Machine Design – I

Course Code: ME 341 Course Teacher: Alma Arbe Mid-term Examination: 2 hours Semester Final Examination: 3 hours	Credit: 03 Total Marks: 150 CIE Marks: 90 SEE Marks: 60

Course Learning Outcomes (CLOs): After completing this course successfully, the students will be able to-

CLO 1	Understand the fundamental principles and concepts of machine design.
CLO 2	Apply selected appropriate materials for different machine components based on mechanical properties and application requirements.
CLO 3	Design and analyze stresses and strains in machine components under different loading conditions
CLO 4	Industry standards and codes in the design of machine components

SL.	Content of Course	Hrs	CLO
1	**Explain Machine Design Concepts:** Articulate the key concepts, theories, and principals involved in machine design.	7	**CLO1**
2	**Select Appropriate Materials:** Choose suitable materials for machine components based on their properties and design requirements.	7	**CLO2**
3	**Design Machine Components:** Design various machine elements, ensuring they meet performance, safety, and reliability criteria.	8	**CLO3**
4	**Analyze Stresses and Strains:** Perform stress and strain analysis on machine components under static and dynamic loads.	8	**CLO4**
5	**Apply Industry Standards:** Utilize relevant industry standards and codes in the design and analysis of mechanical systems.	**8**	**CLO5**

Course plan specifying content, CLOs, teaching learning and assessment strategy mapped with CLOs

Week	Topic	Teaching-Learning Strategy	Assessment Strategy	CLOs
1	**[Week 1: Introduction to Machine Design]** **Class 1:** Course Overview and Objectives • Introduction to the course • Explanation of course structure and objectives **Class 2:** Fundamentals of Machine Design • Definition and importance of machine design • Overview of the design process **Class 3**: Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral)	**CLO1** **CLO2**
2	**[Week 2: Material Selection in Machine Design]** **Class 4:** Properties of Engineering Materials • Mechanical properties of materials **Class 5:** Criteria for material selection **Class 6**: Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral) ▪ Class Test	**CLO1** **CLO2**

Course plan specifying content, CLOs, teaching learning and assessment strategy mapped with CLOs

Week	Topic	Teaching-Learning Strategy	Assessment Strategy	CLOs
3	**[Week 3: Load and Stress Analysis]** **Class 7:** Material Selection Methodologies & Material selection charts and methods, Case studies in material selection **Class 8:** Types of Loads and Stresses • Static and dynamic loads • Types of stresses (tensile, compressive, shear) **Class 9:** Problem Solving	▪ Lecture ▪ Discussion	▪ Question & Answer (Oral)	**CLO1**
4	**Class 10:** Stress-Strain Relationships • Stress-strain curves • Elastic and plastic deformation **Class 11:** Failure Theories • Theories of failure (Maximum Stress, Maximum Strain, Distortion Energy) **Class 12:** Problem Solving	▪ Written exam ▪ MCQ test ▪ Assignment ▪ Presentation	▪ Written exam ▪ MCQ test ▪ Oral test	**CLO2** **CLO3**

Course plan specifying content, CLOs, teaching learning and assessment strategy mapped with CLOs

Week	Topic	Teaching-Learning Strategy	Assessment Strategy	CLOs
5	**Class 13:** Application of failure theories in design **Class 14:** Design for Safety and Reliability • Safety factors and reliability considerations • Designing for fatigue and fracture **Class 15**: Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral)	**CLO1** **CLO2**
6	**Class 16:** Variable Stresses in Machine Parts **Class 17:** Stresses in Compound Cylindrical Shell **Class 18:** Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral)	**CLO1** **CLO2**
7	**Class 19:** Deflection and stiffness **Class 20:** Elastic stability, shock and impact **Class 21:** Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral) ▪ Class Test	**CLO2**

Course plan specifying content, CLOs, teaching learning and assessment strategy mapped with CLOs

Week	Topic	Teaching-Learning Strategy	Assessment Strategy	CLOs
8	**Class 22:** Design and discussion on cylindrical covers **Class 23:** Shaft Design Basics ● Types of shafts and their applications ● Stress analysis in shafts Class 24:	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral) ▪ Class Test	**CLO2**
9	**Class 15:** Design of Shafts Under Combined Loads ● Torsion and bending in shafts **Class 16:** Design equations and examples of shafts **Class 27:** Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral) ▪ Class Test	**CLO2**
10	**Class 28: Types of Fasteners** ● Bolts, screws, and rivets **Class 29:** Applications of different types of fasteners **Class 30:** Problem Solving	▪ Lecture ▪ Discussion	▪ Question & Answer (Oral)	**CLO1**

Course plan specifying content, CLOs, teaching learning and assessment strategy mapped with CLOs

Week	Topic	Teaching-Learning Strategy	Assessment Strategy	CLOs
11	**Class 31:** Types of Welded Joints • Types and applications of welded joints • Stress analysis in welded joints **Class 32:** Bonded Joints Design • Types and applications of bonded joints • Design considerations for bonded joints **Class 33:** Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral) ▪ Class Test	**CLO1** **CLO2** **CLO3**
12	**Class 34:** Rivetted Joints **Class 35:** Cotter joints **Class 36:** Problem Solving	▪ Written exam ▪ MCQ test ▪ Assignment ▪ Presentation	▪ Written exam ▪ MCQ test ▪ Oral test	**CLO2** **CLO3**
13	**Class 37:** Knuckle joints **Class 38:** Keys and Keyways **Class 39:** Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise	▪ Question & Answer (Oral) ▪ Class Test	**CLO2** **CLO3**

Course plan specifying content, CLOs, teaching learning and assessment strategy mapped with CLOs

Week	Topic	Teaching-Learning Strategy	Assessment Strategy	CLOs
14	**Class 40:** Couplings **Class 41:** Mechanical Springs **Class 42:** Problem Solving	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral)	**CLO2** **CLO3**
15	**[Week 16: Course Review and Final Exam Preparation]** **Class 43:** Course Review • Review of key concepts and lessons learned • Preparation for the final exam **Class 44:** Final Exam Preparation • Practice questions and discussions • Tips for effective exam performance	▪ Lecture ▪ Discussion ▪ Problem Solving ▪ Exercise ▪ Assignment	▪ Question & Answer (Oral)	**CLO3** **CLO4**

[Textbooks]

1. **Machine Design: An Integrated Approach** by Robert L. Norton
   - This textbook offers a comprehensive and integrated approach to the principles and practices of machine design, including detailed examples and case studies.
2. **Mechanical Engineering Design** by J.E. Shigley and C.R. Mischke
   - This book provides a thorough overview of mechanical engineering design principles, with a strong focus on the design of machine elements.

[Reference Books]

1. **Design of Machine Elements** by V.B. Bhandari
   - This reference book covers a wide range of topics related to the design of machine elements, providing practical insights and design methodologies.
2. **Fundamentals of Machine Component Design** by Robert C. Juvinall and Kurt M. Marshek
   - This book offers a solid foundation in the principles of machine component design, with numerous worked examples and problems for practice.

MACHINE DESIGNING-I
ME 341
3 CREDITS
5^{TH} SEM

By

Alma Arbe

Lecturer

University of Global Village (UGV)

COURSE INFORMATION

Total Marks 150

Attendance 10%

Quiz 10% (4 quizzes)

Assignment 10% (2 assignments)

Midterm Examination 30% (out of 45)

Final Examination 40% (out of 60)

****Weekly 3 hours of classes**

CONTENT

1. INTRODUCTION TO MACHINE DESIGNING

Mechanical Engineering Design:

Machine designing is the process of creating and developing machines and mechanical systems. It involves understanding the principles of mechanics, materials, and engineering to design components and assemblies that perform specific functions efficiently and safely. The goal is to produce machines that meet desired specifications, are reliable, and can be manufactured economically.

A designer's personal resources of creativeness, communicative ability, and problem-solving skill are intertwined with the knowledge of technology and first principles. Engineering tools (such as mathematics, statistics, computers, graphics, and languages) are combined to produce a plan that, when carried out, produces a product that is functional, safe, reliable, competitive, usable, manufacturable, and marketable, regardless of who builds it or who uses it.

In designing a machine component, it is necessary to have a good knowledge of many subjects such as Mathematics, Engineering Mechanics, Strength of Materials, Theory of Machines, Workshop Processes and Engineering Drawing.

1. INTRODUCTION TO MACHINE DESIGNING

Machine Designing Methods:

1. Adaptive design: Where designer's make minor alternation or modification in the existing designs of the product.

2. Development design: This type of design is made by modifying the existing designs into a new idea by adopting a new material or different method of manufacture. In this case, though the designer starts from the existing design, but the final product may differ quite markedly from the original product.

3. New design: A designer's own idea which needs a lot of studies and calculations. This can be classified as follows :

(a) Rational design (b) Empirical design (c) Industrial design (d) Optimum design (e) System design (f) Element design (g) Computer aided design

Design Considerations:

Type of load and stresses caused by the load	Use of standard parts (gears, pulleys, bearings, etc.)
Motion of the parts or kinematics of the machine	Safety of operation
Selection of materials	Workshop facilities
Form and size of the parts	Number of machines to be manufactured
Frictional resistance and lubrication	Cost of construction
Convenient and economical features	Assembling

1. INTRODUCTION TO MACHINE DESIGNING

Machine Designing Procedure:

- Problem Identification/ AIM
- Preliminary Ideas
- Synthesis
- Analysis and Optimization
- Refinement
- Design of elements
- Evaluation
- Modifications
- Implementation

1. INTRODUCTION TO MACHINE DESIGNING

Remember

While designing any machines or parts of machines some certain **standards** of materials, processes or specifications of parts needs to be taken into considerations. There are also **codes in case of** analysis, design, manufacture, and construction must be followed. Some standards and codes are universal but not all. You can follow the codes and standards according to your assignment or job placements.

While working in Bangladesh you might need to work with American, Indian, Chinese or Japanese standards and codes. Which are all available in the internet.

2. REVISIONAL PHYSICS FOR DESIGNING PURPOSES

Convert the units into Imperial Units.

Fundamental or Supplementary Units:

Fundamental Units	
Length (*l*) Mass (*m*) Time (*t*) Temperature (*T*) Electric current (*I*) Luminous intensity(*Iv*) Amount of substance (*n*)	Metre(m) Kilogram (kg) Second (s) Kelvin (K) Ampere (A) Candela (cd) Mole (mol)
Supplementary units	
Plane angle () Solid angle	Radian (rad) Steradian (sr)

2. REVISIONAL PHYSICS FOR DESIGNING PURPOSES

Derived Units:

Linear Velocity	V	m/s
Linear Acceleration	a	m/s^2
Angular Velocity	ω	Rad/s
Angular Acceleration	α	Rad/s^2
Mass Density	ρ	Kg/m^3
Force, Weight	F, W	N; 1N=1kg-m/s^2
Pressure	P	N/m^2
Work, Energy, Enthalpy	W, E, H	J;1J=1Nm
Power	P	W; 1W=1J/s
Absolute or Dynamic Viscosity	µ	Ns/m^2
Kinetic viscosity	v	M^2/s
Frequency	f	Hz; 1Hz=1 cycle/s
Gas Constant	R	J/kg K
Thermal Conductance	h	W/m^2 K
Thermal Conductivity	k	W/m K
Specific heat	c	J/kg K
Molar Mass or Molecular Mass	M	Kg/mol

2. REVISIONAL PHYSICS FOR DESIGNING PURPOSES

Mass and Weight: $m = W / g$ or $W = m.g$

Inertia: The property of matter that causes it to resist any change in its state of rest or of uniform motion. There are three kinds of inertia- inertia of rest, inertia of motion and inertia of direction. The mass of a body is a measure of its inertia.

Newton's first law of motion: A body continues in a state of rest or of uniform motion in a straight line unless it is acted upon by an external (unbalanced) force.

Newton's law of gravitation: The gravitational force of attraction acting between any two particles is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them. The force of attraction acts along the line joining the two particles. Real bodies having spherical symmetry act as point masses with their mass assumed to be concentrated at their center of mass.

Newton's second law of motion: The rate of change of momentum is equal to the force applied or the force acting on a body is directly proportional to the product of its mass and acceleration produced by the force in the body. (Momentum = mass x velocity; measure of the quantity of motion in a body)

Newton's third law of motion: To every action there is an equal and opposite reaction. The action and reaction act on two different bodies simultaneously.

2. REVISIONAL PHYSICS FOR DESIGNING PURPOSES

*Change of momentum = $mv - mu$

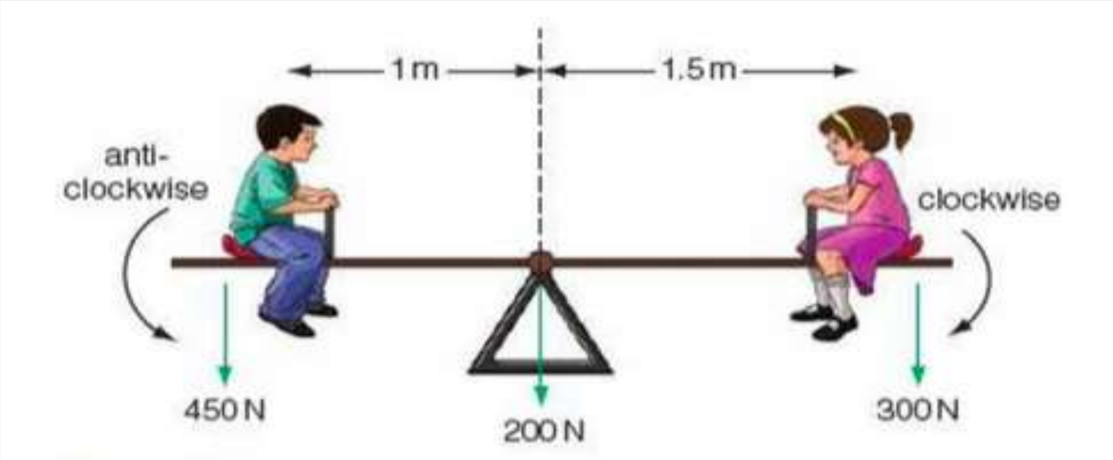
*Rate of change of momentum $= \frac{m(v-u)}{t} = m.a$

*Moment of a force $= F \times l$

Where, F = Force acting on the body, and

l = Perpendicular distance of the point and the line of action of the force (F)

*Moment of a couple $= F \times x$



Couple: The two equal and opposite parallel forces, whose lines of action are different, form a couple

2. REVISIONAL PHYSICS FOR DESIGNING PURPOSES

Mass Moment of Inertia: $I = m1\,(k1)^2 + m2\,(k2)^2 + m3\,(k3)^2 + m4\,(k4)^2 + \ldots..$

Suppose the mass of the body is concentrated in one particular place (defined as centre of mass or centre of gravity), at a distance *k* from the given axis, such that

$$Mk^2 = m_1 (k_1)^2 + m_2 (k_2)^2 + m_3 (k_3)^2 + m_4 (k_4)^2 + \ldots.$$

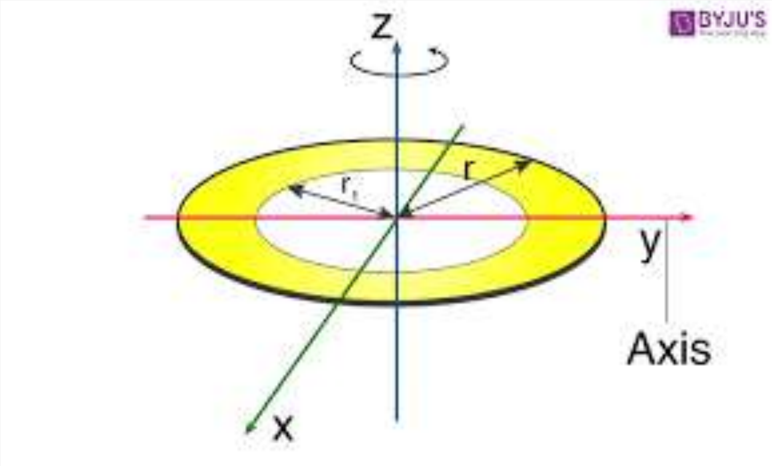
Then, $I = m\,k^2$ $(Kg\text{-}m^2)$

Radius of Gyration: The distance *k* is called the ***radius of gyration.*** It may be defined ***as the distance, from a given reference, where the whole mass of body is assumed to be concentrated to give the same value of I.***

****Moment of Inertia:** Quantitative measure of the rotational inertia of a body.

1. Moment of inertia of a thin disc about an axis through the centre of gravity:

$I = (mr^2)/2 = 0.5\,mr^2$



Question: what will be the formula considering the diameter?

2. REVISIONAL PHYSICS FOR DESIGNING PURPOSES

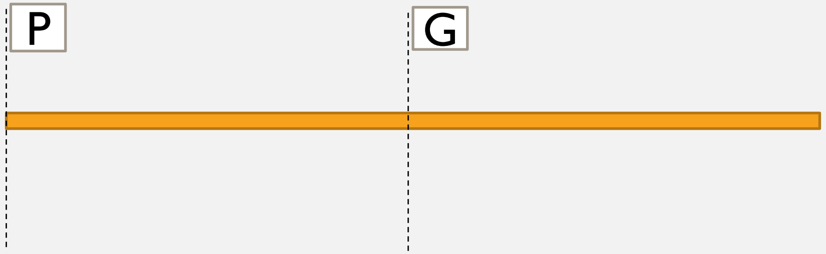
$I_P = I_G + mh^2$

$I_G = moment\ of\ inertia\ about\ an\ axis\ through\ the\ center\ of\ gravity$

h = Distance between two parallel axis

The moment of inertia of a thin rod of length *l,* about an axis through its center of gravity and perpendicular to its length

$$I_G = \frac{ml^2}{12}$$



moment of inertia about a parallel axis through one end of a rod

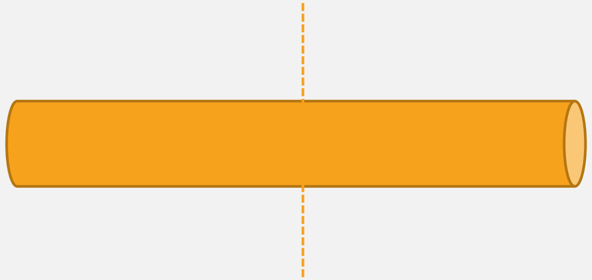
$$I_P = \frac{ml^2}{3}$$

The moment of inertia of a solid cylinder of radius r and length l, about the longitudinal axis or polar axis

$$= \frac{mr^2}{2} = 0.5\ \text{m}\ r^2$$

and moment of inertia through its centre perpendicular to the longitudinal axis

$$= m\left(\frac{r^2}{4} + \frac{l^2}{12}\right)$$



2. REVISIONAL PHYSICS FOR DESIGNING PURPOSES

Power, $P = T.\omega = T \times 2\pi N / 60$ watts (∴ $\omega = 2\pi N/60$)

T is torque in N.m or J
ω is rad/s

Efficiency, $\eta = \frac{power\ output}{power\ input}$

Potential energy, P.E. = $W.\ h = m.g.h$

Strain Energy = Work done = $\frac{1}{2}Wx = \frac{1}{2}sx^2$

What is torque? How is power developed?

The formula of strain energy is similar to Potential Energy but strain energy can be defined as a compressed spring of stiffness (s) N per unit deformation (*i.e.* extension or compression) is deformed through a distance x by a weight W. *It is stored in a spring.*

Efficiency, η = Power output/Power input

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****Weekly 2 hours of classes**

CONTENT

1. Introduction to Machine Designing
2. Revisional Physics for Designing Purposes
3. **Materials and Properties**
4. Manufacturing Processes
5. Load and Stress Analysis
6. Variable Loading in Machine Parts
7. Prevention of Failure
8. Machine Parts
9. Design of Mechanical Element: Shafts
10. Permanent and Non-Permanent Joints

3. MATERIAL AND PROPERTIES

Selection of Materials for Engineering Purposes:

1. Availability of the materials,

2. Suitability of the materials for the working conditions in service

3. The cost of the materials.

Mechanical Properties of Metals:

1. Elasticity
2. Plasticity
3. Strength
4. Stiffness
5. Ductility
6. Brittleness
7. Toughness
8. Malleability
9. Resilience
10. Machineability
11. Creep
12. Fatigue
13. Hardness

PHYSICAL PROPERTIES OF METALS

Metal	Density (kg/m3)	Melting point (°C)	Thermal conductivity (W/m°C)	Coefficient of linear expansion at 20°C (µm/m/°C)
Aluminium	2700	660	220	23.0
Brass	8450	950	130	16.7
Bronze	8730	1040	67	17.3
Cast iron	7250	1300	54.5	9.0
Copper	8900	1083	393.5	16.7
Lead	11400	327	33.5	29.1
Monel metal	8600	1350	25.2	14.0
Nickel	8900	1453	63.2	12.8
Silver	10500	960	420	18.9
Steel	7850	1510	50.2	11.1
Tin	7400	232	67	21.4
Tungsten	19300	3410	201	4.5
Zinc	7200	419	113	12.4
Cobalt	8850	1490	69.2	12.4
Molybdenum	10200	2650	13	4.8
Vanadium	600	1750	-	7.75

3. MATERIAL AND PROPERTIES

Some Mechanical Properties of Metals:

- ***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.
- ***Stiffness:*** It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.
- ***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.
- ***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.
- ***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, aluminium, nickel, zinc, tin and lead.

Note : The ductility of a material is commonly measured by means of percentage elongation and percentage reduction in area in a tensile test.

3. MATERIAL AND PROPERTIES

Some Mechanical Properties of Metals:

- ***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.
- ***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 aluminium.
- ***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 upto the point of fracture. This property is desirable in parts subjected to shock and impact loads.
- ***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.
- ***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.

3. MATERIAL AND PROPERTIES

Some Mechanical Properties of Metals:

- ***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.
- ***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.
- ***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 of a metal is determined by the following tests :**

(a) Brinell hardness test

(b) Rockwell hardness test

(c) Vickers hardness or test or diamond pyramid test

(d) Shore scleroscope

3. MATERIAL AND PROPERTIES

Ferrous Metals:

These king of metals contain iron as their main constituent element. These metals exhibit distinct properties such as high tensile strength, ductility, and hardness, making them essential in various structural and engineering applications. Common examples of ferrous metals include steel, cast iron, and wrought iron.

Principal Iron Ores

Iron Ore	Chemical Formula	Color	Iron Content
Magnetite	Fe_2O_3	Black	72
Haematite	Fe_3O_4	Red	70
Limonite	$FeCO_3$	Brown	60–65
Siderite	$Fe_2O_3 (H_2O)$	Brown	48

Cast Iron

The cast iron is obtained by re-melting pig iron or crude iron with coke and limestone in a furnace (cupola). Cast iron is an alloy of iron and carbon. The carbon contents in cast iron varies from 1.7 per cent to 4.5 per cent. It also contains small amounts of silicon, manganese, phosphorous and sulphur. The carbon in a cast iron is present in either of the following two forms:

1. Free carbon or graphite

2. Combined carbon or cementite

Cast iron is a brittle material, therefore, it cannot be used in those parts of machines which are subjected to shocks. The properties of cast iron which make it a valuable material for engineering purposes are its low cost, good casting characteristics, high compressive strength, wear resistance and excellent machinability. The compressive strength of cast iron is much greater than the tensile strength. Following are the values of ultimate strength of cast iron :

Tensile Strength: 100 – 200 MPa

Compressive Strength: 400 – 1000 MPa

Shear Strength: 120 MPa

3. MATERIAL AND PROPERTIES

Types of Cast Iron:

Grey cast iron: A commercial iron with 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%. It has free graphite present and has a low tensile strength, high compressive strength and no ductility. It can be easily machined and the free graphite in its structure acts as a lubricant therefore it is very suitable for those parts where sliding action is desired. The grey iron castings are widely used for machine tool bodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agricultural implements.

Grey iron castings, as per ASTM Standard

ASTM Designation	*Tensile strength (MPa or N/mm2)*	*Brinell hardness number (B.H.N.)*
Class 20 (ASTM A48)	138	143-187
Class 25 (ASTM A48)	172	156-207
Class 30 (ASTM A48)	207	170-229
Class 35 (ASTM A48)	241	187-241
Class 40 (ASTM A48)	276	197-262

3. MATERIAL AND PROPERTIES

White cast iron: The white cast iron has 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%. It is in the form of carbide (known as cementite) which is the hardest constituent of iron. The white cast iron has a high tensile strength and a low compressive strength. Since it is hard, therefore, it cannot be machined with ordinary cutting tools but requires grinding as shaping process. The white cast iron may be produced by casting against metal chills or by regulating analysis. The chills are used when a hard, wear resisting surface is desired for such products as for car wheels, rolls for crushing grains and jaw crusher plates.

Chilled cast iron: It is a white cast iron produced by quick cooling of molten iron. Most castings are chilled by the mold in which it is transferred and the outer cast quickly hardens but this hardness penetrates to a very small depth (less than 1 mm). Therefore to make the iron cast withstand wear and friction inserts of iron or steel (chills) are inserted into the mold.

Mottled cast iron: It is a product in between grey and white cast iron in composition, colour and general properties. It is obtained in castings where certain wearing surfaces have been chilled. Uses of mottled cast iron are production of rolling mill rolls due to its hardness and wear resistance, making it suitable for metalworking. Certain engine components that require a degree of wear resistance while still being machinable may be made from mottled cast iron. Crusher Plates and Ball Mill Liners in the mining and mineral processing industries, where a combination of impact resistance and durability is needed. Brake Drums and Discs because of its wear resistance and heat dissipation.

3. MATERIAL AND PROPERTIES

Malleable cast iron: It is a cast iron-carbon alloy which solidifies in the as-cast condition in a graphite free structure, *i.e*. total carbon content is present in its combined form as cementite (Fe_3C).

It is ductile and may be bent without breaking or fracturing the section. The tensile strength of the malleable cast iron is usually higher than that of grey cast iron and has excellent machining qualities. It is used for machine parts as a cheaper alternative for steels *e.g*. hubs of wagon wheels, small fittings for railway rolling stock, brake supports, parts of agricultural machinery, pipe fittings, door hinges, locks etc.

In order to obtain a malleable iron castings, it is first casted into moulds of white cast iron. Then by a heat treatment (*i.e*. annealing), the combined carbon of the white cast iron is separated into nodules of graphite. The following two methods are used for this purpose :

1. Whiteheart process, and
2. Blackheart process.

Find explain the two methods and submit in next class.

3. MATERIAL AND PROPERTIES

Whiteheart Malleable Cast Iron: It is obtained by annealing in a decarburizing atmosphere have a silvery-grey fracture with a heart dark grey to black. The microstructure developed in a section depends upon the size of the section. In castings of small sections, it is mainly ferritic with certain amount of pearlite. In large sections, microstructure varies from the surface to the core as follows :

Core and intermediate zone : Pearlite + ferrite + temper carbon

Surface zone : Ferrite.

The microstructure shall not contain flake graphite.

Blackheart Malleable Cast Iron: This material is heat treated specifically to create graphite nodules from the carbon component, improving the material's mechanical properties. The following are the salient features and specifics of Blackheart malleable cast iron:

Composition: Carbon: 2.0-3.0%; Silicon 1.1-1.8%; Manganese: 0.15-0.55%; Sulfur: 0.10% max; Phosphorus: 0.20% max.
Mechanical Properties: Tensile Strength: Typically ranges from 340 to 560 Mpa; Yield Strength: Approximately 240 to 380 Mpa; Elongation: 2-12%, indicating good ductility; Hardness: Generally around 120-180 HB (Brinell Hardness).

3. MATERIAL AND PROPERTIES

Pearlite malleable cast iron: It is a type of malleable iron characterized by a microstructure predominantly consisting of pearlite, which is a lamellar mixture of ferrite and cementite. This iron is produced through a heat treatment process that involves annealing to form graphite nodules and controlled cooling (tempering) to develop pearlite. The presence of pearlite gives the iron high tensile strength and wear resistance, while the graphite nodules provide moderate ductility and good machinability. This combination of properties makes pearlite malleable cast iron suitable for applications requiring a balance of strength and toughness, such as automotive components, heavy machinery parts, and high-pressure pipe fittings.

Nodular or spheroidal graphite cast iron: It is also known as ductile or high-strength cast iron, is created by adding 0.1-0.8% magnesium to molten grey iron, forming graphite nodules. It offers high fluidity, castability, tensile strength, toughness, wear resistance, weldability, and machinability, making it ideal for hydraulic cylinders, cylinder heads, and rolling mill rolls.

Impurities in cast iron impact its properties significantly:

1. Silicon: (up to 4%) promotes the formation of free graphite, enhancing machinability and reducing blow-holes due to its high oxygen affinity.

2. Sulphur: makes cast iron hard and brittle, and should be limited to below 0.1% to avoid poor casting quality.

3. MATERIAL AND PROPERTIES

3. Manganese: (below 0.75%) hardens the iron and counteracts the adverse effects of sulphur, making the iron white and hard.

4. Phosphorus: improves fluidity and fusibility but can cause brittleness. It is typically kept below 1% and is beneficial for intricate or cost-sensitive castings.

Wrought Iron: It is the purest iron which contains at least 99.5% iron but may contain upto 99.9% iron. The typical composition of a wrought iron is Carbon = 0.020%, Silicon = 0.120%, Sulphur = 0.018%, Phosphorus = 0.020%, Slag = 0.070%,and the remaining is iron. he wrought iron is a tough, malleable and ductile material. It cannot stand sudden and excessive shocks. Its ultimate tensile strength is 250 MPa to 500 MPa and the ultimate compressive strength is 300 MPa. It can be easily forged or welded. It is used for chains, crane hooks, railway couplings, water and steam pipes.

3. MATERIAL AND PROPERTIES

Steel: It is an alloy of iron and carbon, with carbon content up to a maximum of 1.5%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel. Other elements e.g. silicon, sulphur, phosphorus and manganese are also present to greater or lesser amount to impart certain desired properties to it. Most of the steel produced now-a-days is plain carbon steel or simply carbon steel. A carbon steel is defined as a steel which has its properties mainly 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 following types 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

Homework: Find out the types of steel, their codes, mechanical and chemical properties in ASTM.

Effect of Impurities on Steel

The following are the effects of impurities like silicon, sulphur, manganese and phosphorus on steel:

1. Silicon: The amount of silicon in the finished steel usually ranges from 0.05 to 0.30%. Silicon is added in low carbon steels to prevent them from becoming porous. It removes the gases and oxides, prevent blow holes and thereby makes the steel tougher and harder.

2. Sulphur: It occurs in steel either as iron sulphide or manganese sulphide. Iron sulphide because of its low melting point produces red shortness, whereas manganese sulphide does not effect so much. Therefore, manganese sulphide is less objectionable in steel than iron sulphide.

3. Manganese: It serves as a valuable deoxidising and purifying agent in steel. Manganese also combines with sulphur and thereby decreases the harmful effect of this element remaining in the steel. When used in ordinary low carbon steels, manganese makes the metal ductile and of good bending qualities. In high speed steels, it is used to toughen the metal and to increase its critical temperature.

4. *Phosphorus:* It makes the steel brittle. It also produces cold shortness in steel. In low carbon steels, it raises the yield point and improves the resistance to atmospheric corrosion. The sum of carbon and phosphorus usually does not exceed 0.25%.

3. MATERIAL AND PROPERTIES

Free cutting steels: It is used for rapid machining, contain higher levels of sulphur (0.08–0.3%) and phosphorus compared to other carbon steels. Their carbon content ranges from 0.1 to 0.45%. Sulphur and phosphorus help break long chips during machining, preventing machine clogging. Lead (0.05–0.2%) is increasingly used instead of sulphur to enhance machinability while maintaining toughness.

Alloy steel: It is enhanced by adding elements other than carbon to improve specific properties. The main alloying elements are nickel, chromium, molybdenum, cobalt, vanadium, manganese, silicon, and tungsten. Each element contributes unique qualities to the steel, used alone or in combination:

Nickel: Increases strength and toughness. Steels with 2-5% nickel and 0.1-0.5% carbon have higher strength, hardness, elastic limit, ductility, and corrosion resistance. A 25% nickel alloy is highly tough and resistant to rust, corrosion, and high temperatures, ideal for boiler tubes, I.C. engine valves, and spark plugs. Invar, a 36% nickel alloy, has near-zero expansion, perfect for measuring instruments and length standards.

Chromium: Enhances hardness, strength, elastic limit, and corrosion resistance. Chrome steels (0.5-2% chromium and 0.1-1.5% carbon) are used for bearings and armor plates. Nickel-chrome steel (3.25% nickel, 1.5% chromium, 0.25% carbon) is used in motor car crankshafts, axles, and gears for its strength and hardness.

Tungsten: Prevents grain growth, increases quenched steel hardening depth, and maintains hardness at high temperatures. Tungsten steel (3-18% tungsten and 0.2-1.5% carbon) is used for cutting tools, dies, valves, taps, and permanent magnets.

3. MATERIAL AND PROPERTIES

Vanadium: Refines grain structure in tool steel. Small additions (<0.2%) significantly boost tensile strength and elastic limit in low and medium carbon steels without losing ductility. Chrome-vanadium steel (0.5-1.5% chromium, 0.15-0.3% vanadium, 0.13-1.1% carbon) offers excellent tensile strength, elastic limit, endurance limit, and ductility, ideal for springs, shafts, gears, pins, and drop-forged parts.

Manganese: Enhances steel strength in hot-rolled and heat-treated conditions. Manganese alloy steels (>1.5% manganese, 0.40-0.55% carbon) are used for gears, axles, shafts, and other parts needing high strength and fair ductility. Manganese steel is used for machinery parts subjected to severe wear.

Silicon: Behaves like nickel steel, with a higher elastic limit than ordinary carbon steel. Silicon steels (1-2% silicon, 0.1-0.4% carbon) are used in electrical machinery, I.C. engine valves, springs, and corrosion-resistant materials.

Cobalt: Provides red hardness by retaining hard carbides at high temperatures and tends to decarburize steel during heat treatment. Cobalt increases hardness, strength, residual magnetism, and coercive magnetic force in magnets.

Molybdenum: Small amounts (0.15-0.30%) with chromium and manganese (0.5-0.8%) boost tensile strength. Molybdenum steel is used for airplane fuselages and automobile parts and can replace tungsten in high-speed steels

3. MATERIAL AND PROPERTIES

Stainless Steel:

Martensitic stainless steel: It contains 12-14% chromium and 0.12-0.35% carbon, is the first stainless steel developed, known for their martensitic structure. These magnetic steels can be hardened through heat treatment, with hardness depending on carbon content. They are weldable, machinable, and suitable for applications requiring mild corrosion resistance. With 0.12% carbon, they remain soft for fabrication; higher carbon allows tensile strengths of 600-900 N/mm^2, or up to 1600 N/mm^2 with lower ductility. Used in hydraulic, steam, and oil pumps, valves, cutlery, springs, and medical instruments, they are unsuitable for contact with non-ferrous metals due to electrolytic corrosion risks.

Ferritic stainless steel: Ferritic stainless steels, containing 16-18% chromium and 0.12% carbon, offer better corrosion resistance than martensitic stainless steels but have limited hardenability by heat treatment. They possess good ductility when softened and are used in cold forming and pressing operations. These steels are ferro-magnetic, have good machinability, and resist scaling and corrosion at elevated temperatures. Adding 1.5-2.5% nickel improves their hardenability and corrosion resistance, making them suitable for pump shafts, spindles, and valves.

3. MATERIAL AND PROPERTIES

Stainless Steel:

Austenitic stainless steels: Commonly known as 18/8 steel (18% chromium, 8% nickel), are non-magnetic, highly corrosion-resistant, and have good mechanical properties at high temperatures. They cannot be hardened by quenching but can be welded and forged. They are used in chemical, food, and dyeing industries for pump shafts, rail car frames, screws, nuts, bolts, and springs. Adding 2-3% molybdenum further enhances corrosion resistance.

Heat resisting steel: These are designed to withstand high temperatures, creep, and oxidation. Key types include:

1. **Low alloy steels**: Contain 0.5% molybdenum, used in superheater tubes and pipes at 400-500°C in steam plants.
2. **Valve steels**: Include **silchrome** (0.4% C, 8% Cr, 3.5% Si) and **Volmax** (0.5% C, 8% Cr, 3.5% Si, 0.5% Mo) for automobile valves; 13/13/3 nickel-chromium-tungsten steel for aeroplane and marine diesel engine valves.
3. **Plain chromium steels**: Martensitic (12-13% Cr) for up to 750°C; Ferritic (18-30% Cr) for up to 1150°C, offering good oxidation resistance.
4. **Austenitic chromium-nickel steels**: Contain ≥18% Cr, 8% Ni, with titanium or niobium for stabilization, suitable for use up to 1100°C in gas turbine discs and blades.

3. MATERIAL AND PROPERTIES

High speed tool steel: These are used for cutting metals at higher speeds than carbon tool steels, maintaining hardness even at red heat. They typically contain tungsten, with additional elements like cobalt, chromium, and vanadium. Types include:

1. **18-4-1 High speed steel**: Contains 18% tungsten, 4% chromium, and 1% vanadium. Used for drills, lathes, milling cutters, etc.
2. **Molybdenum high speed steel**: Contains 6% tungsten, 6% molybdenum, 4% chromium, and 2% vanadium. Known for toughness and cutting ability, used in drilling and tapping.
3. **Super high speed steel (Cobalt steel)**: Contains 20% tungsten, 4% chromium, 2% vanadium, and 12% cobalt. Used for heavy cutting operations due to high cutting efficiency at high temperatures.

Heat Treatment of Steels

Heat treatment involves heating and cooling a metal or alloy in the solid state to achieve certain desirable properties without changing its chemical composition. The main objectives are to increase hardness, relieve stress, improve machinability, soften the metal, modify the structure for better electrical and magnetic properties, change grain size, and enhance resistance to heat, corrosion, and wear. Heat treatment processes are:

3. MATERIAL AND PROPERTIES

Normalising

- Objectives: Refine grain structure, improve machinability and tensile strength, remove strains from cold working, and improve mechanical and electrical properties.
- Process: Heat steel to 30-50°C above its critical temperature, hold for 15 minutes, and cool in still air.
- Applications: Commonly used for castings, forgings, and alloy steels.

Annealing

- Objectives: Soften steel for machining, refine grain size, relieve internal stresses, alter physical properties, and remove trapped gases. Types:
  - **Full Annealing**: Heat steel to above critical temperature, hold, and cool slowly in the furnace.
  - **Process Annealing**: Heat steel below or close to critical temperature, hold, and cool slowly for recrystallization.
- Applications: Common in sheet and wire industries.

Spheroidising

- Objectives: Produce cementite in granular form for improved machinability, especially in high carbon tool steels.
- Process: Heat steel slightly above the lower critical temperature, hold, and cool slowly.
- Result: Improved machinability with lower hardness and tensile strength.

3. MATERIAL AND PROPERTIES

Hardening

- Objectives: Increase hardness for wear resistance and suitability for cutting tools.
- Process: Heat steel above critical temperature, hold, and quench in water, oil, or brine.
- Notes: Low carbon steels do not harden appreciably. Higher carbon content increases hardness.

Surface Hardening or Case Hardening

- Objectives: Harden surface layers for wear resistance while maintaining a tough core.
- Applications: Gears, ball bearings, and railway wheels.
- Methods:
  - **Carburising**: Adding carbon to the surface.
  - **Cyaniding**: Introducing carbon and nitrogen.
  - **Nitriding**: Adding nitrogen.
  - **Induction Hardening**: Using electromagnetic induction.
  - **Flame Hardening**: Using an oxy-gas flame.

3. MATERIAL AND PROPERTIES

Tempering

- Objectives: Reduce brittleness, remove internal stresses, and increase toughness.
- Process: Reheat hardened steel below critical temperature and cool at a desired rate.
- Result: Tougher steel with improved resistance to shock and fatigue.

Non-ferrous Metals:

Non-ferrous metals are those that do not contain iron as their main element. They are widely used in engineering due to their ease of fabrication, resistance to corrosion, electrical and thermal conductivity, and light weight. Key non-ferrous metals include aluminum, copper, lead, tin, zinc, and nickel, each with specific applications and properties.

- **Aluminum**, a light metal with good electrical conductivity and corrosion resistance, is used in aircraft, automobiles, and cooking utensils. **Aluminum alloys** like Duralumin, Y-alloy, Magnalium, and Hindalium, improve the metal's strength and are used in aerospace and automotive industries.

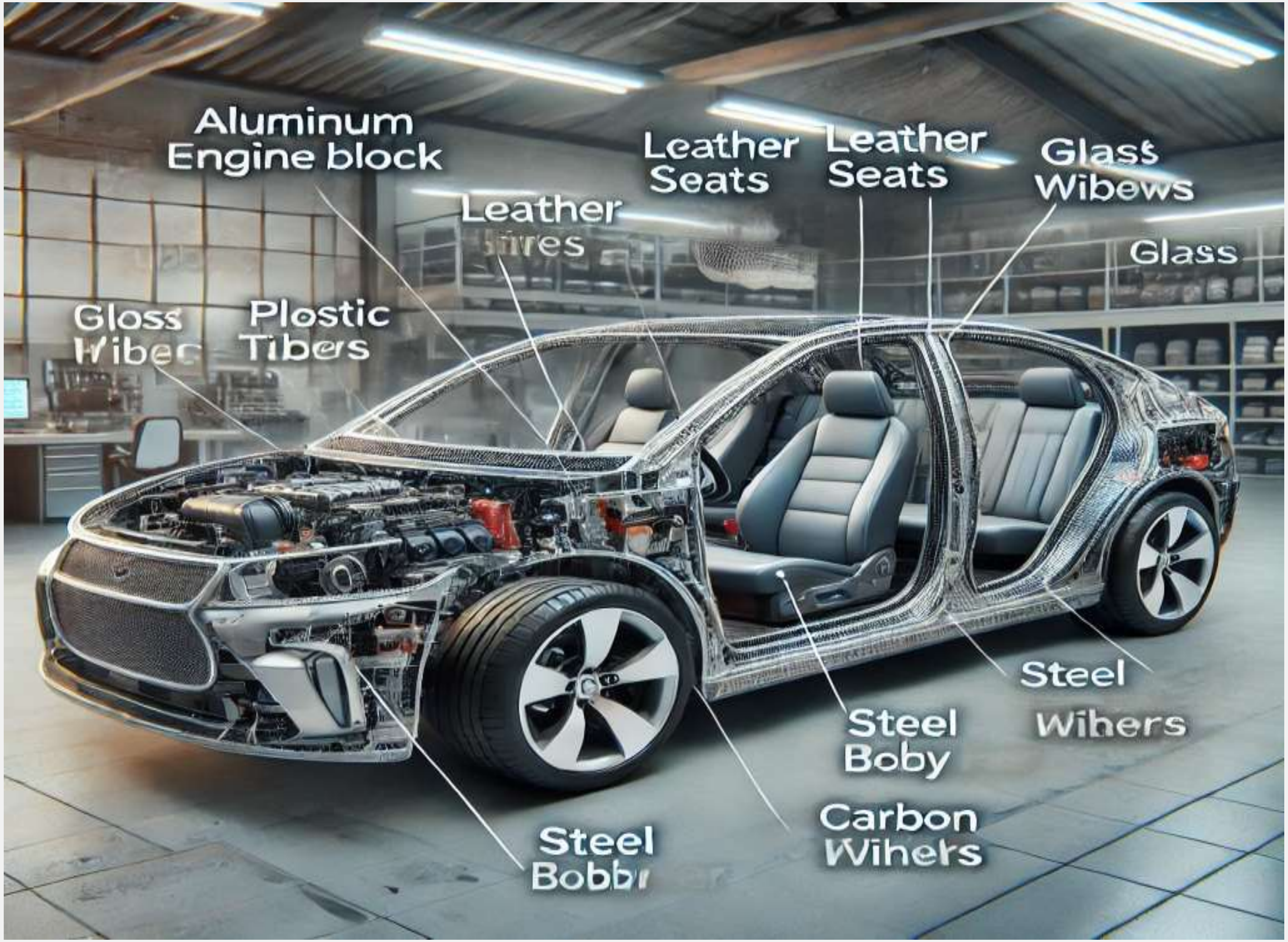
3. MATERIAL AND PROPERTIES

- **Copper**, known for its electrical conductivity, is used in electrical cables, coins, and household utensils. **Copper alloys** like brass (copper-zinc) and bronze (copper-tin) have varying compositions that provide different mechanical properties, corrosion resistance, and are used in marine applications, springs, and bearings.
- **Lead** and **tin** are soft metals used in solders, coatings, and bearings, while **zinc** is primarily used in die casting. **Nickel-based alloys** like Monel, Inconel, Nichrome, and Nimonic are valued for their strength and corrosion resistance, especially in high-temperature applications such as gas turbines and heating elements.

3. MATERIAL AND PROPERTIES

Indian standard designation	Composition in percentages	Uses
Cartridge brass	Copper = 70 Zinc = 30	It is a cold working brass used for cold rolled sheets, wire drawing, deep drawing, pressing and tube manufacture.
Yellow brass (Muntz metal)	Copper = 60 Zinc = 40	It is suitable for hot working by rolling, extrusion and stamping.
Leaded brass	Copper = 62.5 Zinc = 36 Lead = 1.5	These are used for plates, tubes, etc
Admiralty brass	Copper = 70 Zinc = 29 Tin = 1	
Naval brass	Copper = 59 Zinc = 40 Tin = 1	It is used for marine castings
Nickel brass (German silver or Nickel silver)	Copper = 60 – 45 Zinc = 35 – 20 Nickel = 5 – 35	It is used for valves, plumbing fittings, automobile fitting, type writer parts and musical instruments

3. MATERIAL AND PROPERTIES



MACHINE DESIGNING-I
ME 341
3 CREDITS
5TH SEM

By

Alma Arbe

Lecturer

University of Global Village (UGV)

COURSE INFORMATION

Total Marks 150

Attendance 10%

Quiz 10% (4 quizzes)

Assignment 10% (2 assignments)

Midterm Examination 30% (out of 45)

Final Examination 40% (out of 60)

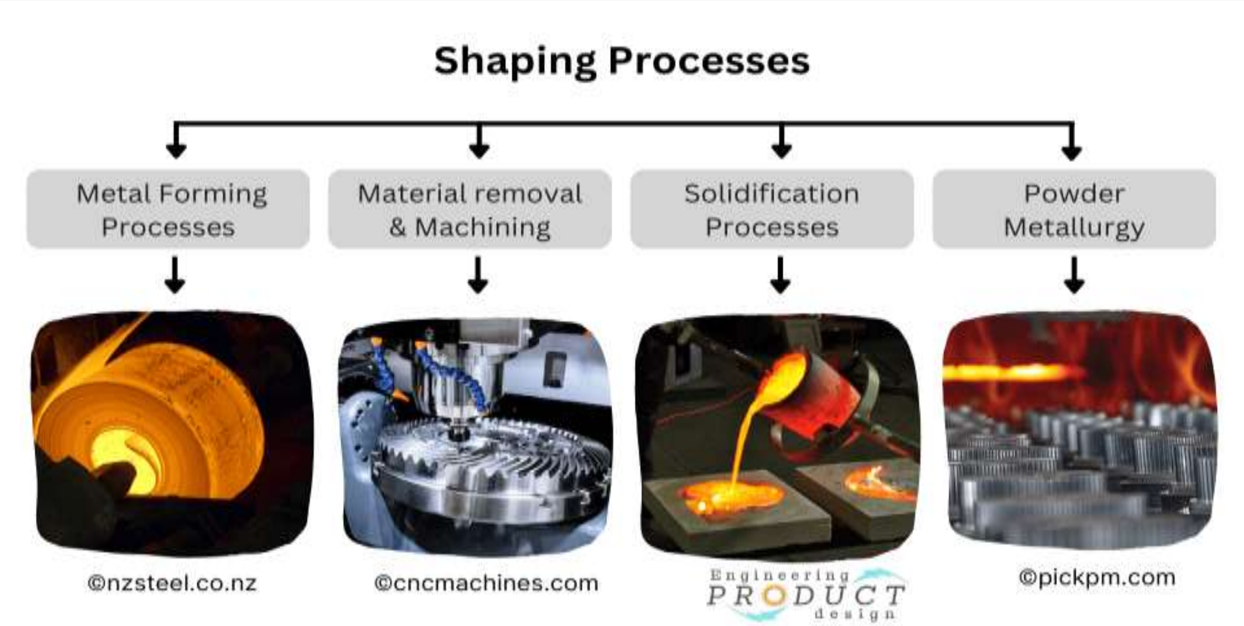
****Weekly 2 hours of classes**

CONTENT

4. MANUFACTURING PROCESSES

Manufacturing processes refer to the methods and techniques used to convert raw materials into finished goods or products. These processes vary depending on the type of product being manufactured, the materials used, and the desired production scale. Below is an overview of various manufacturing processes in mechanical engineering:

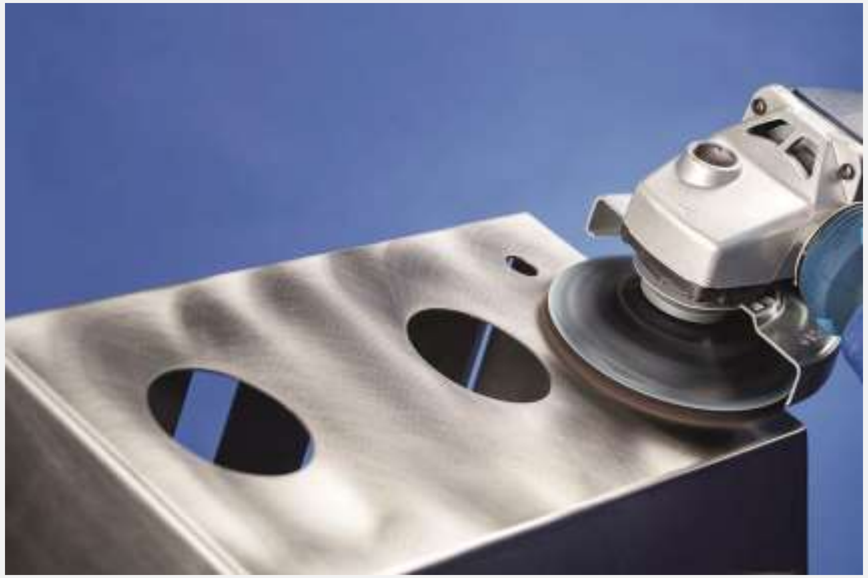
Primary Shaping Processes: These processes are utilized for the initial formation of machine components. Some of the common methods include casting, forging, extruding, rolling, drawing, bending, shearing, spinning, powder metal forming, and squeezing.



4. MANUFACTURING PROCESSES

Machining Processes: are used to finalize the shape of machine components, ensuring they meet the precise dimensions specified in the design. Common operations include turning, planning, shaping, drilling, boring, reaming, sawing, broaching, milling, grinding, and hobbing.

Surface Finishing Processes: These are employed to achieve a smooth and polished finish on machine components. Typical operations include polishing, buffing, honing, lapping, abrasive belt grinding, barrel tumbling, electroplating, superfinishing, and sheradizing.



4. MANUFACTURING PROCESSES

Joining Processes: These are used to assemble machine components together. Common methods include welding, riveting, soldering, brazing, screw fastening, pressing, and sintering.

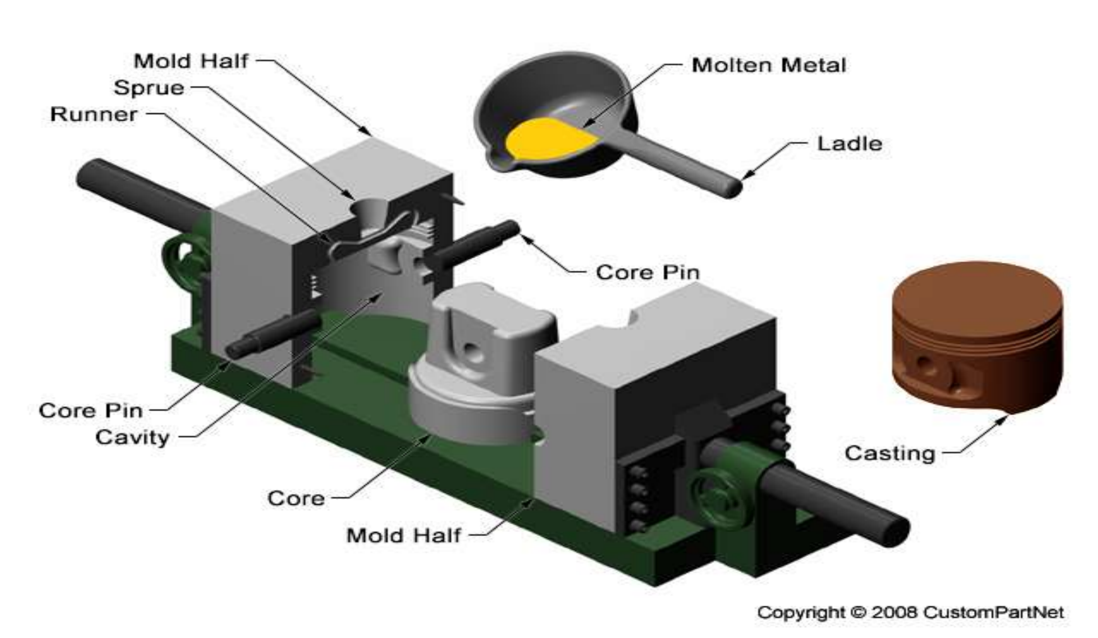
Processes Affecting Change in Properties: These processes are used to modify the properties of machine components to suit specific operational requirements. Examples include heat treatment, hot-working, cold-working, and shot peening.

4. MANUFACTURING PROCESSES

Below some important manufacturing processes and their types are discussed:

Casting: Casting is a fundamental manufacturing process in Mechanical Engineering. It involves melting ingots in a furnace, such as a cupola or other foundry furnace, and then pouring the molten metal into molds made of metal or sand. The main casting processes include:

a. Sand mould casting: This process involves pouring molten metal into a sand mold to produce castings. It is particularly suited for larger components. It is used because of its cost-effectiveness, flexibility in design, size capability, ease of adjustment and thermal properties.

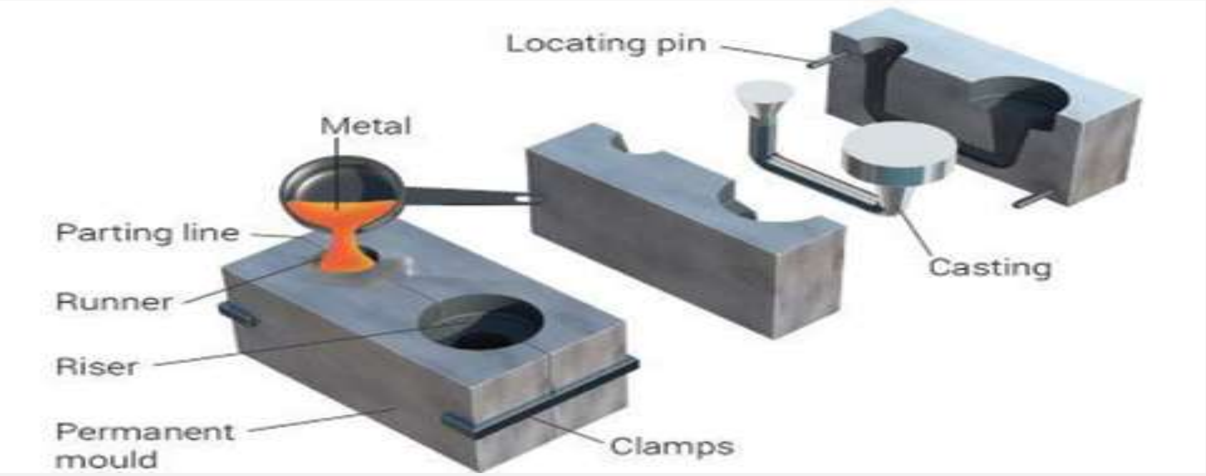


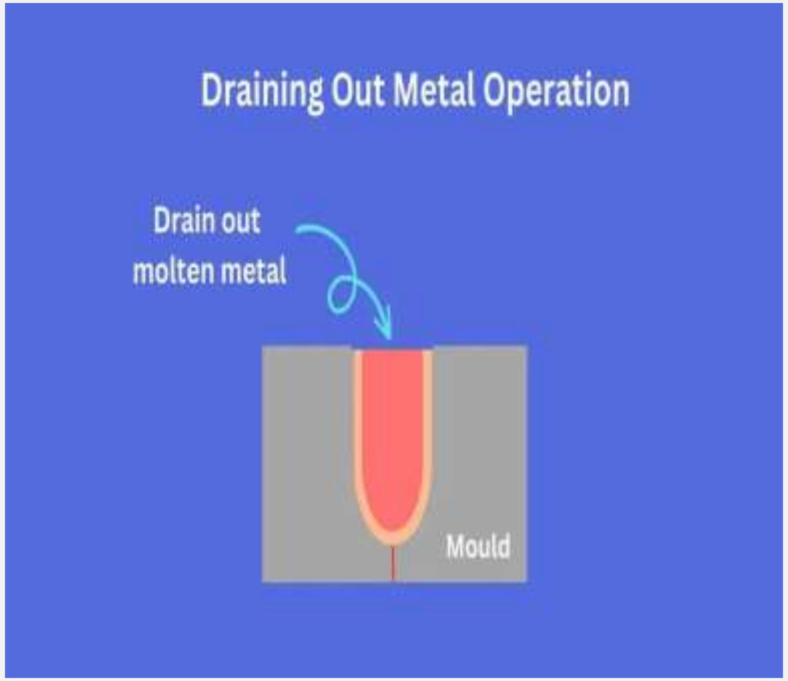
b. Permanent Mould Casting: Molten metal is poured into a reusable metallic mold. This technique is commonly used to cast aluminum pistons, parts of electric irons, cooking utensils, gears, and similar items. The advantages of permanent mold casting include:

- A more desirable fine-grained structure.
- The ability to achieve precise dimensions with close tolerances.
- The ease of casting holes as small as 6.35 mm in diameter using metal cores.

4. MANUFACTURING PROCESSES

c. Slush casting: It is a special form of permanent metal mould casting. This method is used for production of hollow castings without the use of cores.





d. Die Casting: It involves forcing molten metal into a permanent mold (die) under pressure. Used in automotive parts like fuel pumps and steering wheels.

Advantages

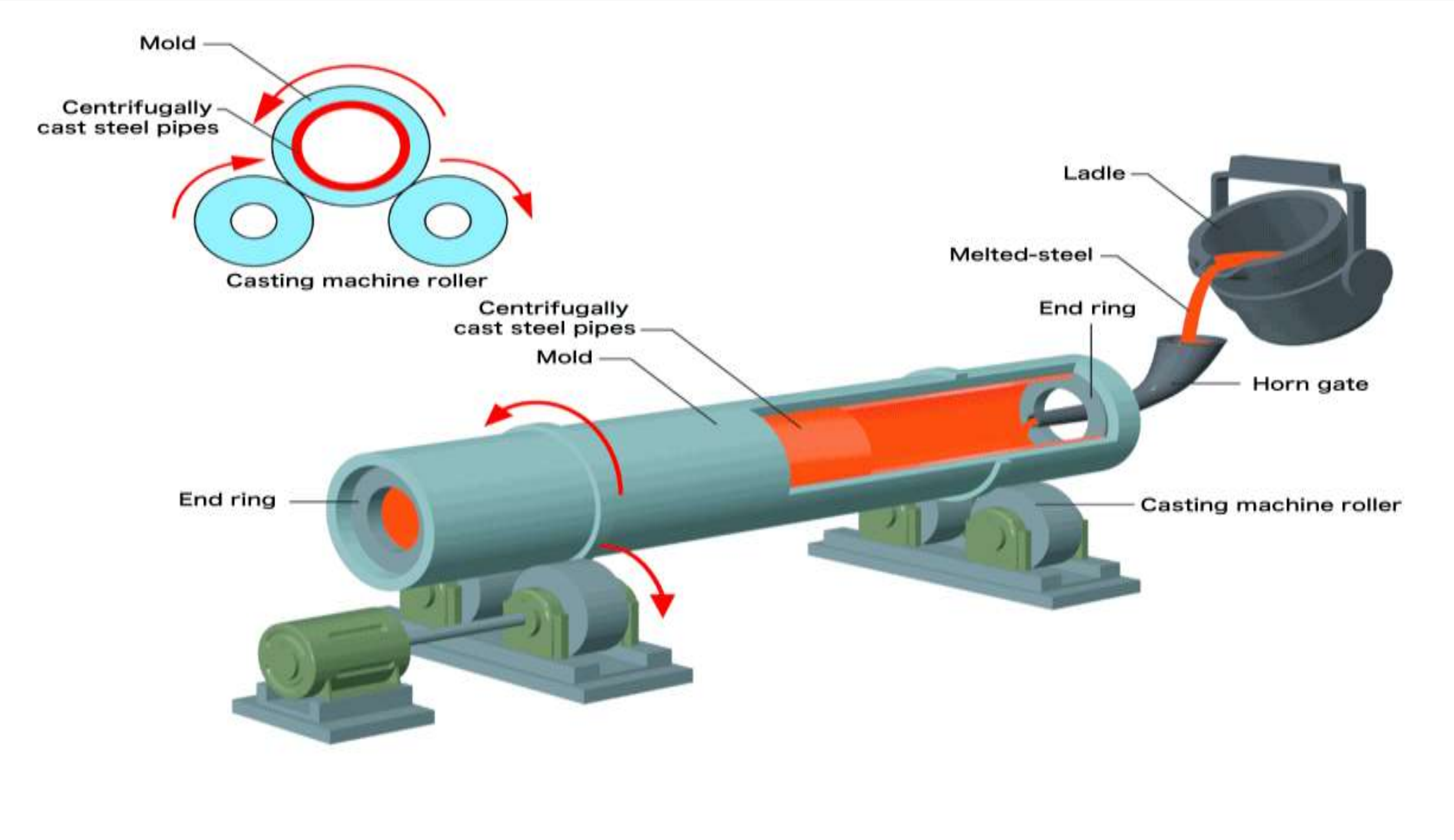
- High production rate (700 castings/hour) and long die life
- Excellent surface finish and precise dimensions.
- Requires less space and can produce thin, complex shapes.

Disadvantages

- High equipment costs.
- Most effective for non-ferrous alloys with low melting points
- Requires specialized maintenance skills.

4. MANUFACTURING PROCESSES

e. Centrifugal Casting: Centrifugal casting involves pouring molten metal into a rotating mold, which results in high-density castings with improved solidification. This process is used to produce items like pipes, cylinder liners, and bearings.



4. MANUFACTURING PROCESSES

What to consider when designing casting?

When designing a casting, key considerations include the casting's intended function, ensuring its soundness and strength, and simplifying production for ease of manufacturing. Additionally, safety measures and cost-effectiveness must be prioritized to achieve an efficient and economical production process. Therefore, a few rules should be kept in mind while designing:

1. **Avoid Sharp Corners:** Minimize sharp corners and excessive fillets to prevent stress concentrations.
2. **Uniform Thickness:** Ensure sections are of uniform thickness where possible; if variation is necessary, transition gradually.
3. **Smooth Transitions:** Avoid abrupt changes from thick to thin sections to prevent defects.
4. **Simplicity:** Design castings to be as simple as possible while maintaining a good appearance.
5. **Large Surfaces:** Avoid large flat surfaces, as achieving true surfaces can be challenging.
6. **Allowance for Contraction**: Include appropriate allowances in the pattern to account for contraction stresses.
7. **Curved Shapes:** Use curved shapes like pulley arms to improve contraction stress resistance.
8. **Limit Stiffeners:** Minimize the use of stiffening ribs and webs to avoid defects like hot tears and shrinkage.
9. **Pattern and Moulding Simplicity:** Design for easier pattern creation and simpler moulding processes.
10. **Core Support:** Ensure adequate support for cores within the mold.

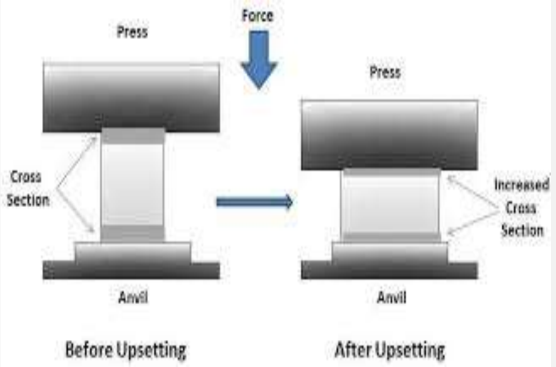
4. MANUFACTURING PROCESSES

11. **Avoid Deep Pockets:** Reduce deep, narrow pockets to lower cleaning costs.
12. **Limit Inserts:** Use metal inserts sparingly in the casting.
13. **Marking Placement:** Avoid placing markings on vertical surfaces to ease pattern withdrawal.
14. **Tolerances:** Apply a tolerance of ±1.6 mm for small castings (below 300 mm), or ±0.8 mm for greater accuracy.

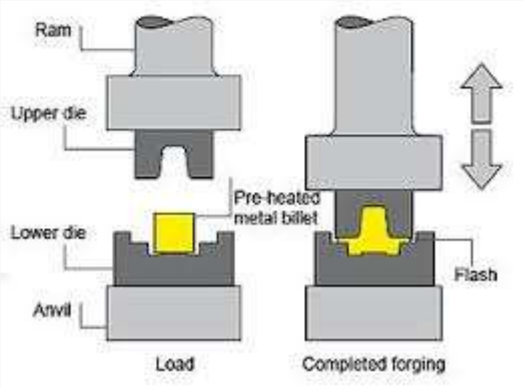
Forging: Metal forging is a manufacturing process where metal is shaped by applying compressive forces, typically using a hammer or a die. The process can be performed at various temperatures, depending on the material and the desired properties of the final product. The main types of forging are shown below:

Smith Forging or Hand Forging

Power Forging



Machine forging or upset forging



Drop forging

4. MANUFACTURING PROCESSES

The **advantages** of forging process:

1. It **refines** the structure of the metal.
2. It **renders** the **metal stronger** by setting the direction of grains.
3. It effects considerable **saving in time, labour and material** as compared to the production of a similar item by cutting from a solid stock and then shaping it.
4. The reasonable **degree of accuracy** may be obtained by forging.
5. The forgings may be **welded**.

Temperature Ranges for Forging metals and alloys

Material	Forging temperature (°C)	Material	Forging temperature (°C)
Wrought iron	900 – 1300	Stainless steel	940 – 1180
Mild steel	750 – 1300	Aluminium and magnesium alloys	350 – 500
Medium carbon steel	750 – 1250	Copper, brass and bronze	600 – 950
High carbon and alloy steel	800 – 1150		

4. MANUFACTURING PROCESSES

When designing a forging, consider the following guidelines:

1. Ensure the forged components achieve a radial grain or fiber flow.
2. For forgings with flash, such as drop and press forgings, position the parting line to divide the piece into two equal halves.
3. The parting line should ideally lie in a single plane.
4. Provide sufficient draft angles on surfaces to allow easy removal from the dies.
5. Avoid sharp corners to reduce stress concentrations and simplify the forging process.
6. Minimize pockets and recesses to reduce die wear.
7. Ribs should be designed to avoid being too high and thin.
8. Avoid overly thin sections to ensure easy metal flow.

4. MANUFACTURING PROCESSES

Mechanical Working of Metals: The mechanical working of metal is described as hot working and cold working depending upon whether the metal is worked above or below the recrystallisation temperature. The metal is subjected to mechanical working for the following purposes :

1. To reduce the original block or ingot into desired shapes, 2. To refine grain size, and 3. To control the direction of flow lines.

Types of metal working includes **Hot Working Processes** and **Cold Working Processes**. The short descriptions with categories are given below:

Hot Working Process: Hot working processes of metals refer to shaping and forming techniques conducted at temperatures above the recrystallization temperature of the metal. This ensures that the metal remains in a ductile and workable state, reducing the risk of fracturing while allowing significant deformation. This includes hot rolling, hot forging, hot piercing, hot drawing or cupping, hot spinning and hot extrusion.

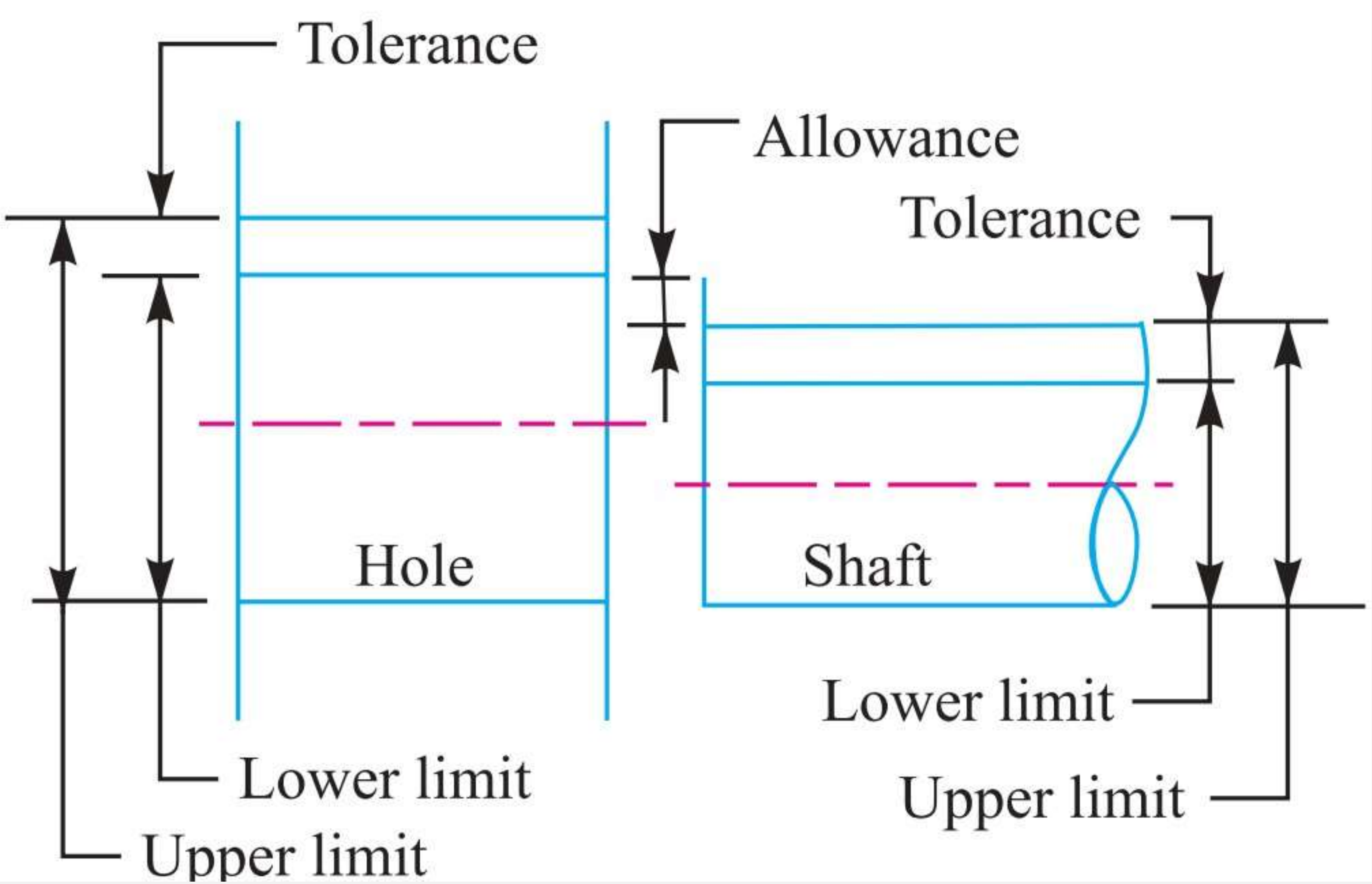
Cold Working Processes: Most of the cold working processes are performed at room temperature. The cold working distorts the grain structure and does not provide an appreciable reduction in size. It requires much higher pressures than hot working. The different types of cold working processes are cold rolling, cold forging, cold drawing, cold spinning, cold extrusion, cold bending and cold peening.

4. MANUFACTURING PROCESSES

Limit System: A limit system in manufacturing is a set of rules and guidelines used to control the dimensions of manufactured parts, ensuring that they fit together properly in an assembly. When an assembly is made of two parts, **enveloped surface** (or **shaft** for cylindrical part) is the part to be inserted and the other in which one enters is called **enveloping surface** (or **hole** for cylindrical part). The term shaft refers not only to the diameter of a circular shaft, but it is also used to designate any **external dimension** of a part. The term hole refers not only to the diameter of a circular hole, but it is also used to designate any **internal dimension** of a part.

Key Components of a Limit System:

1. **Normal or Basic Size:** The nominal size is the theoretical, exact size of a part as specified in the design. It serves as the reference dimension from which tolerances are applied.
2. **Limit of Sizes:** These are the maximum and minimum permissible dimensions that a part can have. The Upper Limit is the maximum allowed size, and the Lower Limit is the minimum allowed size.
3. **Allowance:** It is the difference between the basic dimensions of the mating parts. The allowance may be positive or negative.
4. **Tolerance**: It is the permissible amount of variation in a part's dimensions from its nominal size. It defines the upper and lower limits within which the actual dimension of the part must fall. The tolerance may be unilateral or bilateral.


Tolerance
Allowance
Tolerance
Hole
Shaft
Lower limit
Upper limit
Lower limit
Upper limit

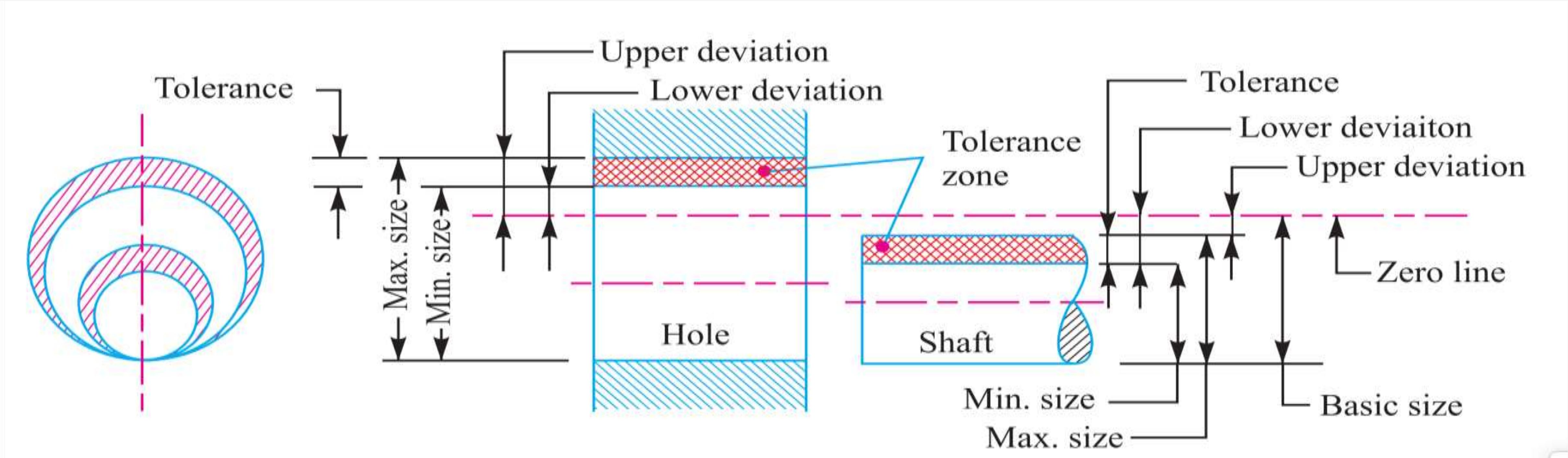
4. MANUFACTURING PROCESSES

(*a*) Unilateral tolerance. (*b*) Bilateral tolerance.

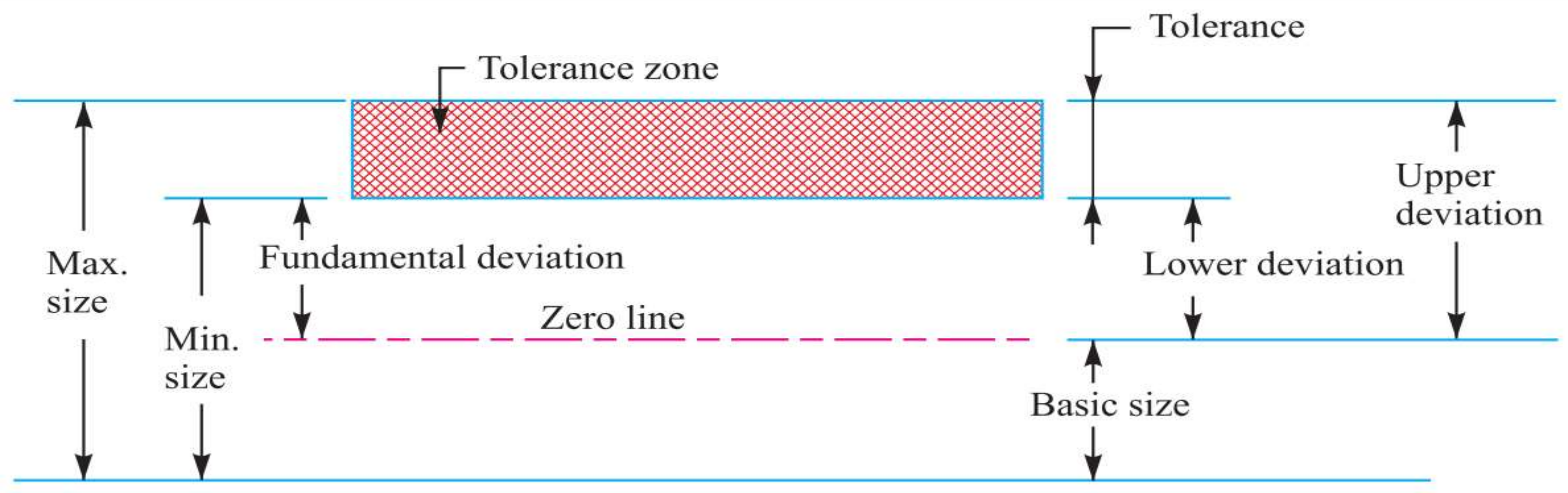
When all the tolerance is allowed on one side of the nominal size, e.g. $20^{+0.000}_{-0.004}$, , then it is said to be unilateral system of tolerance. The unilateral system is mostly used in industries as it permits changing the tolerance value while still retaining the same allowance or type of fit.

When the tolerance is allowed on both sides of the nominal size, *e.g.*$20^{+0.002}_{-0.002}$, then it is said to be ***bilateral system of tolerance.*** In this case + 0.002 is the upper limit and – 0.002 is the lower limit.

4. MANUFACTURING PROCESSES



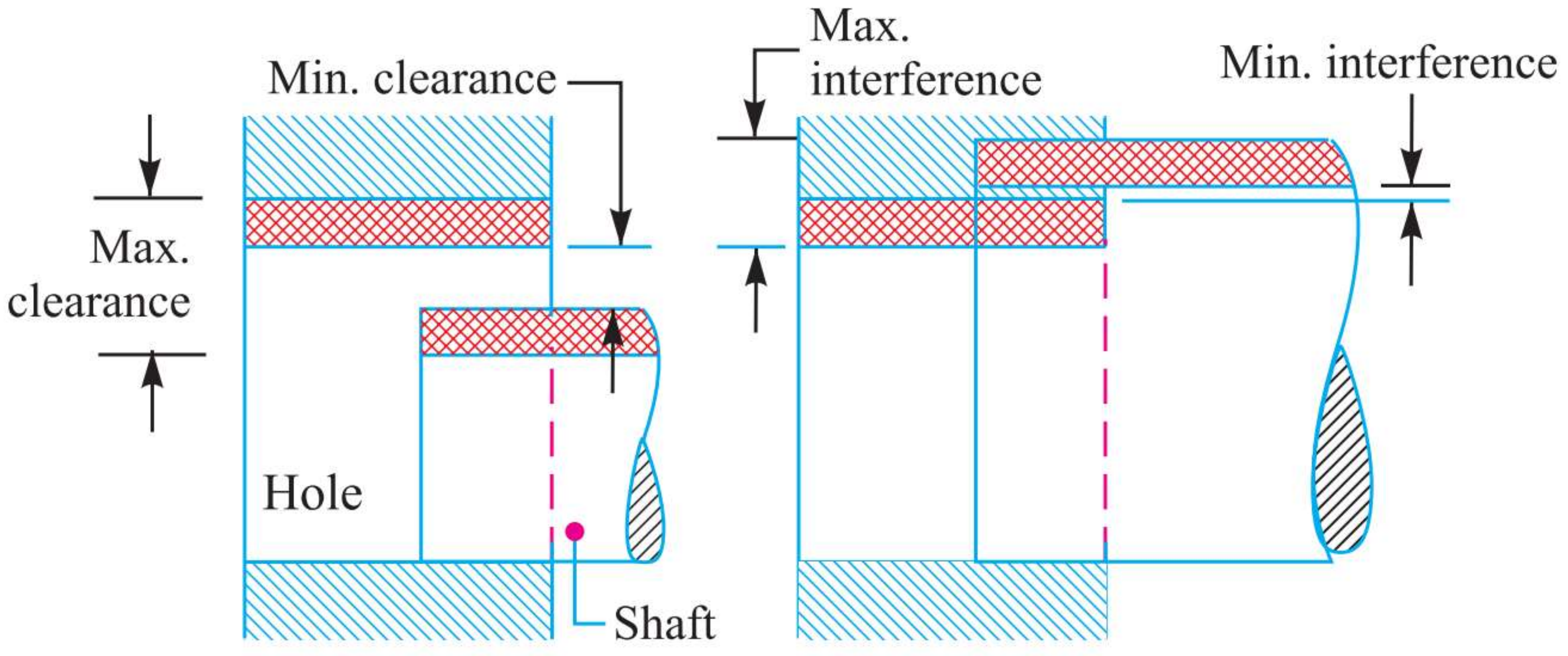
Upper deviation: The upper deviation of a hole is represented by a symbol ES (Ecart Superior) and of a shaft, it is represented by es.
Lower deviation: The lower deviation of a hole is represented by a symbol EI (Ecart Inferior) and of a shaft, it is represented by ei.
Mean deviation: It is the arithmetical mean between the upper and lower deviations.



Fundamental deviation: It is one of the two deviations which is conventionally chosen to define the position of the tolerance zone in relation to zero line

4. MANUFACTURING PROCESSES

Fit: It refers to the relationship between the dimensions of two mating parts, such as a hole and a shaft. The type of fit determines how tightly or loosely the parts will fit together.



(a) Clearance fit. (b) Interference fit. (c) Transition fit.

Clearance fit: the size of the hole is always larger than the size of the shaft, allowing free movement or sliding between the two parts. in a clearance fit, the tolerance zone of the hole is entirely above the tolerance zone of the shaft. the difference between the minimum size of the hole and the maximum size of the shaft is known as **minimum clearance** whereas the difference between the maximum size of the hole and minimum size of the shaft is called **maximum clearance.** Clearance fits are used in applications where **free movement** is required, such as in **bearings, bushings,** and **couplings**.

Example: A door hinge where the pin (shaft) needs to rotate freely within the hinge (hole).

Interference fit: The tolerance zone of the hole is entirely below the tolerance zone of the shaft that is he size of the shaft is larger than the size of the hole. Interference fits are used where a permanent, secure connection is needed, such as in **press-fit assemblies, gear hubs,** and **dowel pins**. The interference fits may be **shrink fit, heavy drive fit** and **light drive fit**. the difference between the maximum size of the hole and the minimum size of the shaft is known as **minimum interference**, whereas the difference between the minimum size of the hole and the maximum size of the shaft is called **maximum interference.**

Example: A metal bushing pressed into a housing, where the tight fit ensures no movement or play.

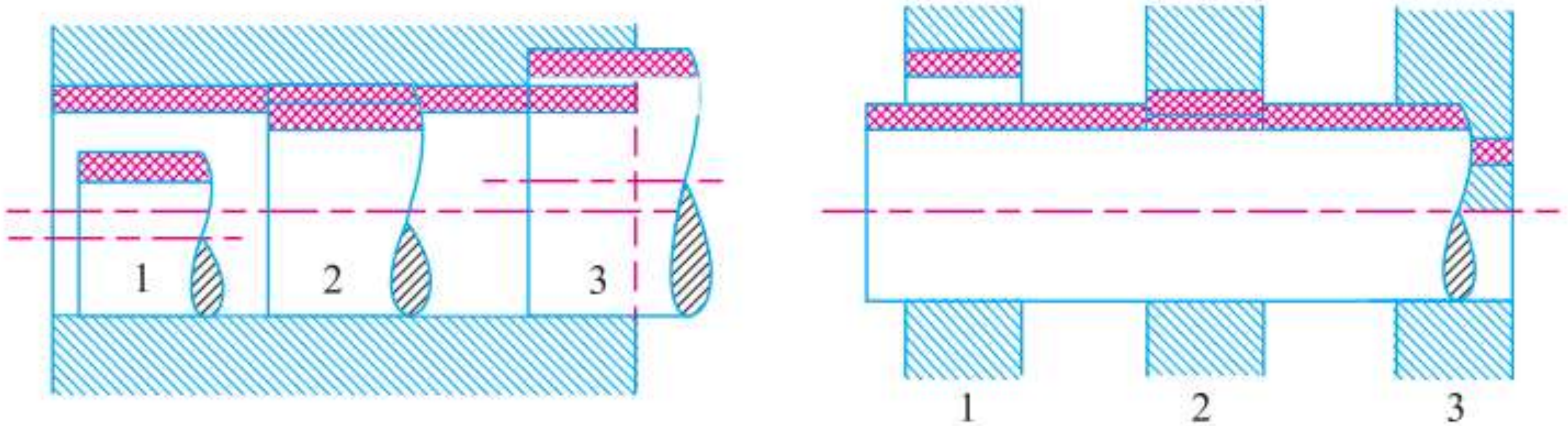
Transition Fit: The size limits for the mating parts are so selected that either a clearance or interference may occur depending upon the actual size of the mating parts. It may be noted that in a transition fit, the tolerance zones of hole and shaft overlap. The transition fits may be **force fit, tight fit** and **push fit**. Transition fits are used where precise alignment is important, and the parts must either have **minimal clearance** or **slight interference**, such as in **keyways, pulleys,** or **wheels on shafts**.

Example: A gear that needs to be mounted on a shaft with minimal play but still allows for removal if necessary.

The two bases of limit system

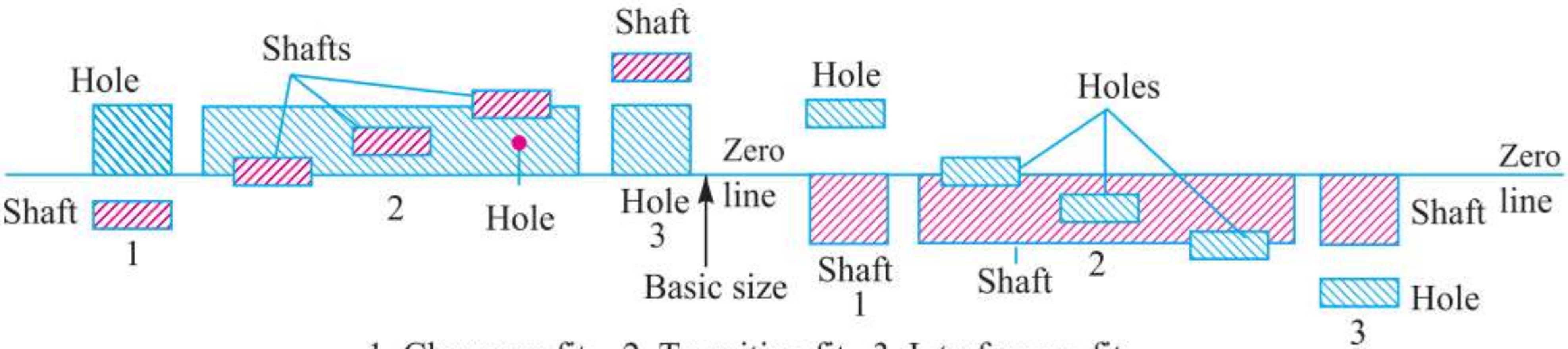
1. Hole basis system: When the hole is kept as a constant member (i.e. when the lower deviation of the hole is zero) and different fits are obtained by varying the shaft size, then the limit system is said to be on a hole basis.

2. Shaft basis system: When the shaft is kept as a constant member (i.e. when the upper deviation of the shaft is zero) and different fits are obtained by varying the hole size, then the limit system is said to be on a shaft basis.



1. Clearance fit. 2. Transition fit. 3. Interference fit.

(*a*) Hole basis system. (*b*) Shaft basis system.



1. Clearance fit. 2. Transition fit. 3. Interference fit.

(*a*) Hole basis system. (*b*) Shaft basis system.

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ME 341
3 CREDITS
5^{TH} SEM

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CONTENT

4. MANUFACTURING PROCESSES: BASIS OF LIMIT

The system of limits and fits comprises **18 grades of fundamental tolerances** i.e. grades of accuracy of manufacture and **25 types of fundamental deviations indicated by letter symbols for both holes and shafts** (capital letter A to ZC for holes and small letters a to Zc for shafts) in diameter steps ranging from 1 to 500 mm. A unilateral hole basis system is recommended but if necessary a unilateral or bilateral shaft basis system may also be used. The **18 tolerance** grades are designated **as IT 01, IT 0 and IT 1 to IT 16**. These are called standard tolerances.

The **standard tolerances for grades IT 5 to IT 7 are determined in terms of standard tolerance unit (i) in microns**, where

i (microns) = $\mathbf{0.45\sqrt[3]{D} + 0.001D}$**, where D is the size or geometric mean diameter in mm**

**** 1 micron = 0.001 mm**

Use following equations to obtain the standard tolerance unit of grades IT 01, IT 0 and IT 1

For IT 01, i (microns) = $0.3 + 0.008\,D$

For IT 0, i (microns) = $0.5 + 0.012\,D$

For IT 1, i (microns) = $0.8 + 0.020\,D$

4. MANUFACTURING PROCESSES: BASIS OF LIMIT

Note:

Tolerance grades, also known as **IT (International Tolerance) grades**, are standardized classifications that describe the permissible variation in dimensions for manufacturing processes.

Development of the IT Grades: The mathematical models were standardized into IT grades, where IT stands for "International Tolerance." Each grade represents a specific range of acceptable variation relative to the nominal dimension. The IT grades range from **IT01 (finest tolerance)** to **IT18 (coarsest tolerance)**.

Establishing Relative Magnitudes: The relative magnitude of each tolerance grade is calculated based on a formula that takes into account the nominal size of the part and a constant that varies depending on the IT grade. The general formula for determining the tolerance is:

$$\textit{\textbf{Tolerance}} = k \times \sqrt[3]{D} + C$$

D is the nominal size of the part.

k and C are constants that depend on the IT grade.

4. MANUFACTURING PROCESSES: BASIS OF LIMIT

Remember *H* stands for a dimension whose lower deviation refers to the basic size. The hole ***H*** for which the **lower deviation is zero** is called a ***basic hole***. Similarly, for shafts, ***h*** stands for a dimension whose upper deviation refers to the basic size. The shaft *h* for which the **upper deviation is zero** is called a ***basic shaft***.

How to read the numbers of holes and shafts?

100 H6/g5 means basic size is **100 mm** and the tolerance grade for the hole is 6 and for the shaft is 5. A fit is designated by its basic size followed by symbols representing the limits of each of its two components, the hole being quoted first.

How to calculate deviation?

The magnitude and sign for one of the two deviations (i.e. either upper or lower deviation), which is known as fundamental deviation, will be determined by means of formulae. The other deviation may be calculated by using the absolute value of the standard tolerance (IT) from the following relation:

$$ei = es - IT \quad \text{or} \quad es = ei + IT$$

It may be noted for shafts ***a*** to ***h***, the upper deviations (***es***) are considered positive whereas for shafts ***j*** to ***Zc***, the lower deviation (***ei***) is to be considered negative.

4. MANUFACTURING PROCESSES: BASIS OF LIMIT

Let us do some CALCULATIONS

Problem 4.1: The dimensions of the mating parts, according to basic hole system, are given as follows :

Hole : 25.00 mm & 25.02 mm **Shaft :** 24.97 mm & 24.95 mm

*Find the **hole tolerance**, **shaft tolerance** and **allowance**?*

(Remember the figure? Use it as a reference to solve)

Hole Tolerance = Upper limit of hole – Lower limit of hole = 25.02 – 25 = 0.02 mm

Shaft tolerance = Upper limit of shaft – Lower limit of shaft = 24.97 – 24.95 = 0.02 mm

Allowance = Lower limit of hole – Upper limit of shaft = 25.00 – 24.97 = 0.03 mm

4. MANUFACTURING PROCESSES: BASIS OF LIMIT

Problem 4.2: *Calculate the* ***tolerances, fundamental deviations*** *and* ***limits of sizes*** *for the* ***shaft*** *designated as* ***40 H8 / f7.***

Shaft designation = 40 H8 / f 7 which means that the basic size is 40 mm and the tolerance grade for the hole is 8 (i.e. I T 8) and for the shaft is 7 (i.e. I T 7).

First Calculate Tolerances:

Geometric mean diameter: $D = \sqrt{30 \times 50} = 38.73$ mm

Standard tolerance unit: $i = 0.45\sqrt[3]{D} + 0.001D$ = 1.56 microns = 1.56 × 0.001 = 0.001 56 mm (1 micron = 0.001 mm)

Standard tolerance for the hole of grade 8 (I T 8) = 25 i = 25 × 0.001 56 = 0.039 mm

Standard tolerance for the shaft of grade 7 (I T 7) = 16 i = 16 × 0.001 56 = 0.025 mm

Second Step is to calculate Fundamental Deviation:

We know that, fundamental deviation (lower deviation) for hole H is Zero, $\therefore$ ***EI* = 0**

Fundamental deviations for shaft f are

Upper deviation, es$= -5.5(D)^{0.41} = -\ 24.63\ or -\ 25\ microns = -\ 25\ \times\ 0.001\ = -\ 0.025\ mm$

Lower deviation, ei = $es - I\ T$ = – 0.025 – 0.025 = – 0.050 mm

4. MANUFACTURING PROCESSES: BASIS OF LIMIT

Third Step is to calculate Limits of sizes:

lower limit for hole = Basic size = 40 mm

Upper limit for hole = Lower limit for hole + Tolerance for hole = 40 + 0.039 = 40.039 mm

Upper limit for shaft = Lower limit for hole or Basic size – Fundamental deviation (Upper Deviation)

= 40-0.025=39.975 (Shaft *f* lies below the zero line)

Lower limit for shaft = Upper limit for shaft – Tolerance for shaft = 39.975 – 0.025 = 39.95 mm

Home Work:

1. Give the dimensions for the hole and shaft for the following:

   (a) A 12 mm electric motor sleeve bearing;

   (b) A medium force fit on a 200 mm shaft; and

   (c) A 50 mm sleeve bearing on the elevating mechanism of a road grader.

4. MANUFACTURING PROCESSES: BASIS OF LIMIT

2. A journal of nominal or basic size of 75 mm runs in a bearing with close running fit. Find the limits of shaft and bearing. What is the maximum and minimum clearance?
3. A medium force fit on a 75 mm shaft requires a hole tolerance and shaft tolerance each equal to 0.225 mm and average interference of 0.0375 mm. Find the hole and shaft dimensions.
4. Find the extreme diameters of shaft and hole for a transition fit H7/n6, if the nominal or basic diameter is 12 mm. What is the value of clearance and interference?
5. A gear has to be shrunk on a shaft of basic size 120 mm. An interference fit $H7/u6$ is being selected. Determine the minimum and maximum diameter of the shaft and interference.

MACHINE DESIGNING-1
ME 341
3 CREDITS
5^{TH} SEM

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CONTENT

5. LOAD AND STRESS ANALYSIS

In mechanical engineering, surface roughness plays a critical role in determining the quality of a component's surface finish. The **Centre Line Average (CLA)** method and the **Root Mean Square (RMS)** method are commonly used techniques for quantifying surface roughness.

Centre Line Average (CLA) Method: Also known as Arithmetic Average (Ra), this method measures the average deviation of surface roughness from the mean line (centerline). This method gives a straightforward average of roughness but doesn't account for extreme variations, making it less sensitive to outliers.

$$Ra = \frac{1}{L}\int_0^L |y(x)|\,dx$$

Root Mean Square (RMS) Method: This method measures the root mean square value of the deviations from the centerline. RMS provides a higher emphasis on larger deviations (peaks and valleys) compared to CLA.

$$Rq = \sqrt{\frac{1}{L}\int_0^L y^2(x)\,dx}$$

- L is the sampling length,
- y(x) is the vertical deviation of the surface profile from the centerline/mean line.

Example: Surface Profile Data

Let's assume we have the following surface roughness deviations (in micrometers, μm) from the mean line of a machined surface measured over a sampling length of **5 mm**: **{−4,2,−3,5,−1}** (μm)

Centre Line Average (CLA) Method (Ra):

Surface profile deviations: {-4, 2, -3, 5, -1}

Absolute values: {4, 2, 3, 5, 1}

Using the formula for Ra:

$$Ra = \frac{1}{N}\sum_{i=1}^{N}|y_i|$$

Where N is the number of data points and y_i is each deviation.

$$\boldsymbol{Ra = \frac{1}{5}(4+2+3+5+1) = \frac{15}{5} = 3\ \mu m}$$

Root Mean Square (RMS) Method (Rq):

The RMS method squares the deviations, averages them, and takes the square root.

Using the same surface profile deviations: {-4, 2, -3, 5, -1}

First, square each deviation: squared values: {16,4,9,25,1}

Using the formula for **Rq**:

$$Rq = \sqrt{\frac{1}{N}\sum_{i=1}^{N} y_i^2}$$

$$Rq = \sqrt{\frac{1}{5}(16 + 4 + 9 + 25 + 1)} = \sqrt{\frac{55}{5}} = \sqrt{11} = 3.32\ \mu m$$

➡ In real-world applications, you would use these methods to analyze whether a surface meets the required roughness specifications, as surface finish can impact factors like wear resistance, friction, and fatigue life of mechanical components.

5. LOAD AND STRESS ANALYSIS

Homework
Find 5 examples for each and bring to next class.

What do you mean by load? What are the types that comes to your mind?

It is defined as **any external force acting upon a machine part.** Some common loads are:

- ***Dead or steady load:*** A load is said to be a dead or steady load, when it does not change in magnitude or direction.
- ***Live or variable load:*** A load is said to be a live or variable load, when it changes continually.
- ***Suddenly applied or shock loads:*** A load is said to be a suddenly applied or shock load, when it is suddenly applied or removed.
- ***Impact load:*** A load is said to be an impact load, when it is applied with some initial velocity.

Stress: The internal force per unit area at any section of the body resisting any external force is known as unit stress or simply a stress. It is denoted by a Greek letter sigma (σ). Mathematically,

Stress, $\sigma = P/A$

P = Force or load acting on a body, and **A** = Cross-sectional area of the body.

In S.I. units, the stress is usually expressed in Pascal (Pa) such that 1 Pa = 1 N/m^2. In actual practice, we use bigger units of stress i.e. megapascal (MPa) and gigapascal (GPa), such that

1 MPa = 1 × 10^6 N/m^2 = 1 N/mm^2 and 1 GPa = 1 × 10^9 N/m^2 = 1 kN/mm

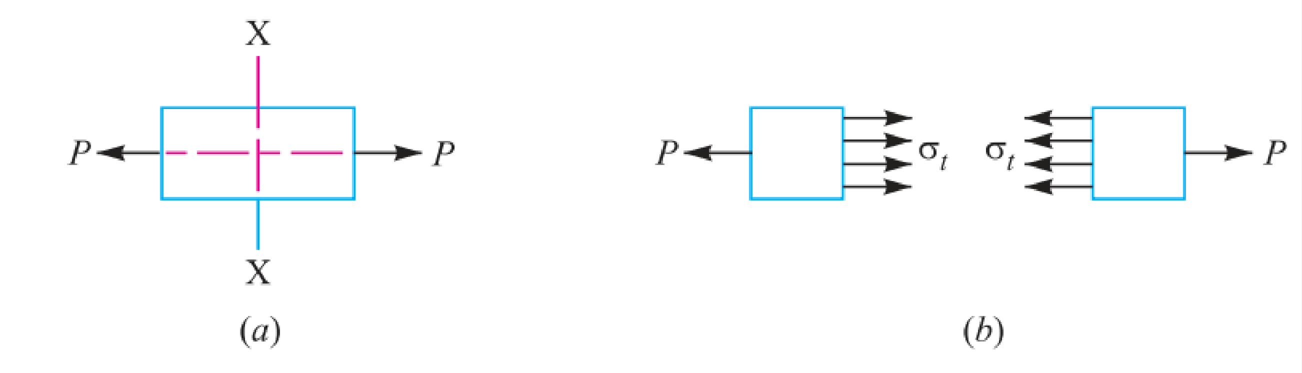
5. LOAD AND STRESS ANALYSIS

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

Strain, $\varepsilon = \delta l / l$ **or** $\delta l = \varepsilon . l$

Where, **δl** = Change in length of the body, and **l** = Original length of the body.

Tensile Stress and Strain:

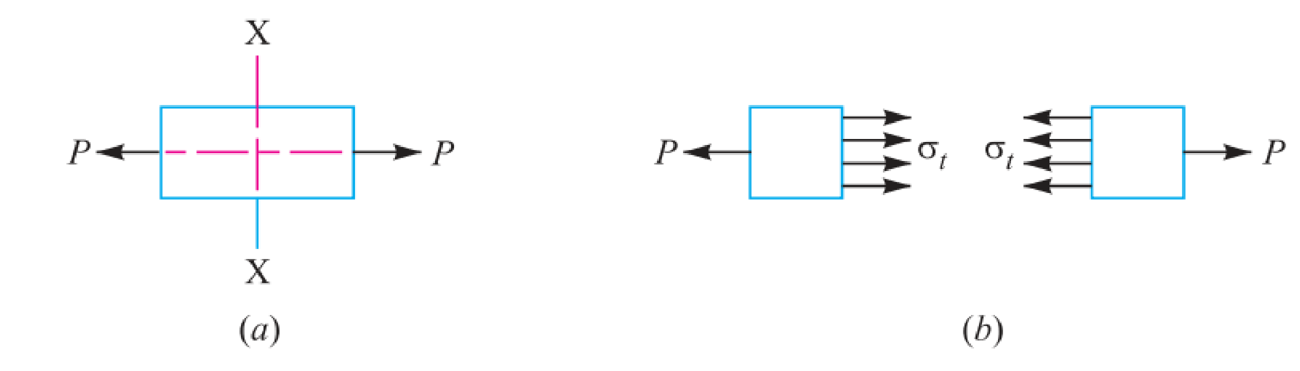


When a body is subjected to two equal and opposite axial pulls *P* (also called tensile load) as shown in Fig.(*a*), then the stress induced at any section of the body is known as ***tensile stress*** as shown in Fig. (*b*). A little consideration will show that due to the tensile load, there will be a decrease in cross-sectional area and an increase in length of the body. The ratio of the increase in length to the original length is known as ***tensile strain.***

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

Strain, $\varepsilon = \delta l / l$ **or** $\delta l = \varepsilon . l$

Where, **δl** = Change in length of the body, and **l** = Original length of the body.

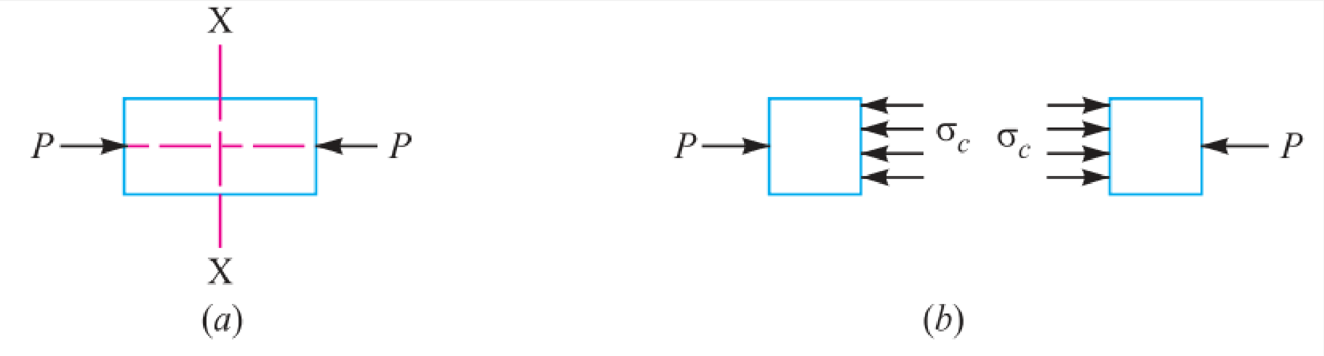


Tensile Stress and Strain:

Two equal and opposite axial pulls *P* is called tensile load in Fig.(*a*), acting at any section of the body is known as ***tensile stress*** as shown in Fig. (*b*). It shows that the cross sectional area decreases and length increases the ratio of the increase in length to the original length is known as ***tensile strain*.**

Tensile stress, $\sigma_t = P/A$ **and** **tensile strain,** $\varepsilon_t = \delta l / l$

P = Axial tensile force acting on the body, **A** = Cross-sectional area of the body,
l = Original length, and **δl** = Increase in length.



Compressive Stress and Strain: When a body is subjected to two equal and opposite axial pushes *P* (compressive load) as shown in (*a*), then the stress induced at any section of the body is known as ***compressive stress*** as shown in (*b*). Due to the compressive load, there will be an increase in cross-sectional area and a decrease in length of the body. The ratio of the decrease in length to the original length is known as ***compressive strain.***

Compressive stress, $\boldsymbol{\sigma_c = P/A}$ and **compressive strain,** $\boldsymbol{\varepsilon_c = \delta l/l}$

P = Axial compressive force acting on the body, A = Cross-sectional area of the body,

l = Original length, and **δl** = Decrease in length.

Note : In case of tension or compression, the area involved is at right angles to the external force applied

5. LOAD AND STRESS ANALYSIS

Young's Modulus or Modulus of Elasticity: Hooke's law states that when a material is loaded within elastic limit, the stress is directly proportional to strain, i.e.

$$\sigma \propto \varepsilon \qquad \text{or} \qquad \sigma = E.\varepsilon$$

$$E = \frac{\sigma}{\varepsilon} = \frac{P \times l}{A \times \delta l}$$

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/m^2 or kN/mm^2. It may be noted that Hooke's law holds good for tension as well as compression.

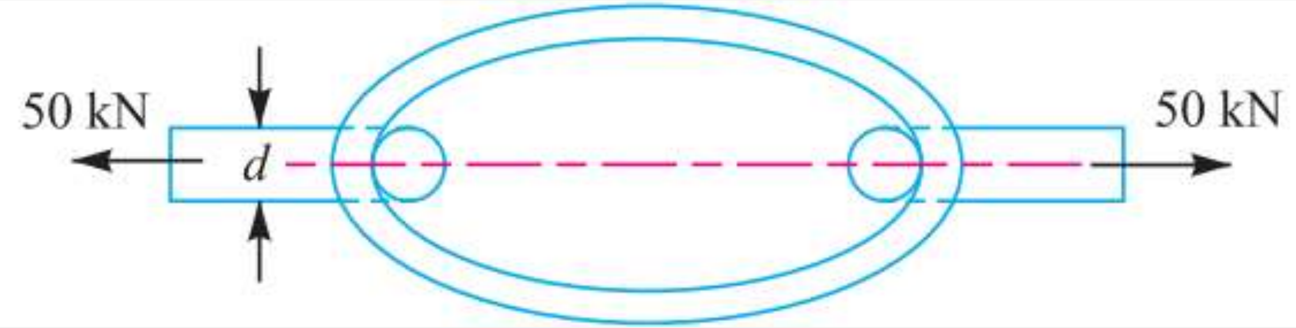
Values of E for the commonly used engineering materials

Material	*Modulus of elasticity (E) in GPa i.e. GN/m² or kN/mm²*
Steel and Nickel	200 to 220
Wrought iron	190 to 200
Cast iron	100 to 160
Copper	90 to 110
Brass	80 to 90
Aluminium	60 to 80
Timber	10

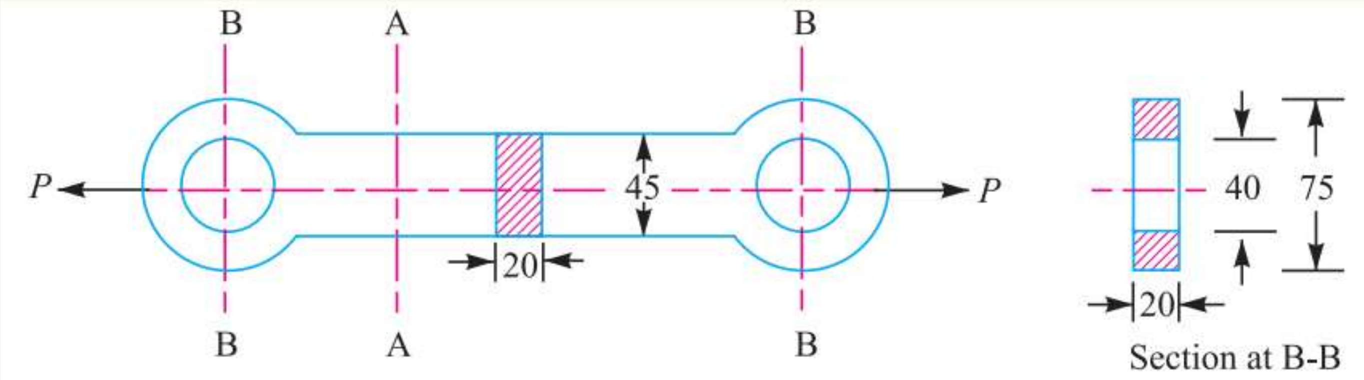
5. LOAD AND STRESS ANALYSIS

Solve the following math problems:

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



2. *A cast iron link, as shown in Fig. 4.4, is required to transmit a steady tensile load of 45 kN. Find the tensile stress induced in the link material at sections A-A and B-B.*

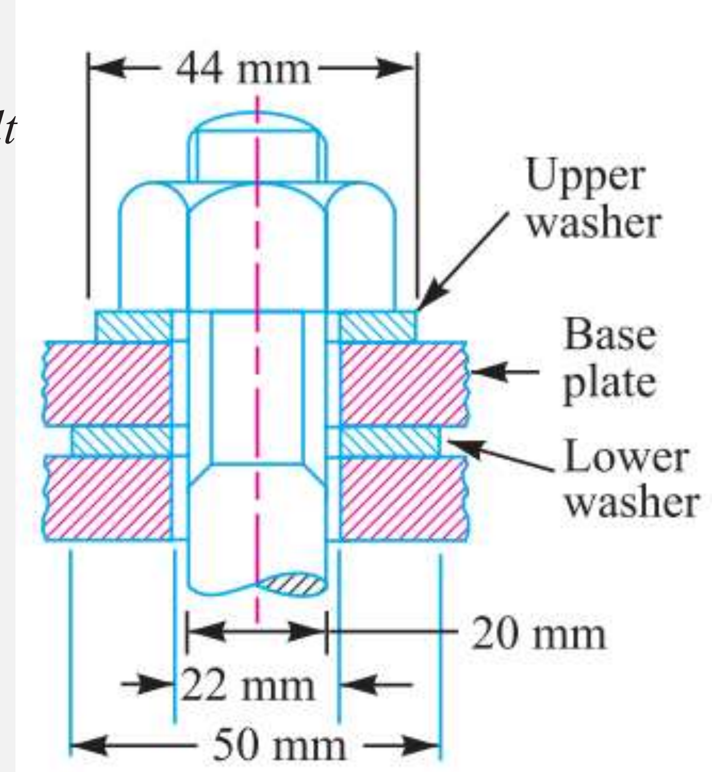


5. LOAD AND STRESS ANALYSIS

3. *A hydraulic press exerts a total load of 3.5 MN. This load is carried by two steel rods, supporting the upper head of the press. If the safe stress is 85 MPa and E = 210 kN/mm^2, find : 1. diameter of the rods, and 2. extension in each rod in a length of 2.5 m.*

4. *A rectangular base plate is fixed at each of its four corners by a 20 mm diameter bolt and nut as shown in the figure. The plate rests on washers of 22 mm internal diameter and 50 mm external diameter. Copper washers which are placed between the nut and the plate are of 22 mm internal diameter and 44 mm external diameter.*

If the base plate carries a load of 120 kN (including self-weight, which is equally distributed on the four corners), calculate the stress on the lower washers before the nuts are tightened. What could be the stress in the upper and lower washers, when the nuts are tightened so as to produce a tension of 5 kN on each bolt?

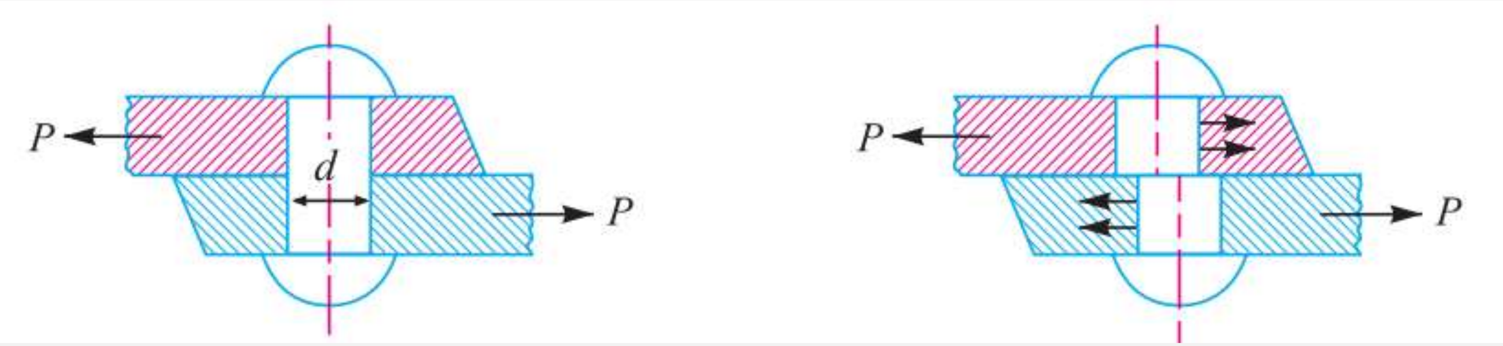


5. *The piston rod of a steam engine is 50 mm in diameter and 600 mm long. The diameter of the piston is 400 mm and the maximum steam pressure is 0.9 N/mm^2. Find the compression of the piston rod if the Young's modulus for the material of the piston rod is 210 kN/mm^2.*

5. LOAD AND STRESS ANALYSIS

Shear Stress: When two equal and opposite forces acts tangentially upon a resisting body resulting it to shear off or torn apart is shown as shear stress and the strain occurring due to shear stress is known as shear strain. Shear stress is known by tau (τ) and shear strain is known by phi (ϕ)

Shear stress, τ = $\frac{\textbf{Tangential Force}}{\textbf{Resisting Area}}$



If the tangential force is resisted by one cross-section of the rivet (or when shearing takes place at one cross-section of the rivet), then the rivets are said to be in ***single shear.*** In single shear area resisting the shear off the rivet is

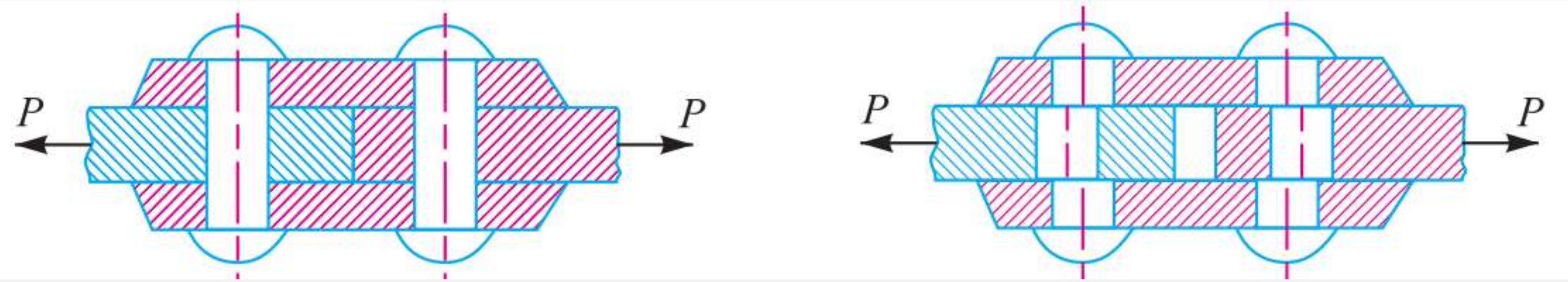
$$A = \frac{\pi}{4} \times d^2$$

Single Shear Stress on the rivet cross section, $\tau = \frac{P}{A} = \frac{P}{\frac{\pi}{4} \times d^2} = \frac{4P}{\pi d^2}$

5. LOAD AND STRESS ANALYSIS

If the tangential force P tends to shear off the rivet at two cross sections then 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 in ***double shear***. Then the area resisting the shear off the rivet is

$$A = \frac{2\pi d^2}{4}$$



Double Shear Stress on the rivet cross section, $\tau = \frac{P}{A} = \frac{P}{\frac{2\pi}{4}\times d^2} = \frac{2P}{\pi d^2}$

5. LOAD AND STRESS ANALYSIS

Notes : 1. All lap joints and single cover butt joints are in single shear, while the butt joints with double cover plates 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 the operations must overcome the ultimate shearing resistance of the material to be cut. If a hole of diameter *'d'* is to be punched in a metal plate of thickness *'t'*, then the area to be sheared, $\boldsymbol{A = \pi d \times t}$

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

$$\boldsymbol{P = A \times \tau_u = \pi d \times t \times \tau_u}$$

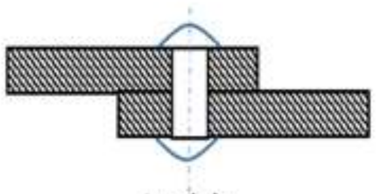
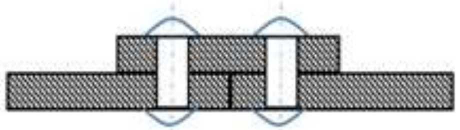
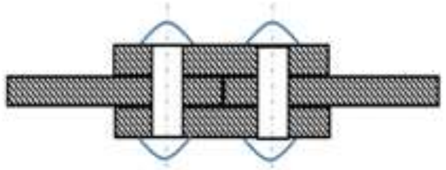
where τ_u = Ultimate shear strength of the material of the plate

Within the elastic limit, the shear stress is directly proportional to shear strain,

$$\boldsymbol{\tau \propto \phi} \quad \textbf{or} \quad \boldsymbol{\tau = C \,.\, \phi} \quad \textbf{or} \quad \boldsymbol{\frac{\tau}{\phi} = C}$$

Where, C = Constant of proportionality, known as ***shear modulus or modulus of rigidity***. It is also denoted by N or G

5. LOAD AND STRESS ANALYSIS

Sr.no.	Lap joint	Butt joint
1)	Two plates are parallel to each.	Two plates are inline and third strap is parallel to both plate.
2)	Plates connected by overlapping each other.	Two plates are connected by overlapping third strap.
3)	Plates are directly riveted to each other.	Third strap plate is use to connect two plates.
4)	It has only one type but riveted lines may be increase.	It has two types as single strap and double strap as riveted lines may be increase.
5)	 Lap joint	 Single strap butt joint  Double strap butt joint

Values of *C* for commonly used materials

Material	*Modulus of rigidity (C) in GPa i.e. GN/m^2 or kN/mm^2*
Steel	80 to 100
Wrought iron	80 to 90
Cast iron	40 to 50
Copper	30 to 50
Brass	30 to 50
Timber	10

5. LOAD AND STRESS ANALYSIS

Bearing Stress/ Crushing Stress: It is a localised compressive stress at the surface of contact between two members of a machine part, that are relatively at rest. The bearing stress is taken into account in the design of riveted joints, cotter joints, knuckle joints, etc. If such bearing stress id subjected to load *P* then,

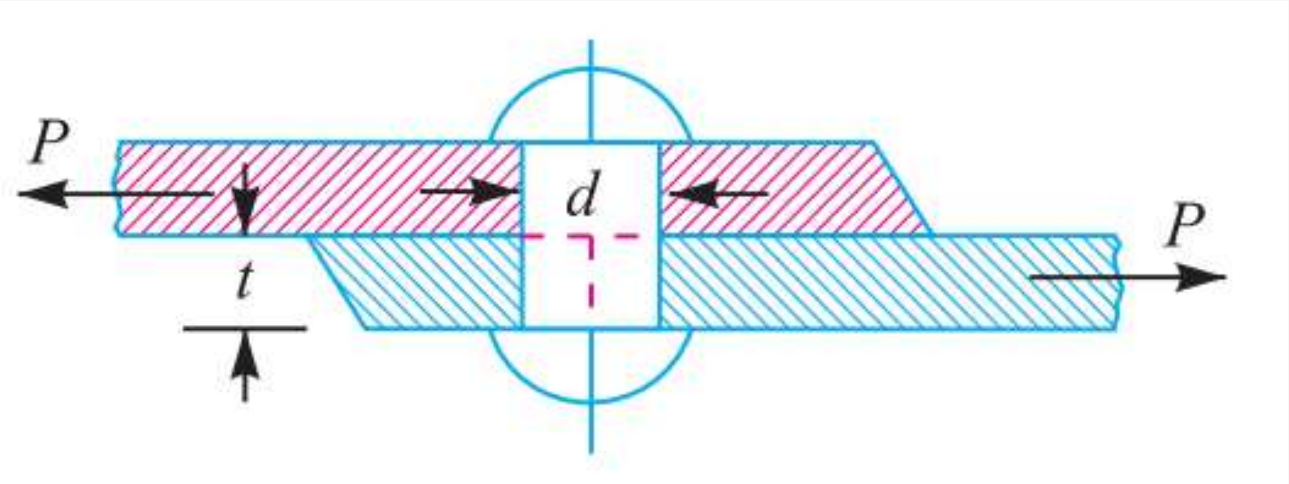
$$\sigma_b \,(or\ \sigma_c) = \frac{P}{d\,.\,t\,.\,n}$$

Where , d = Diameter of the rivet,

t = Thickness of the plate,

d.t = Projected area of the rivet, and

n = Number of rivets per pitch length in bearing or crushing



5. LOAD AND STRESS ANALYSIS

Bearing Pressure: The local compression which exists at the surface of contact between two members of a machine part that are in relative motion, is called bearing pressure. Used in the design of a journal supported in a bearing, pins for levers, crank pins, clutch lining, etc.

A journal rotating in a fixed bearing as shown in Fig. (*a*). The journal exerts a bearing pressure on the curved surfaces of the brasses immediately below it. The distribution of this bearing pressure will not be uniform, but it will be in accordance with the shape of the surfaces in contact and deformation characteristics of the two materials. The distribution of bearing pressure is shown in Fig. (b). Since the actual bearing pressure is difficult to determine, therefore the average bearing pressure is

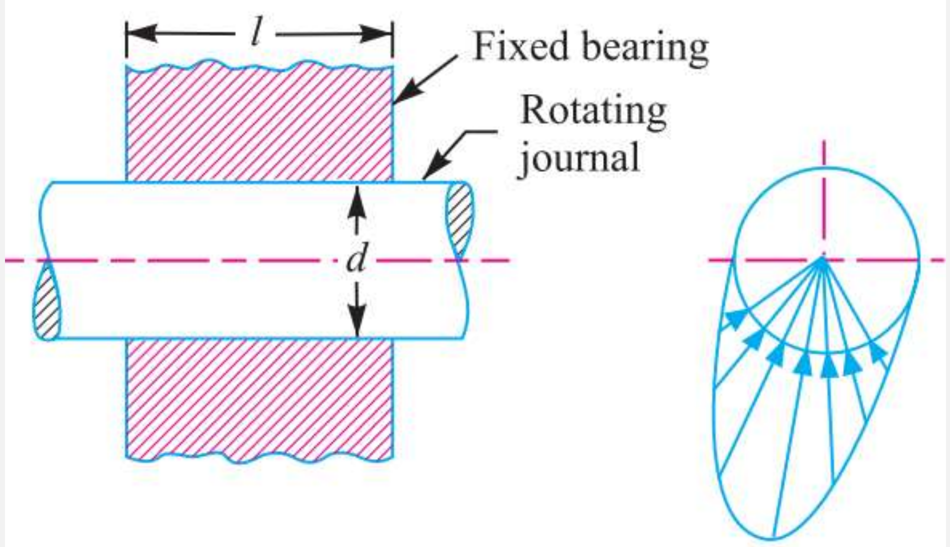
$$P_b = \frac{P}{l\,.d}$$

where P_b = Average bearing pressure,

P = Radial load on the journal,

l = Length of the journal in contact, and

d = Diameter of the journal.



(*a*) Journal supported in a bearing.

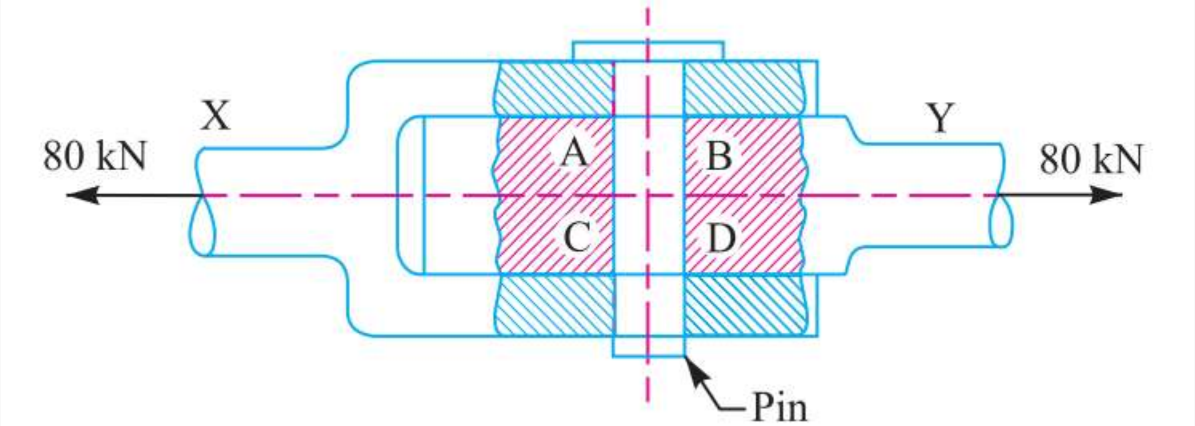
(*b*) Distribution of bearing pressure.

5. LOAD AND STRESS ANALYSIS

Solve the following math problems:

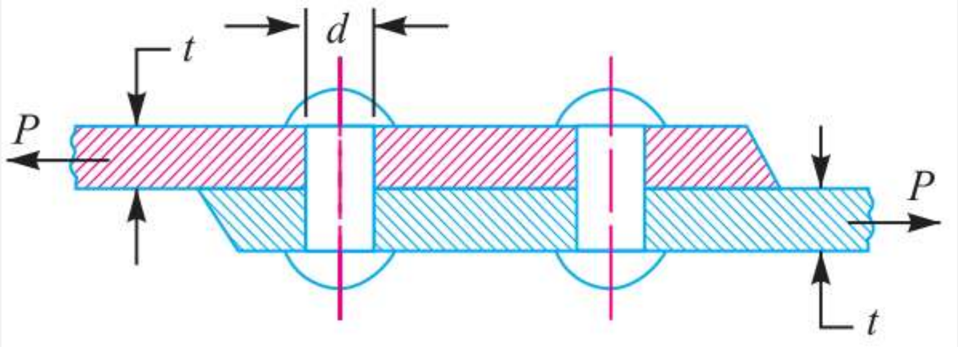
6. Calculate the force required to punch a circular blank of 60 mm diameter in a plate of 5 mm thick. The ultimate shear stress of the plate is 350 N/mm^2.

7. A pull of 80 kN is transmitted from a bar X to the bar Y through a pin as shown below. If the maximum permissible tensile stress in the bars is 100 N/mm^2 and the permissible shear stress in the pin is 80 N/mm^2, find the diameter of bars and of the pin.



5. LOAD AND STRESS ANALYSIS

8. Two plates 16 mm thick are joined by a double riveted lap joint as shown below. The rivets are 25 mm in diameter. Find the crushing stress induced between the plates and the rivet, if the maximum tensile load on the joint is 48 kN.



9. A journal 25 mm in diameter supported in sliding bearings has a maximum end reaction of 2500 N. Assuming an allowable bearing pressure of 5 N/mm^2, find the length of the sliding bearing.

5. LOAD AND STRESS ANALYSIS

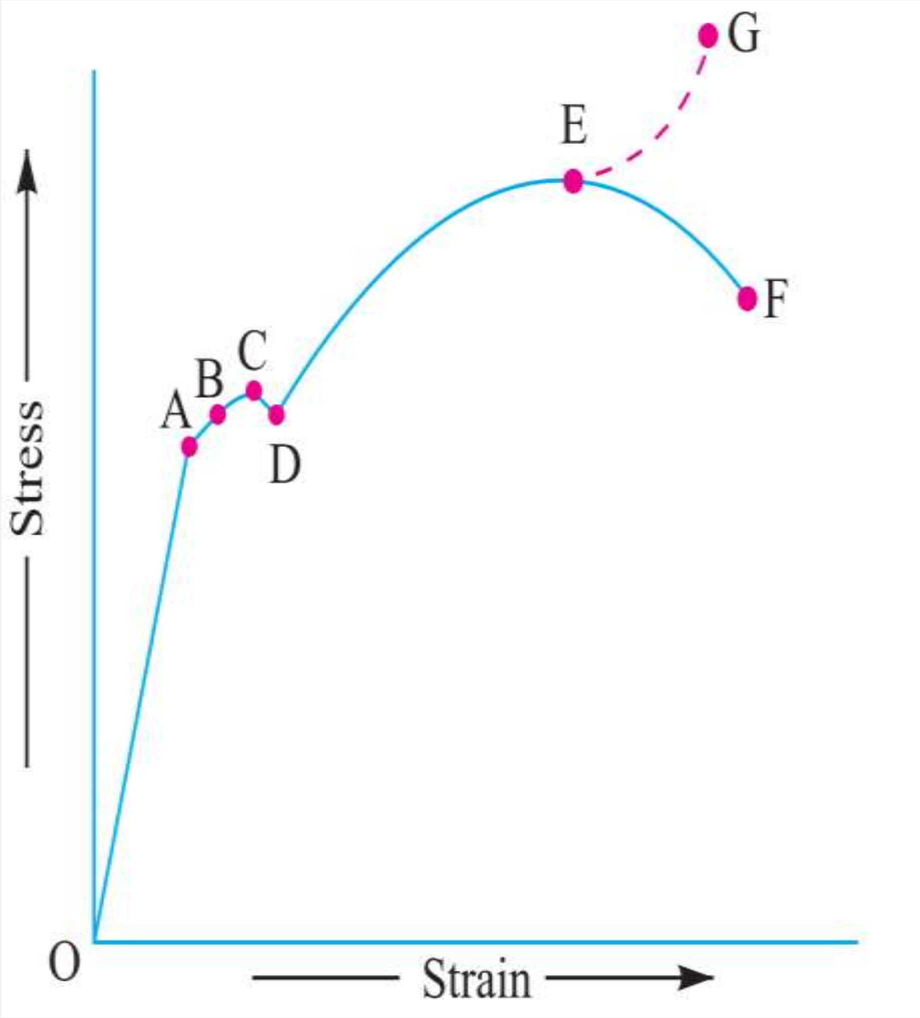
Stress vs Strain Curve: It is obtained after applying tensile load to material through tensile test to know the mechanical properties of the material. The various properties that can be obtained through tensile test are:

Proportional Limit: From point O to A showing the material is elastic upto A.

Elastic Limit: Point A to B, showing it will regain its shape though a little deviation occurred.

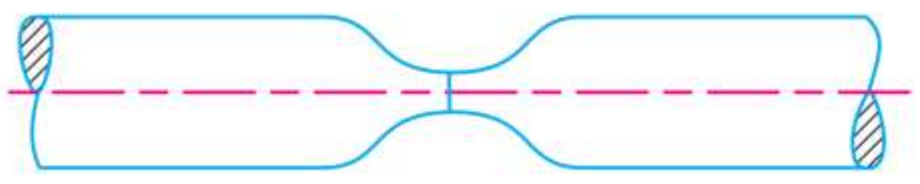
Yield Point: When the material stressed beyond B then it will enter plastic stage. The material will no longer gain its original shape. Strain increases faster with stress until point C. after yielding commences the stress drops to D which shows material suddenly reduces its resistance. Therefore there are two yield points C and D namely upper yield points and lower yield points.

Ultimate Stress: From point D to E, The gradual increase in the strain (or length) of the specimen is followed with the uniform reduction of its cross-sectional area. The work done, during stretching the specimen, is transformed largely into heat and the specimen becomes hot. At E, the stress, which attains its maximum value is known as ultimate stress.



5. LOAD AND STRESS ANALYSIS

Breaking stress: the stress (or load) necessary to break away the specimen, is less than the maximum stress. The stress is, therefore, reduced until the specimen breaks away at point F. The stress corresponding to point F is known as breaking stress.



(*b*) Shape of specimen after elongation.

Percentage reduction in area:

Let,

A = Original cross-sectional area, and

a = Cross-sectional area at the neck.

Then, reduction in area = A – a

And, percentage reduction in area = $\frac{A-a}{A} \times 100$

Percentage elongation:

Let, **l = Gauge length or original length**, and

L = Length of specimen after fracture or final length.

∴ Elongation = L – l

and percentage elongation = $\frac{L-l}{l} \times 100$

5. LOAD AND STRESS ANALYSIS

According to Urwin, The increase in length ca be expressed as

$$\delta l = b.l \times C.\sqrt{A}$$

Therefore, percentage elongation = $\frac{\delta l}{l} \times 100$

where l = Gauge length, A = Cross-sectional area, and

b and C = Constants depending upon the quality of the material

Safe or Allowable Stress: When designing machine parts, keep the stress lower than the maximum or ultimate stress at which failure of the material takes place. This stress is known as the **working/design/safe/allowable stress**.

Factor of Safety: Depending on the materials at **static loading** the factor of safety is calculated, in general the formula is

$$factor\ of\ safety = \frac{maximum\ stress}{Working\ Stress}$$

But for ductile materials e.g. mild steel it is

$$factor\ of\ safety = \frac{yield\ point\ \ stress}{Working\ Stress}$$

And for brittle materials e.g. cast iron it is

$$factor\ of\ safety = \frac{Ultimate\ stress}{Working\ Stress}$$

5. LOAD AND STRESS ANALYSIS

Selection of Factor of Safety

The selection of a proper factor of safety to be used in designing any machine component depends 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 design engineer should consider the following points :

1. The reliability of the properties of the material and change of these properties during service ;
2. The reliability of test results and accuracy of application of these results to actual machine parts;
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.

Values of factor of safety for some materials

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 and alloys	6	9	15
Leather	9	12	15
Timber	7	10 to 15	20

Solve the following math problems:

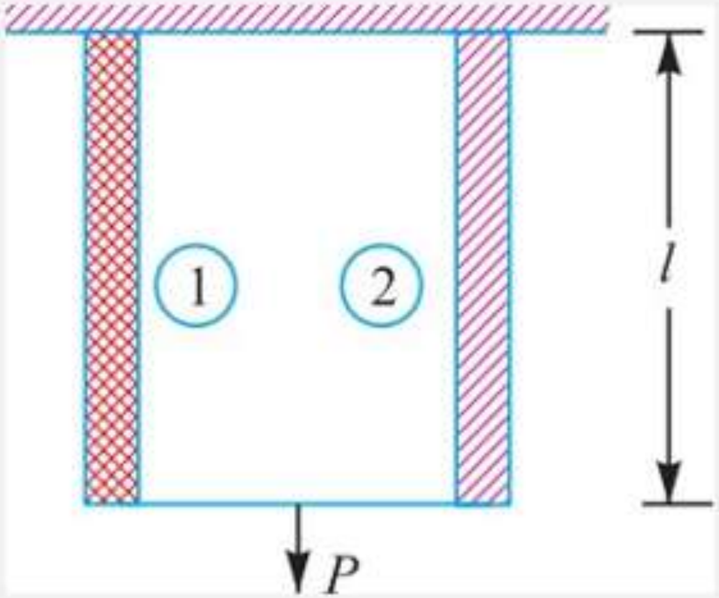
10. *A mild steel rod of 12 mm diameter was tested for tensile strength with the gauge length of 60 mm. Following observations were recorded : Final length = 80 mm; Final diameter = 7 mm; Yield load = 3.4 kN and Ultimate load = 6.1 kN. Calculate : 1. yield stress, 2. ultimate tensile stress, 3. percentage reduction in area, and 4. percentage elongation.*

LECTURE SHEET 6

Stresses in Composite Bars:

Consider a composite bar made up of two different materials

Let, P_1 = Load carried by bar 1,
A_1 = Cross-sectional area of bar 1,
σ_1 = Stress produced in bar 1,
E_1 = Young's modulus of bar 1,
P_2, A_2, σ_2, E_2 = 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, $\mathbf{P = P_1 + P_2}$ **...(i)**

Stress in bar 1, $\sigma_1 = \frac{P_1}{A_1}$

and strain in bar 1, $\varepsilon = \frac{\sigma_1}{E_1} = \frac{P_1}{A_1.E_1}$

$\therefore$ Elongation of bar 1, $\delta \boldsymbol{l}_{\mathbf{1}} = \frac{P_1.l}{A_1.E_1}$

Similarly, elongation of bar 2, $\delta \boldsymbol{l}_{\mathbf{2}} = \frac{P_2.l}{A_2.E_2}$

Since, $\delta l_1 = \delta l_2$

Therefore, $\frac{P_1.l}{A_1.E_1} = \frac{P_2.l}{A_2.E_2}$ **or** $\boldsymbol{P_1 = P_2 \times \frac{A_1.E_1}{A_2.E_2}}$ **... (ii)**

$$\boldsymbol{P_2 = P \times \frac{A_2.E_2}{A_1.E_1 + A_2.E_2}} \quad \textbf{... (iii)}$$

$$\boldsymbol{P_1 = P \times \frac{A_1.E_1}{A_1.E_1 + A_2.E_2}} \quad \textbf{... (iv)}$$

We Know,

$$\frac{P_1.l}{A_1.E_1} = \frac{P_2.l}{A_2.E_2}$$

$$\therefore \frac{\sigma_1}{E_1} = \frac{\sigma_2}{E_2}$$

$$\boldsymbol{\sigma_1 = \frac{E_1}{E_2} \times \sigma_2} \ \textbf{...(v)}$$

$$\boldsymbol{\sigma_2 = \frac{E_2}{E_1} \times \sigma_1} \ \textbf{...(vi)}$$

(**Modular Ratio** of two materials, $\frac{E_1}{E_2}$)

Stresses produced in different bars, $\boldsymbol{P = P_1 + P_2 = \sigma_1 . A_1 + \sigma_2 . A_2}$

The following procedures should be kept in view while calculating stress in composite bars:

1. The extension or contraction of the bar being equal, the strain i.e. deformation per unit length is also equal.
2. The total external load on the bar is equal to the sum of the loads carried by different materials.

Thermal Stresses

Let,

l = Original length of the body,

t = Rise or fall of temperature, and

α = Coefficient of thermal expansion,

∴ Increase or decrease in length, $\boldsymbol{\delta l = l.\,\alpha.t}$

If the materials expansion is prevented by fixed rigid support at the end of the body, then compressive strain induced in the body,

$$\varepsilon_c = \frac{\delta l}{l} = \frac{l.\alpha.t}{l} = \alpha.t$$

∴ **Thermal stress**, $\sigma_{th} = \varepsilon_c.E = \alpha.t.E$

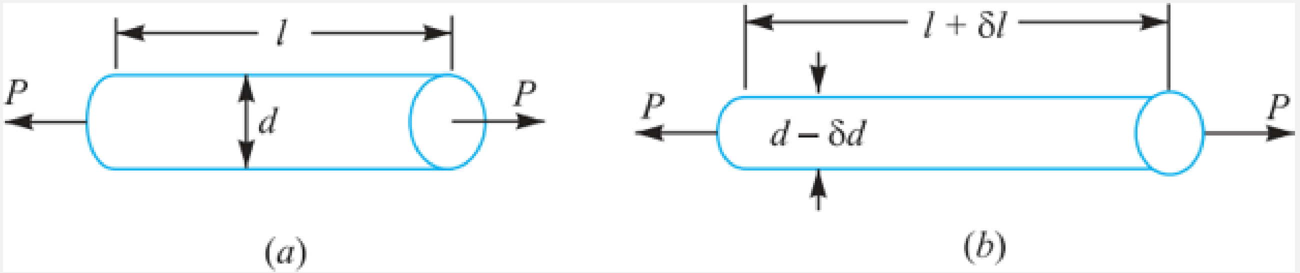
Circumferential or Hoop Strain:

Strain, $\varepsilon = \frac{\pi D - \pi d}{\pi d} = \frac{D-d}{d}$

∴ Circumferential or **hoop stress**, $\sigma = E.\varepsilon = \frac{E(D-d)}{d}$

Example: When a thin tyre is shrunk on to a wheel of diameter D, its internal diameter d is a little less than the wheel diameter. When the tyre is heated, its circumference π d will increase to π D. In this condition, it is slipped on to the wheel. When it cools, it wants to return to its original circumference π d, but the wheel if it is assumed to be rigid, prevents it from doing so.

Linear and Lateral Strain:



Poisson's Ratio:

When a body is stressed within elastic limit, the lateral strain bears a constant ratio to the linear strain, which is known as Poisson's Ratio and it is denoted by $1/m$ or μ.

$$\frac{\textit{Lateral Strain}}{\textit{Linear Strain}} = constant$$

Values of Poisson's ratio for commonly used materials:

S.No.	*Material*	*Poisson's ratio (1/m or μ)*
1.	Steel	0.25 to 0.33
2.	Cast iron	0.23 to 0.27
3.	Copper	0.31 to 0.34
4.	Brass	0.32 to 0.42
5.	Aluminium	0.32 to 0.36

6.	Concrete	0.08 to 0.18
7.	Rubber	0.45 to 0.50

Volumetric Strain: The ratio of the change in volume to the original volume due to external forces on a body is known as ***volumetric strain***.

$\boldsymbol{\varepsilon_v = \delta V / V}$

where, δV = Change in volume, and
V = Original volume

Volumetric strain of a rectangular body subjected to an axial force is given as

$$\varepsilon_v = \frac{\delta V}{V} = \varepsilon\left(1 - \frac{2}{m}\right) ;\ where\ \ \varepsilon = Linear\ strain$$

Volumetric strain of a rectangular body subjected to three mutually perpendicular forces is given by

$$\varepsilon_v = \varepsilon_x + \varepsilon_y + \varepsilon_z$$

Where, ε_x, ε_y and ε_z are the strains in the directions x-axis, y-axis and z-axis respectively.

Bulk Modulus: The ratio of the direct stress to the corresponding volumetric strain due to three mutually perpendicular stresses of equal intensity on a body is known as bulk modulus.

$$K = \frac{\textit{Direct stress}}{\textit{Volumetric strain}} = \frac{\sigma}{\delta V/V}$$

Relation Between Bulk Modulus and Young's Modulus:

$$K = \frac{m.E}{3(m-2)} = \frac{E}{3(1-2\mu)}$$

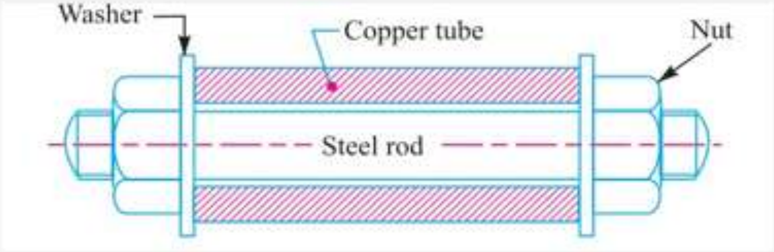
Relation Between Young's Modulus and Modulus of Rigidity:

$$G = \frac{m.E}{2(m+1)} = \frac{E}{2(1+2\mu)}$$

Exercise:

1. A bar 3 m long is made of two bars, one of copper having E = 105 GN/m^2 and the other of steel having E = 210 GN/m^2. Each bar is 25 mm broad and 12.5 mm thick. This compound bar is stretched by a load of 50 kN. Find the increase in length of the compound bar and the stress produced in the steel and copper. The length of copper as well as of steel bar is 3 m each.

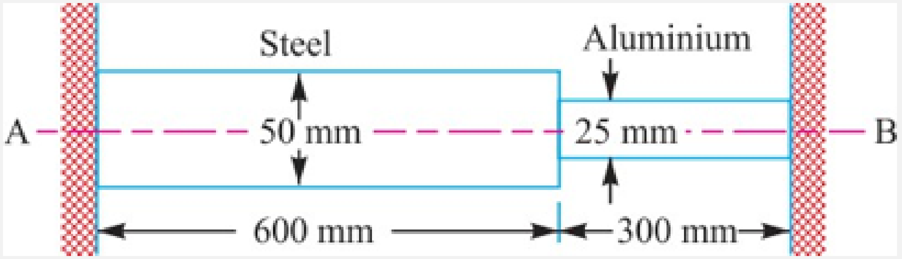
2. A central steel rod 18 mm diameter passes through a copper tube 24 mm inside and 40 mm outside diameter, as shown below. It is provided with nuts and washers at each end. The nuts are tightened until a stress of 10 MPa is set up in the steel. Calculate the stress now existing in the steel. Take $E_s = 2E_c$.



3. A thin steel tyre is shrunk on to a locomotive wheel of 1.2 m diameter. Find the internal diameter of the tyre if after shrinking on, the hoop stress in the tyre is 100 MPa. Assume E = 200 kN/mm^2. Find also the least temperature to which the tyre must be heated above that of the wheel before it could be slipped on. The coefficient of linear expansion for the tyre is 6.5 × 10–6 per °C.

*4. A composite bar made of aluminium and steel is held between the supports as shown in below. The bars are stress free at a temperature of 37°C. What will be the stress in the two bars when the temperature is 20°C, if **(a)** the supports are unyielding; and **(b)** the supports yield and 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 E_s = 210 GPa ; E_a = 74 GPa ; α_s = 11.7 × 10–6 / °C ; and α_a = 23.4 × 10–6 / °C.



5. A copper bar 50 mm in diameter is placed within a steel tube 75 mm external diameter and 50 mm internal diameter of exactly the same length. The two pieces are rigidly fixed together by two pins 18 mm in diameter, one at each end passing through the bar and tube. Calculate the stress induced in the copper bar, steel tube and pins if the temperature of the combination is raised by 50°C. Take E_s = 210 GN/m^2 ; E_c = 105 GN/m^2 ; α_s = 11.5 × 10^{-6}/°C and α_c = 17 × 10^{-6}/°C.

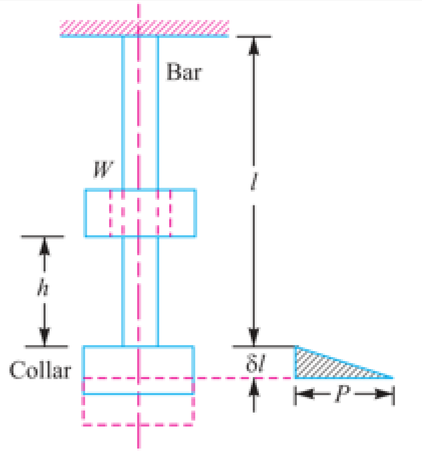
*6. A mild steel rod supports a tensile load of 50 kN. If the stress in the rod is limited to 100 MPa, find the size of the rod when the cross-section is **1.** circular, **2.** square, and **3.** rectangular with **width = 3 × thickness.***

7. A steel bar 2.4 m long and 30 mm square is elongated by a load of 500 kN. If poisson's ratio is 0.25, find the increase in volume. Take E = 0.2 × 10^6 N/mm^2.

Impact Stress: The stress produced in the member due to the falling load is known as ***impact stress.***

Imagine a bar carrying a load W at a height h and falling on the collar provided at the lower end,

Let, A = Cross-sectional area of the bar,
E = Young's modulus of the material of the bar,
l = Length of the bar,
δl = Deformation of the bar,
P = Force at which the deflection δl is produced,
σ_i = Stress induced in the bar due to the application of impact load,
h = Height through which the load falls



Strain energy gained by the system, $= \frac{1}{2} \times P \times \delta l$
Potential energy lost by the weight, $= W(h + \delta l)$

Since the energy gained by the system is equal to the potential energy lost by the weight, therefore
$\frac{1}{2} \times P \times \delta l = W(h + \delta l)$

$$\frac{1}{2}\sigma_i \times A \times \frac{\sigma_i \times l}{E} = W\,(h + \frac{\sigma_i \times l}{E})$$

$$\therefore \qquad \frac{Al}{2E}(\sigma_i)^2 - \frac{Wl}{E}(\sigma_i) - Wh = 0$$

From the above equation we can conclude that,

$$\sigma_i = \frac{W}{A}\left(\ 1 + \sqrt{1 + \frac{2hAE}{Wl}}\right)$$

When h=0, $\sigma_i = 2W/A$, the stress in the bar when the load is applied suddenly is double of the stress induced due to gradually applied load.

Resilience, Strain Energy

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 or shocks.

Mathematically, strain energy stored in a body due to tensile or compressive load or resilience,

$$U = \frac{(\sigma^2 \times V)}{2E}$$

Modulus of resilience = $\frac{\sigma^2}{2E}$

Where, σ = tensile or compressive stress,

V = volume of the body

E = young's modulus of the material of the body

Note: 1. When a body is subjected to a shear load, then modulus of resilience (shear) = $\frac{\tau^2}{2C}$

Where, τ = Shear stress

C = modulus of rigidity

2. When the body is subjected to torsion then modulus of resilience = $\frac{\tau^2}{4C}$

Exercises:

8. An unknown weight falls through 10 mm on a collar rigidly attached to the lower end of a vertical bar 3 m long and 600 mm^2 in section. If the maximum instantaneous extension is known to be 2 mm, what is the corresponding stress and the value of unknown weight? Take E = 200 kN/mm^2.

9. A wrought iron bar 50 mm in diameter and 2.5 m long transmits a shock energy of 100 N-m. Find the maximum instantaneous stress and the elongation. Take E = 200 GN/m^2.

10. A reciprocating steam engine connecting rod is subjected to a maximum load of 65 kN. Find the diameter of the connecting rod at its thinnest part, if the permissible tensile stress is 35 N/mm^2.

11. The maximum tension in the lower link of a Porter governor is 580 N and the maximum stress in the link is 30 N/mm^2. If the link is of circular cross-section, determine its diameter.

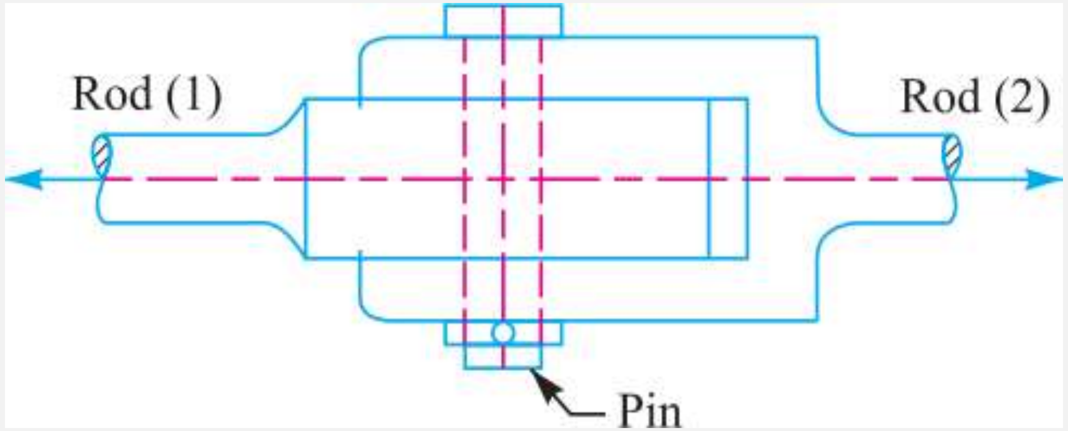
12. A wrought iron rod is under a compressive load of 350 kN. If the permissible stress for the material is -52.5 N/mm^2, calculate the diameter of the rod.

13. A load of 5 kN is to be raised by means of a steel wire. Find the minimum diameter required, if the stress in the wire is not to exceed 100 N/mm^2.

14.A square tie bar 20 mm × 20 mm in section carries a load. It is attached to a bracket by means of 6 bolts. Calculate the diameter of the bolt if the maximum stress in the tie bar is 150 N/mm^2 and in the
bolts is 75 N/mm^2.

15.The diameter of a piston of the steam engine is 300 mm and the maximum steam pressure is 0.7 N/mm^2. If the maximum permissible compressive stress for the piston rod material is 40 N/mm^2, find the size of the piston rod.

16.Two circular rods of 50 mm diameter are connected by a knuckle joint, as shown below, by a pin of 40 mm in diameter. If a pull of 120 kN acts at each end, find the tensile stress in the rod and shear stress in the pin.



MACHINE DESIGNING-I
ME 341
3 CREDITS
5^{TH} SEM

By

Alma Arbe

Lecturer

University of Global Village (UGV)

CONTENT

5. VARIABLE LOADING IN MACHINE PARTS

Torsional Shear Stress: the action of two equal and opposite couples acting in parallel planes (or torque or twisting moment), then the machine member is said to be subjected to ***torsion.*** The stress set up by torsion is known as ***torsional shear stress.*** It is zero at the centroidal axis and maximum at the outer surface.

We know that the torsional shear stress is zero at the centroidal axis and maximum at the outer surface. The maximum torsional shear stress at the outer surface of the shaft may be obtained from the following equation:

$$\frac{\tau}{r} = \frac{T}{J} = \frac{C.\theta}{l} \quad ..... \qquad \text{(i)}$$

***It is known as Torsion Equation.**

Where,

τ = Torsional shear stress induced at the outer surface of the shaft or maximum shear stress,

r = Radius of the shaft,

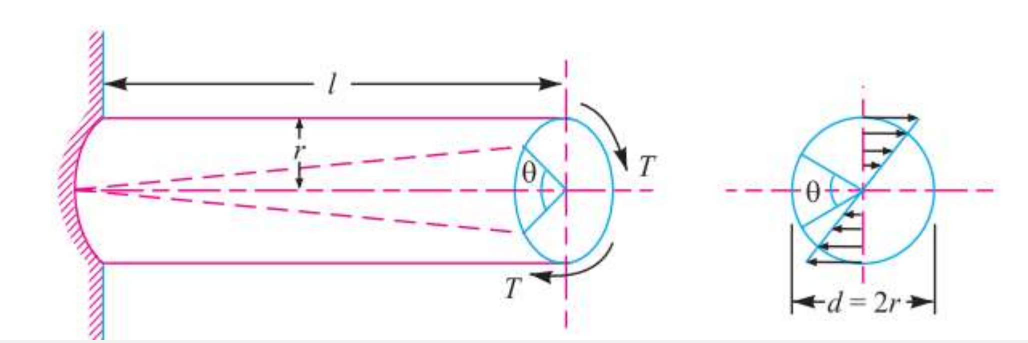
T = Torque or twisting moment,

J = Second moment of area of the section about its polar axis or polar moment of inertia,

C = Modulus of rigidity for the shaft material, l = Length of the shaft, and

θ = Angle of twist in radians on a length l.

5. VARIABLE LOADING IN MACHINE PARTS



The equation is known as torsion equation. It is based on the following assumptions:

1. The material of the shaft is uniform throughout.
2. The twist along the length of the shaft is uniform.
3. The normal cross-sections of the shaft, which were plane and circular before twist, remain plane and circular after twist.
4. All diameters of the normal cross-section which were straight before twist, remain straight with their magnitude unchanged, after twist.
5. The maximum shear stress induced in the shaft due to the twisting moment does not exceed its elastic limit value.

5. VARIABLE LOADING IN MACHINE PARTS

The torsional shear stress at a distance x from the centre of the shaft is

$$\frac{\boldsymbol{\tau_x}}{\boldsymbol{x}} = \frac{\boldsymbol{\tau}}{\boldsymbol{r}}$$

From equation (i) $\frac{T}{J} = \frac{\tau}{r}$ or $T = \tau \times \frac{J}{r}$

The polar moment of inertia for a solid shaft of diameter d,

$$J = I_{xx} + I_{yy} = \frac{\pi}{64} \times d^4 + \frac{\pi}{64} \times d^4 = \frac{\pi}{64} \times d^4$$

$$T = \frac{\pi}{16} \times \tau \times d^3$$

The polar moment of inertia for a hollow shaft with an external diameter d_0 and internal diameter of d_i,

$$J = \frac{\pi}{32}\left[(d_o)^4 - (d_i)^4\right]$$

$$r = \frac{d_o}{2}$$

$$T = \frac{\pi}{16} \times \tau \left[\frac{(d_o)^4 - (d_i)^4}{d_o}\right] = \frac{\pi}{16} \times \tau (d_o)^3 (1 - k^4) \qquad \left(\therefore k = \frac{d_i}{d_o}\right)$$

These above equations are used to calculate the strength of the shaft as the strength depends on the maximum torque.

5. VARIABLE LOADING IN MACHINE PARTS

Power transmitted by the shaft:

$$P = \frac{2\pi \mathrm{N}.T}{60} = T.\omega$$

Here, T = Torque transmitted in N.m

ω = Angular speed in rad/s. $\left(\omega = \frac{2\pi N}{60}\right)$

Composite shaft: Two shafts of different parameter connected to each other. When driving torque is provided at one end and the resisting torque at the other end then the shafts are at series but if the driving torque is applied at the joint of the two shafts and the resisting torques are at both ends of the shafts then the shafts are said to be at parallel.

Total angle of twist for shafts in series, $\boldsymbol{\theta = \theta_1 + \theta_2 = \frac{T.l_1}{C_1 J_1} + \frac{T.l_2}{C_2 J_2}}$

If C_1+C_2=C, $\boldsymbol{\theta = \frac{T.l_1}{CJ_1} + \frac{T.l_2}{CJ_2} = \frac{T}{C}\left[\frac{l_1}{J}{}_1 + \frac{l_2}{J_2}\right]}$

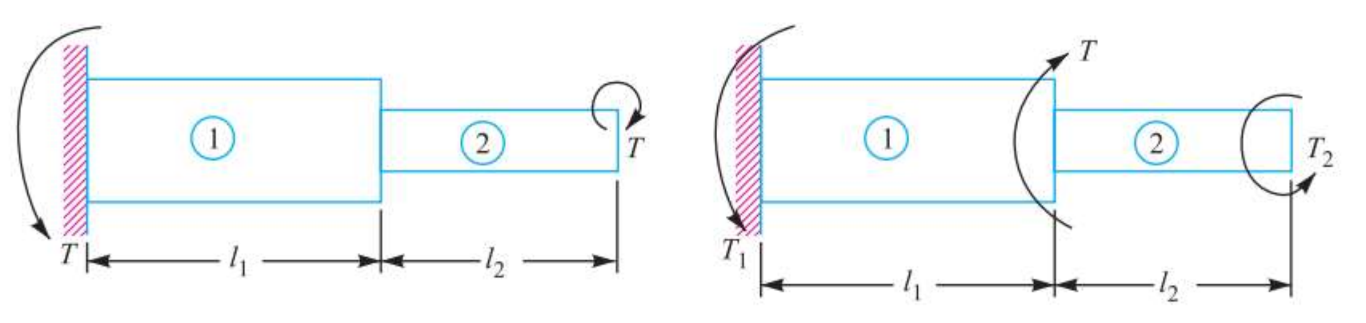
Total angle of twist for shafts in parallel, $\boldsymbol{\theta_1 = \theta_2}$

$$\boldsymbol{\frac{T_1.\, l_1}{C_1 J_1} = \frac{T_2.\, l_2}{C_2 J_2}} \qquad \boldsymbol{or} \qquad \boldsymbol{\frac{T_1}{T_2} = \frac{l_1}{l_2} \times \frac{C_1}{C_2} \times \frac{J_1}{J_2}}$$

$$\boldsymbol{T = T_1 + T_2}$$

5. VARIABLE LOADING IN MACHINE PARTS

If $C_1 = C_2$, $\frac{T_1}{T_2} = \frac{l_1}{l_2} \times \frac{J_1}{J_2}$



(*a*) Shafts in series.   (*b*) Shafts in parallel.

5. VARIABLE LOADING IN MACHINE PARTS

1. A shaft is transmitting 100 kW at 160 r.p.m. Find a suitable diameter for the shaft, if the maximum torque transmitted exceeds the mean by 25%. Take maximum allowable shear stress as 70 MPa.

2. A shaft is transmitting 97.5 kW at 180 r.p.m. If the allowable shear stress in the material is 60 MPa, find the suitable diameter for the shaft. The shaft is not to twist more that 1° in a length of 3 metres. Take C = 80 GPa.

- *a. What load applied to tangent to the rim of the wheel produce a torsional shear of 60 MPa?*
- *b. How many degrees will the wheel turn when this load is applied?*

3. A steel shaft ABCD having a total length of 3.5 m consists of three lengths having different sections as follows:

AB is hollow having outside and inside diameters of 100 mm and 62.5 mm respectively, and BC and CD are solid. BC has a diameter of 100 mm and CD has a diameter of 87.5 mm. If the angle of twist is the same for each section, determine the length of each section. Find the value of the applied torque and the total angle of twist, if the maximum shear stress in the hollow portion is 47.5 MPa and shear modulus, C = 82.5 GPa.