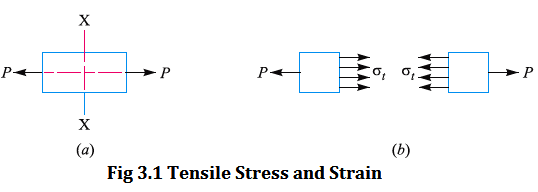
Mathematically,Strain, ε = δl / l or δl = ε.l

Where δl = Change in length of the body, andl = Original length of the body.

**3.5 Tensile Stress and Strain**

When a body is subjected to two equal and opposite axial pulls P (also called tensile load) as shown in Fig. 3.1 (a), then the stress induced at any section of the body is known as ***tensile stress*** as shown in Fig. 3.1 (b).

A little consideration will show that due to the tensile load, there will be adecrease in cross-sectional area and an increase in length of the body. The ratio of the increase inlength to the original length is known as ***tensile strain.***



Let P = Axial tensile force acting on the body,

A = Cross-sectional area of the body,

l = Original length, and

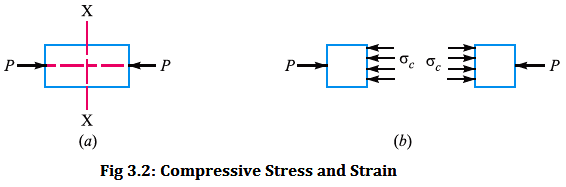
δl = Increase in length.

∴ Tensile stress, = P/A and tensile strain, = δl / l

**3.6 Compressive Stress and Strain**

When a body is subjected to twoequal and opposite axial pushes P (alsocalled compressive load) as shown in Fig. 3.2 (a), then the stress induced at anysection of the body is known as***compressive stress***as shown in Fig. 3.2(b).

A little consideration will show thatdue to the compressive load, there will bean increase in cross-sectional area and adecrease in length of the body. The ratioof the decrease in length to the originallength is known as ***compressive strain.***



Let P = Axial compressive force acting on the body,

A = Cross-sectional area of the body,

l = Original length, and

δl = Decrease in length.

∴ Compressive stress, = P/A and compressive strain, = δl / l

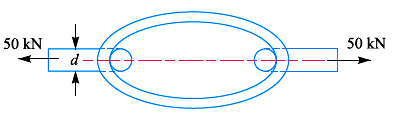
**3.7 Young's Modulus or Modulus of Elasticity**

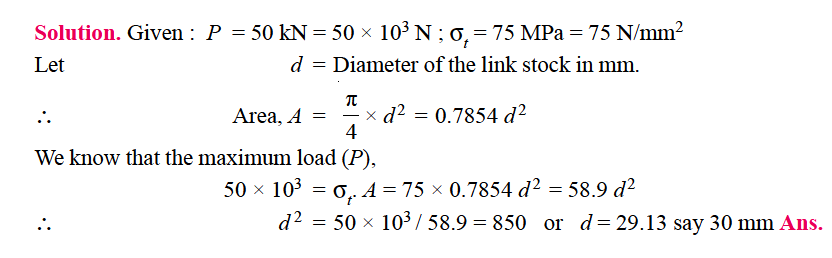
Hooke's law states that when a material is loaded within elastic limit, the stress is directlyproportional to strain, i.e.

= where E is a constant of proportionality known as Young's modulus or modulus of elasticity.

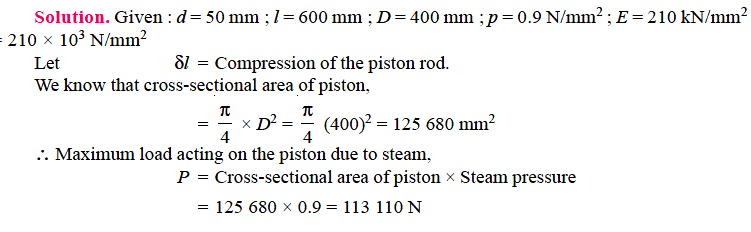
In S.I.units, it is usually expressed in GPa i.e. GN/m² or kN/mm². It may be noted that Hooke's law holdsgood for tension as well as compression.

**Q 1:**A coil chain of a crane required to carry a maximum load of 50 kN, as shown below. Find the diameter of the link stock, if the permissible tensile stress in the link material is not toexceed 75 MPa.





**Q 2:**The piston rod of a steam engine is 50 mm in diameter and 600 mm long. Thediameter of the piston is 400 mm and the maximum steam pressure is 0.9 N/mm². Find the compressionof the piston rod if the Young's modulus for the material of the piston rod is 210 kN/mm².



We know that Cross- Sectional area of Piston RodA =

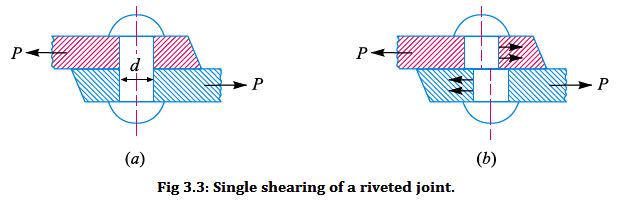
& Young’s Modulus = 210 \* 10³ =

**3.8 Shear Stress and Strain**

When a body is subjected to two equal and oppositeforces acting tangentially across the resisting section, as aresult of which the body tends to shear off the section, then the stress induced is called shear stress.

The corresponding strain is known as shear strain and it is measured by the angular deformationaccompanying the shear stress. The shear stress and shear strain are denoted by the Greek letters tau(τ) and phi (ϕ) respectively. Mathematically,

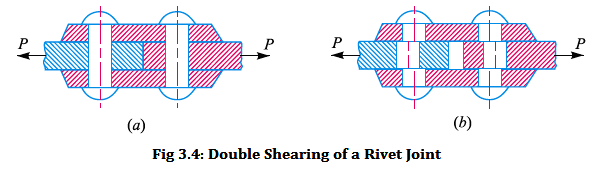
Consider a body consisting of two plates connected by a rivet as shown in Fig. 3.3 (a). In thiscase, the tangential force P tends to shear off the rivet at one cross-section as shown in Fig. 3.3 (b). Itmay be noted that when the tangential force is resisted by one cross-section of the rivet (or whenshearing takes place at one cross-section of the rivet), then the rivets are said to be in single shear. Insuch a case, the area resisting the shear off the rivet,



& Shear stress on the rivet cross-section,

Now let us consider two plates connected by the two cover plates as shown in Fig. 3.4 (a). Inthis case, the tangential force P tends to shear off the rivet at two cross-sections as shown in Fig. 3.4 (b). It may be noted that when the tangential force is resisted by two cross-sections of the rivet (or when the shearing takes place at two cross-sections of the rivet), then the rivets are said to be indouble shear. In such a case, the area resisting the shear off the rivet,

& Shear stress on the rivet cross-section,



Notes:

1. All lap joints and single cover butt joints are in single shear, while the butt joints with double coverplates are in double shear.

2. In case of shear, the area involved is parallel to the external force applied.

3. When the holes are to be punched or drilled in the metal plates, then the tools used to perform theoperations must overcome the ultimate shearing resistance of the material to be cut. If a hole of diameter‘d’ isto be punched in a metal plate of thickness ‘t’, then the area to be sheared,**A = π d × t**

&the maximum shear resistance of the tool or the force required to punch a hole,

**P = A × = π d × t ×** where = Ultimate shear strength of the material of the plate.

**3.9 Shear Modulus or Modulus of Rigidity**

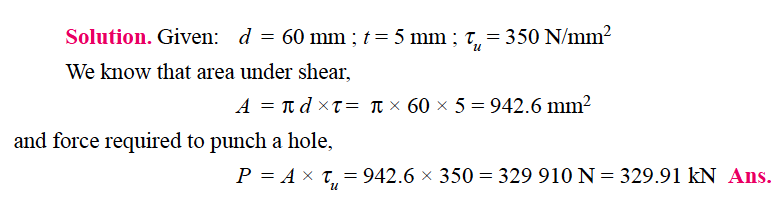
It has been found experimentally that within the elastic limit, the shear stress is directlyproportional to shear strain. Mathematically

Where

Constant of proportionality, known as shear modulus or modulus

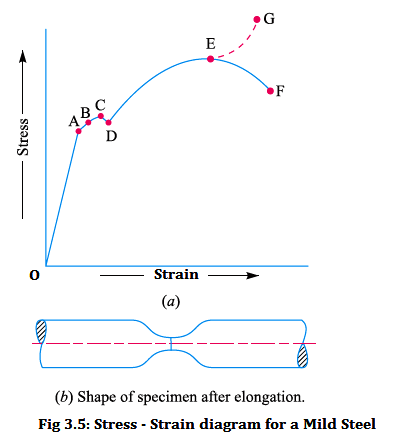
of rigidity. We can also denote by N or G.

**Q 3:** Calculate the force required to punch a circular blank of 60 mm diameter in aPlate of 5 mm thick. The ultimate shear stress of the plate is 350 N/mm².

****

**3.10 Stress-strain Diagram**

* In designing various parts of a machine, it is necessary to know how the material will function in service.
* For this, certain characteristics or properties of the material should be known.
* The mechanical properties mostly used in mechanical engineering practice are commonly determined from a standard tensile test.
* This test consists ofgradually loading a standard specimen of a material and noting the corresponding values of load and elongation until the specimen fractures.
* The load is applied and measured by a testing machine. The stress is determined by dividing the load values by the original cross-sectional area of the specimen. The elongation is measured by determining the amounts that two reference points on the specimen are moved apart by the action of the machine.
* The original distance between the two reference points is known as gauge length.
* The strain is determined by dividing the elongation values by the gauge length. The values of the stress and corresponding strain are used to draw the stress-strain diagram of the material tested.
* A stress-strain diagram for mild steel under tensile test is shown in Fig. 3.5 (a). The various properties of the material are discussed below :



**1. Proportional limit**: We see from the diagramthat from point O to A is a straight line, which representsthat the stress is proportional to strain. Beyond point A,the curve slightly deviates from the straight line. It isthus obvious, that Hooke's law holds good up to point Aand it is known as proportional limit. It is defined asthat stress at which the stress-strain curve begins to deviatefrom the straight line.

**2. Elastic limit:** It may be noted that even if theload is increased beyond point A up to the point B, thematerial will regain its shape and size when the load isremoved. This means that the material has elasticproperties up to the point B. This point is known as elasticlimit. It is defined as the stress developed in the materialwithout any permanent set.

**3. Yield point:** If the material is stressed beyondpoint B, the plastic stage will reach i.e. on the removalof the load; the material will not be able to recover itsoriginal size and shape. A little consideration will showthat beyond point B, the strain increases at a faster rate with any increase in the stress until the pointC is reached. At this point, the material yields before the load and there is an appreciable strainwithout any increase in stress. In case of mild steel, it will be seen that a small load drops to D,immediately after yielding commences. Hence there are two yield points C and D. The points C andD are called the upper and lower yield points respectively. The stress corresponding to yield point isknown as yield point stress.

**4. Ultimate stress:**  At D, the specimen regains some strength and higher values of stresses arerequired for higher strains, than those between A and D. The stress (or load) goes on increasing till the point E is reached. The gradual increase in the strain (or length) of the specimen is followed with theuniform reduction of its cross-sectional area. The work done, during stretching the specimen, istransformed largely into heat and thespecimen becomes hot. At E, thestress, which attains its maximumvalue, is known as ultimate stress.

Itis defined as the largest stressobtained by dividing the largest valueof the load reached in a test to theoriginal cross-sectional area of thetest piece.

**5. Breaking stress:**  After thespecimen has reached the ultimatestress, a neck is formed, whichdecreases the cross-sectional area ofthe specimen, as shown in Fig. 3.5 (b). A little consideration will showthat the stress (or load) necessary tobreak away the specimen, is less thanthe maximum stress. The stress is, therefore, reduced until the specimen breaks away at point F. Thestress corresponding to point F is known as **breaking stress**.

**6. Percentage reduction in area:** It is the difference between the original cross-sectional areaand cross-sectional area at the neck (i.e. where the fracture takes place). This difference is expressedas percentage of the original cross-sectional area.

Let A = Original cross-sectional area, and

a = Cross-sectional area at the neck.

Then reduction in area = A – a

Percentage reduction in area =

**7. Percentage elongation:**It is the percentage increase in the standard gauge length (i.e. originallength) obtained by measuring the fractured specimen after bringing the broken parts together.

Let l = Gauge length or original length, and

L = Length of specimen after fracture or final length.

∴ Elongation = L – l

Percentage elongation =

**Q 4:**A mild steel rod of 12 mm diameter was tested for tensile strength with thegauge length of 60 mm. Following observations were recorded:

Final length = 80 mm; Final diameter = 7 mm; Yield load = 3.4 kN and Ultimate load = 6.1 kN.

Calculate: 1. yield stress, 2. ultimate tensile stress, 3. percentage reduction in area, and4. percentage elongation.

Sol: Given

We know that Original area of the rod,

Final area of the rod,

1. Yield Stress:

2. Ultimate Tensile Stress:

3. Percentage reduction in area

4. Percentage elongation =

**3.11 Working Stress**

When designing machine parts, it is desirable to keep the stress lower than the maximum orultimate stress at which failure of the material takes place. This stress is known as the working stressor design stress. It is also known as ***safe or allowable stress.***

**3.12 Factor of Safety**

* It is defined, in general, as the ratio of the maximum stress to the working stress. Mathematically, Factor of safety =
* In case of **ductile materials** e.g. mild steel, where the yield point is clearly defined, the factor of safety is based upon the yield point stress. In such cases,

∴ Factor of safety =

* In case of **brittle materials** e.g. cast iron, the yield point is not well defined as for ductile materials. Therefore, the factor of safety for brittle materials is based on ultimate stress.

∴ Factor of safety =

This relation may also be used for ductile materials.

**3.13 Selection of Factor of Safety**

The selection of a proper factor of safety to be used in designing any machine componentdepends upon a number of considerations, such as the material, mode of manufacture, type of stress,general service conditions and shape of the parts. Before selecting a proper factor of safety, a designengineer should consider the following points:

1. The reliability of the properties of the material and change of these properties duringservice;

2. The reliability of test results and accuracy of application of these results to actual machineparts;

3. The reliability of applied load;

4. The certainty as to exact mode of failure;

5. The extent of simplifying assumptions;

6. The extent of localised stresses;

7. The extent of initial stresses set up during manufacture;

8. The extent of loss of life if failure occurs; and

9. The extent of loss of property if failure occurs.

Each of the above factors must be carefully considered and evaluated. The **high factor of safetyresults in unnecessary risk of failure**. The values of factor of safety based on ultimate strength fordifferent materials and type of load are given in the following table 3.1:

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Steady Load | Live Load | Shock Load |
| Cast Iron | 5 to 6 | 8 to 12 | 16 to 20 |
| Wrought Iron | 4 | 7 | 10 to 15 |
| Steel | 4 | 8 | 12 to 16 |
| Soft Materials & Alloys | 6 | 9 | 15 |
| Leather | 9 | 12 | 15 |
| Timber | 7 | 10 to 15 | 20 |
| **Table 3.1: Values of Factor of Safety** | | | |
|

**3.14 Stresses in Composite Bars**

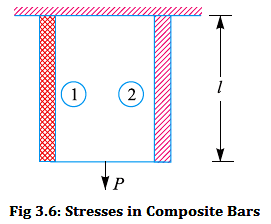
A composite bar may be defined as a bar made up of two or more different materials, joinedtogether, in such a manner that the system extends or contracts as one unit, equally, when subjected totension or compression.

In case of composite bars, the following points should be kept in view:

1. The extension or contraction of the bar being equal, the strain i.e. deformation per unitlength is also equal.

2. The total external load on the bar is equal to the sum of the loads carried by differentmaterials.

Consider a composite bar made up of two different materials as shown in Fig. 3.6.



Let = Load carried by bar 1,

= Cross-sectional area of bar 1,

= Stress produced in bar 1,

E1 = Young's modulus of bar 1,

= Corresponding values of bar 2,

P = Total load on the composite bar,

l = Length of the composite bar, and

δl = Elongation of the composite bar.

We know that P = …………..... (I)

Stress in Bar 1, = & strain in Bar 1

Similarly

Since

………… (II)

But P = = =

Or ………… (III)

………… (IV)

We know that

or

Similarly

From the above equations, we can find out the stresses produced in the different bars. We alsoknow that

P = =. From this equation, we can also find out the stresses produced in different bars.

Note: The Ratio is known as **modular ratio** of the two materials.

**Q 5:**

A bar 3 m long is made of two bars, one of copper having E = 105 GN/m² andthe other of steel having E = 210 GN/m². Each bar is 25 mm broad and 12.5 mm thick. This compoundbar is stretched by a load of 50 kN. Find the increase in length of the compound bar and the stressproduced in the steel and copper. The length of copper as well as of steel bar is 3 m each.

Sol: Given;

**Increase in length of the compound bar**

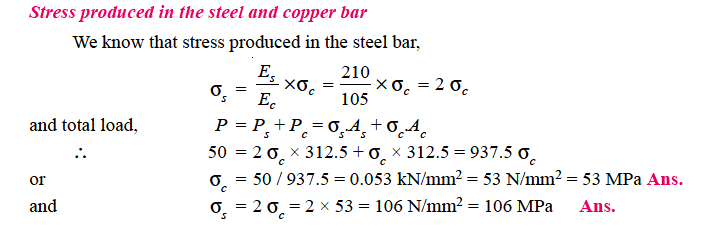
Let δl = Increase in length of thecompound bar.

The compound bar is shown in Fig. 3.6. We know that

Cross-sectional area of each bar,.

And load shared by the steel bar,

Since the elongation of both the bars is equal, therefore



**3.15 Stresses due to Change in Temperature—Thermal Stresses**

Whenever there is some increase or decrease in the temperature of a body, it causes the body toexpand or contract. A little consideration will show that if the body is allowed to expand or contractfreely, with the rise or fall of the temperature, no stresses are induced in the body. But, if the deformationof the body is prevented, some stresses are induced in the body. Such stresses are known as **thermal stresses**.

Let = Original length of the body,

t = Rise or fall of temperature, and

α = Coefficient of thermal expansion,

∴ Increase or decrease in length, δl =. α.t

If the ends of the body are fixed to rigid supports, so that its expansion is prevented, thencompressive strain induced in the body,

Notes:

1. When a body is composed of two or different materials having different coefficient of thermalexpansions, then due to the rise in temperature, the material with higher coefficient of thermal expansion will besubjected to compressive stress whereas the material with low coefficient of expansion will be subjected totensile stress.

2. When a thin tyre is shrunk on to a wheel of diameter D, its internal diameter d is a little less than thewheel diameter. When the tyre is heated, its circumference πd will increase to πD. In this condition, it isslipped on to the wheel. When it cools, it wants to return to its original circumference πd, but the wheel if it isassumed to be rigid, prevents it from doing so.

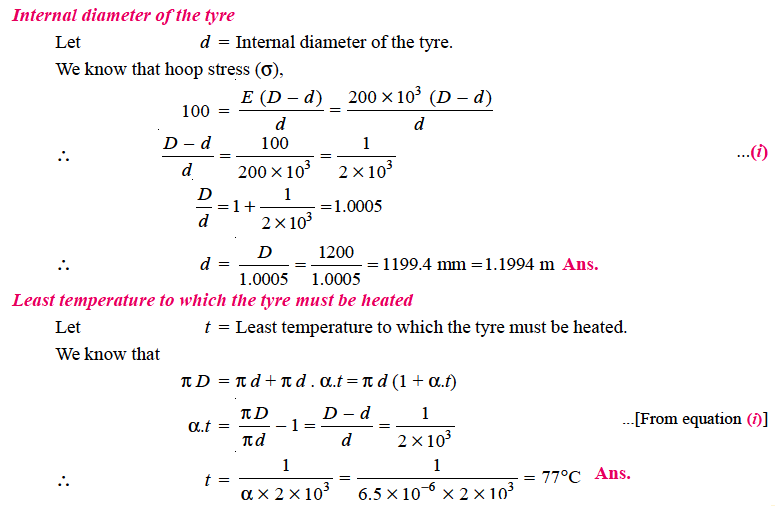
This strain is known as **circumferential or hoop strain**.

**Q 6:**

A thin steel tyre is shrunk on to a locomotive wheel of 1.2 m diameter. Find theinternal diameter of the tyre if after shrinking on, the hoop stress in the tyre is 100 MPa. AssumeE = 200 kN/mm². Find also the least temperature to which the tyre must be heated above that of thewheel before it could be slipped on. The coefficient of linear expansion for the tyre is 6.5 × per °C.

Sol: Given D = 1.2 m = 1200 mm; σ = 100 MPa = 100 N/mm²;

E = 200 KN/mm² = 200 \* 10³ N/mm²; α = 6.5 × per °C.

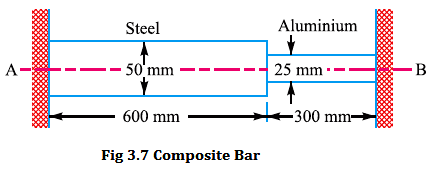


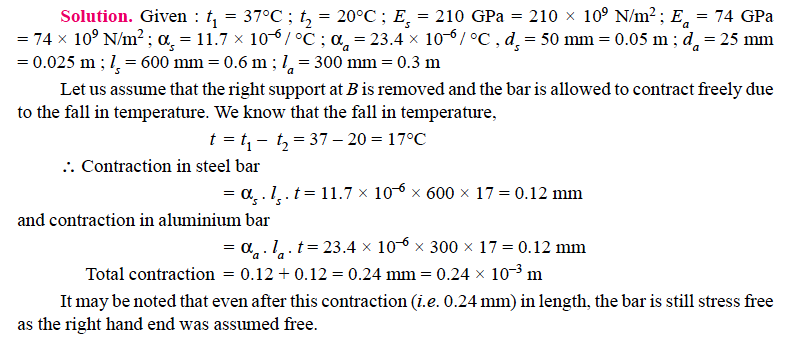
**Q 7:**

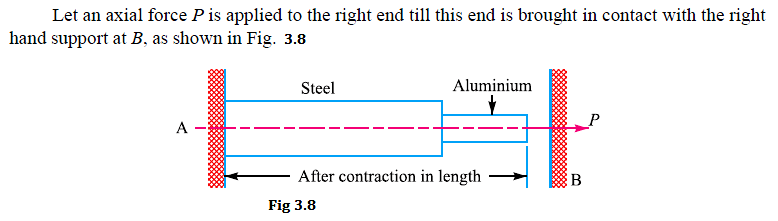
A composite bar made of aluminium and steel is held between the supports asshown in Fig. 3.7. The bars are stress free at a temperature of 37°C. What will be the stress in thetwo bars when the temperature is 20°C, if (a) the supports are unyielding; and (b) the supports yieldand come nearer to each other by 0.10 mm?

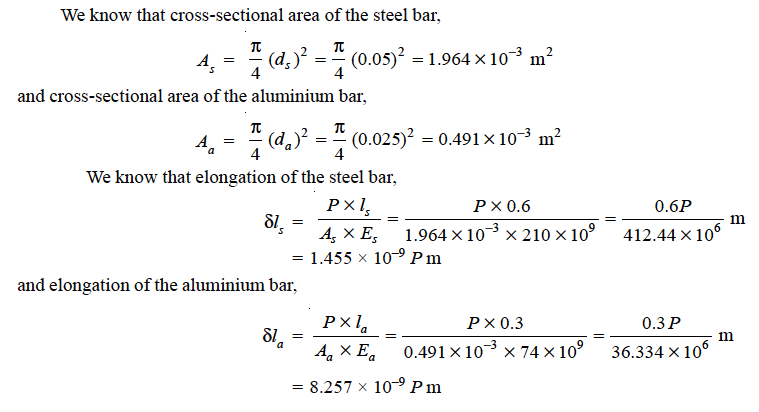
It can be assumed that the change of temperature is uniform all along the length of the bar.

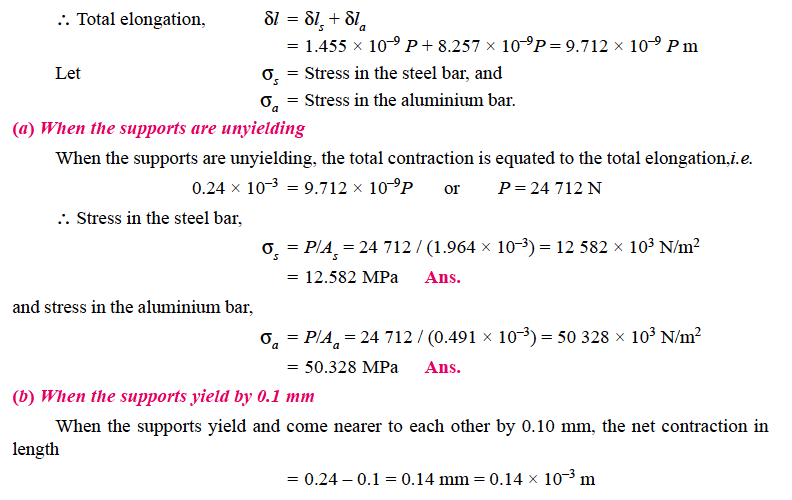
Take = 210 GPa; = 74 GPa;= 11.7 × / °C;= 23.4 × / °C.

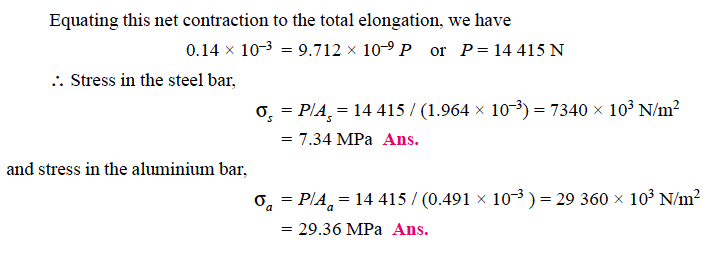






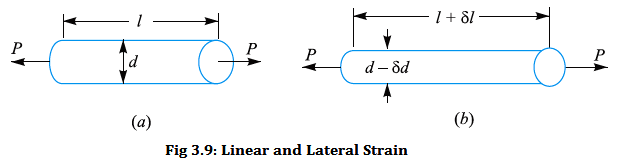






**3.16 Linear & Lateral Strain**

Consider a circular bar of diameter d and length l, subjected to a tensile force P as shown inFig. 3.9 (a).



A little consideration will show that due to tensile force, the length of the bar increases by anamount δl and the diameter decreases by an amount δd, as shown in Fig. 3.9 (b). Similarly, if the baris subjected to a compressive force, the length of bar will decrease which will be followed by increasein diameter.

It is thus obvious, that every direct stress is accompanied by a strain in its own direction whichis known as **linear strain** and an opposite kind of strain in every direction, at right angles to it, isknown as **lateral strain**.

**3.17 Poisson's Ratio**

It has been found experimentally that when a body is stressed within elastic limit, the lateralstrain bears a constant ratio to the linear strain, mathematically,

This constant is known as **Poisson's ratio** and is denoted by 1/m or μ.

**3.18 Volumetric Strain**

When a body is subjected to a system of forces, it undergoes some changes in its dimensions. Inother words, the volume of the body is changed.

The ratio of the change in volume to the originalvolume is known as volumetric strain. Mathematically, volumetric strain, = δV / V

Where δV = Change in volume, and V = Original volume.

**3.19 Bulk Modulus**

When a body is subjected to three mutually perpendicular stresses, of equal intensity, then theratio of the direct stress to the corresponding volumetric strain is known as bulk modulus. It isusually denoted by **K**. Mathematically, bulk modulus,

K =

**Note:**

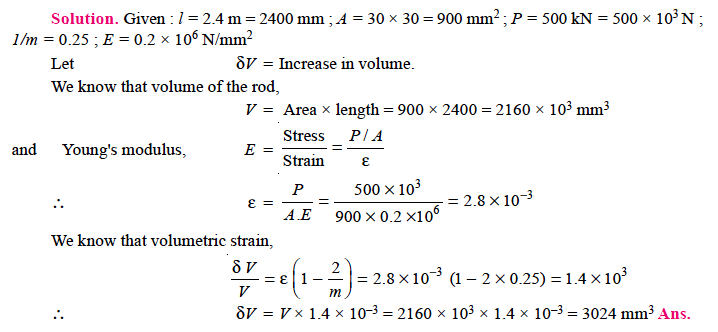
* Relation Between Bulk Modulus and Young’s Modulus is

K =

* Relation Between Young’s Modulus and Modulus of Rigidity

G =

**Q 8:**A steel bar 2.4 m long and 30 mm square is elongated by a load of 500 kN. IfPoisson’s ratio is 0.25, find the increase in volume. Take E = 0.2 × 106 N/mm².



**3.20** **Resilience**

When a body is loaded within elastic limit, it changes its dimensions and on the removal of theload, it regains its original dimensions. So long as it remains loaded, it has stored energy in itself. Onremoving the load, the energy stored is given off as in the case of a spring.

This energy, which isabsorbed in a body when strained within elastic limit, is known as strain energy.

The strain energy isalways capable of doing some work.The strain energy stored in a body due to external loading, within elastic limit, is known as**resilience** and the maximum energy which can be stored in a body up to the elastic limit is called**proof resilience**.

The proof resilience per unit volume of a material is known as **modulus of resilience**.

It is an important property of a material and gives capacity of the material to bear impact orshocks. Mathematically, strain energy stored in a body due to tensile or compressive load or resilience, U =

And Modulus of resilience =

Where σ = Tensile or compressive stress,

V = Volume of the body, and

E = Young's modulus of the material of the body.

Notes:

1. When a body is subjected to a shear load, then modulus of resilience (shear) =

where τ = Shear stress, and

C = Modulus of rigidity.

2. When the body is subjected to torsion, then modulus of resilience =

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