INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad -500 043

CIVIL ENGINEERING

COURSE LECTURE NOTES

Course Name	**MATERIALS, TESTING AND EVALUATION**
Course Code	ACEB08
Programme	B.Tech
Semester	IV
Course Coordinator	Mr. K. Anand Goud, Assistant Professor
Course Faculty	Mr. A. JagadishBabu
Lecture Numbers	1-60
Topic Covered	All

COURSE OBJECTIVES (COs):

The course should enable the students to:	
I	Make measurements of behaviour of various materials used in Civil Engineering.
II	Provide physical observations to complement concepts learnt.
III	Introduce experimental procedures and common measurement instruments, equipment, devices.
IV	Disclose the variety of established material testing procedures and techniques.

COURSE LEARNING OUTCOMES (CLOs):

Students, who complete the course, will have demonstrated the ability to do the following:

ACEB08.01	Identify the properties of engineering materials like cement, sand, concrete, ceramics, bitumen, structural steel etc.
ACEB08.02	Explain the classification of engineering materials and uses of materials.
ACEB08.03	Understand the manufacturing process of cement, concrete, bitumen, glass, plastics, metals, paints and other engineering materials.
ACEB08.04	Classify the steel, glass, varnishes, adhesives, carbon composites.
ACEB08.05	Explain the mechanical behaviour and characteristics of different metals.
ACEB08.06	Understand the importance of elasticity principle, characteristics and plastic deformation of metals.
ACEB08.07	Explain standards for different materials, stress-strain interpretation.
ACEB08.08	Describe the fundamentals of internal friction, creep, brittle fracture of steel.

ACEB08.09	Understand the concept of fatigue of materials, structural integrity assessment procedure.
ACEB08.10	Perform the mechanical testing of various metals like iron, steel and non-ferrous metals.
ACEB08.11	Explain elastic deformation and plastic deformation of metals.
ACEB08.12	Understand the impact testing, fatigue and creep of materials.
ACEB08.13	Explain fracture toughness of different materials like steel and non-ferrous metals.
ACEB08.14	Explain the testing procedures of bricks and sand.
ACEB08.15	Describe the testing procedures of fresh and hardened concrete.
ACEB08.16	Understand the properties of soil by conducting the different tests.
ACEB08.17	Explicate the procedures of testing bitumen and bitumen mixes.
ACEB08.18	Understand the testing procedures of polymers and polymer based materials.
ACEB08.19	Explain the behaviour of metals under various loads.
ACEB08.20	Describe the mechanical behaviour of composite materials.
ACEB08.21	Discuss the properties of cementitious materials like fly ash, blast furnace slag.

SYLLABUS

Module-I	**INTRODUCTION TO ENGINEERING MATERIALS**
Cements, Sand, Concrete (plain, reinforced and steel fiber / glass fiber reinforced, light weight concrete, high Performance Concrete, Polymer Concrete) Ceramics, and Refractories, Bitumen and asphaltic materials, Timbers, Glass and Plastics, Structural Steel and other Metals, Paints and Varnishes, Acoustical Material and geo-textiles, rubber and asbestos, laminates and adhesives, Graphene, Carbon composites and other engineering materials including properties and uses.	
Module-II	**INTRODUCTION TO MATERIAL TESTING**
Introduction to material Engineering; Mechanical behavior and mechanical characteristics; Elasticity principle and characteristics; plastic deformation of metals; tensile test-standards for different material (brittle, quasi-brittle, elastic) True stress-strain interpretation of tensile test; hardness tests; bending and torsion test; strength of ceramic; Internal friction, creep fundaments and characteristics; Brittle fracture of steel-temperature transition approach; Background of fracture mechanics; fracture toughness testing for different materials; concept of fatigue of materials; Structural integrity assessment procedure and fracture mechanics.	
Module-III	**STANDARD TESTING & EVALUATION PROCEDURES**
Mechanical testing of various metals; naming systems for various irons, steels and nonferrous metals; elastic deformation; plastic deformation. Impact test and transition temperatures; fracture mechanics background; fracture toughness-different materials; Fatigue of material; Creep.	
Module-IV	**STANDARD TESTING PROCEDURES**
Tests & testing of bricks, Tests & testing of sand, Tests & testing of concrete, Tests & testing of soils, Tests & testing of bitumen & bituminous mixes.	
Module-V	**TESTING PROCEDURES OF SPECIAL MATERIALS**
Testing of polymers and polymer based materials, tests and testing of metals, special materials, composites and cementitious materials. Explanation of mechanical behavior of these materials.	
Text Books:	
1. Chudley, R., Greeno, "building construction handbook", R. Butterorth Heinemann, 6th edition, 2006. 2. Khanna, S.K., Justo, C.E.G and Veeraragavan, A, "Highway Materials and Pavement Testing", Nem Chand & Bros, 5th Edition.	

3.	Various related updated & recent standards of BIS, IRC, ASTM, RILEM, AASHTO, etc. corresponding to materials used for Civil Engineering applications.
Reference Books:	
4.	KyriakosKomvopoulos, “Mechanical Testing of Engineering Materials”, Cognella, 2011.
5.	E.N. Dowling, “Mechanical Behaviour of Materials”, Prentice Hall International, 1993.
6.	American Society for Testing and Materials (ASTM), Annual Book of ASTM Standards (post 2000)

MODULE-I

INTRODUCTION TO ENGINEERING MATERIALS

INTRODUCTION:

Materials’ testing is a respected and established technique which is used to ascertain both the physical and mechanical properties of raw materials and components. It can be used to examine all materials like steel, ceramics or composite materials etc.

Due to the great diversity in the usage of buildings and installations and the various processes of production, a great variety of requirements are placed upon building materials calling for a very wide range of their properties: strength at low and high temperatures, resistance to ordinary water and sea water, acids and alkalis etc. Also, materials for interior decoration of residential and public buildings, gardens and parks, etc. should be, by their very purpose, pleasant to the eye, durable and strong. Specific properties of building materials serve as a basis for subdividing them into separate groups. For example, mineral binding materials are subdivided into air and hydraulic-setting varieties. The principal properties of building materials predetermine their applications. Only a comprehensive knowledge of the properties of materials allows a rational choice of materials for specific service conditions.

PRINCIPAL PROPERTIES OF BUILDING MATERIALS:

For a material to be considered as building material, it should have required engineering properties suitable for construction works.This property of building a material is responsible for its quality and capacity and helps to decide applications of these materials.

Such properties of building materials are categorized as follows.

1. Physical properties
2. Mechanical properties
3. Chemical properties
4. Electrical properties
5. Magnetic properties
6. Thermal properties

PHYSICAL PROPERTIES:

Bulk Density

Bulk density is the ratio of mass to the volume of the material in its natural state that is including voids and pores. It is expressed in kg/m3. Bulk density influences the mechanical properties of materials like strength, heat and conductivity etc.

bulk density values of some of the engineering materials are given below.

Building material	Bulk density (kg/m3)
Brick	1600-1800
Sand	1450 – 1650
Steel	7850
Heavy concrete	1800 – 2500

Light concrete	500 – 1800
Granite	2500 – 2700

Porosity

Porosity gives the volume of the material occupied by pores. It is the ratio of volume of pores to the volume of material.

Porosity influences many properties like thermal conductivity, strength, bulk density, durability etc.

Durability

The property of a material to withstand against the combined action of atmospheric and other factors is known as durability of material.

If the material is more durable, it will be useful for longer life. Maintenance cost of material is dependent of durability.

Density

Density is the ratio of mass of the material to its volume in homogeneous state.

Almost all the physical properties of materials are influenced by its density values. Density values of some building materials are given below.

Material	Density (kg/m^3)
Steel	7800 – 7900
Brick	2500 -2800
Granite	2600 – 2900
Wood	1500

Bulk density

Bulk density is another important property of building materials. The bulk density is measured in its natural states. So they have the influence of pores and voids.

Bulk density is the mass occupied per unit volume in its natural state.

Specific Gravity

Specific gravity is the ratio of mass of given substance to the mass of water at 4°C for the equal volumes. Specific gravity of some materials is listed below.

Material	Specific gravity
Steel	7.82
Cast iron	7.20
Aluminum	2.72

Fire Resistance

The ability to withstand against fire without changing its shape and other properties. Fire resistance of a material is tested by the combined actions of water and fire. Fireproof materials should provide more safety in case of fire.

Frost Resistance

The ability of a material to resist freezing or thawing is called frost resistance. It is depends upon the density and bulk density of material. Denser materials will have more frost resistance. Moist materials have low frost resistance and they lose their strength in freezing and become brittle.

Weathering Resistance

The property of a material to withstand against all atmospheric actions without losing its strength and shape. Weathering effects the durability of material. For example corrosion occurs in iron due to weathering. To resist this paint layer is provided.

Spalling Resistance

The ability of a material to undergo certain number of cycles of sharp temperature variations without failing is known as spalling resistance. It is the dependent of coefficient of linear expansion.

Water Absorption

The capacity of a material to absorb and retain water in it is known as water absorption. It is expressed in % of weight of dry material. It depends up on the size, shape and number of pores of material.

Water Permeability

The ability of a material to permit water through it is called water permeability. Dense materials like glass metals etc. are called impervious materials which cannot allow water through it.

Refractoriness

The property of a material which cannot melts or lose its shape at prolonged high temperatures (1580°C or more).

Example: fire clay is high refractory material.

MECHANICAL PROPERTIES:

Mechanical properties of the materials are find out by applying external forces on them. These are very important properties which are responsible for behavior of a material in its job. The mechanical properties are,

Strength

The capacity of a material to resist failure caused by loads acting on it is called as strength. The load may be compressive, tensile or bending. It is determined by dividing the ultimate load taken by the material with its cross sectional area. Strength is an important property for any construction materials. So, to provide maximum safety in strength, factor of safety is provided for materials and it is selected depending on nature of work, quality of material, economic conditions etc.

Hardness

The property of materials to resist scratching by a herder body. MOHS scale is used to determine the hardness of materials. Hardness is most important to decide the usage of particular aggregate. It also influences the workability.

Elasticity

The capacity of a material to regain its initial shape and size after removal of load is known as elasticity and the material is called as elastic material. Ideally elastic materials obey Hooke's law in which stress is directly proportional to strain. This gives modulus of elasticity as the ratio of unit stress to unit deformation. Higher the values of modulus of elasticity lower the deformations.

Plasticity

When the load is applied on the material, if it will undergo permanent deformation without cracking and retain this shape after the removal of load then it is said to be plastic material and this property is called as plasticity. They give resistance against bending, impact etc.
Examples: steel, hot bitumen etc.

Brittleness

When the material is subjected to load, if it fails suddenly without causing any deformation then it is called brittle material and this property is called as brittleness.
Examples: concrete, cast-iron etc.

Fatigue

If a material is subjected to repeated loads, then the failure occurs at some point which is lower than the failure point caused by steady loads. This behavior is known as fatigue.

Impact strength

If a material is subjected to sudden loads and it will undergo some deformation without causing rupture is known as its impact strength. It designates the toughness of material.

Abrasion Resistance

The loss of material due to rubbing of particles while working is called abrasion. The abrasion resistance for a material makes it durable and provided long life.

Creep

Creep the deformation caused by constant loads for long periods. It is time dependent and occurs at very slow rate. It is almost negligible in normal conditions. But at high temperature conditions creep occur rapidly.

AGGREGATES

Aggregates are the important constituents of the concrete which give body to the concrete and also reduce shrinkage. Aggregates occupy 70 to 80 % of total volume of concrete.

Classification of Aggregates Based on Shape

We know that aggregate is derived from naturally occurring rocks by blasting or crushing etc., so, it is difficult to attain required shape of aggregate. But, the shape of aggregate will affect the workability of concrete. So, we should take care about the shape of aggregate. This care is not only applicable to parent rock but also to the crushing machine used.

Aggregates are classified according to shape into the following types

1. Rounded aggregates
2. Irregular or partly rounded aggregates
3. Angular aggregates
4. Flaky aggregates
5. Elongated aggregates
6. Flaky and elongated aggregates

Rounded Aggregate

The rounded aggregates are completely shaped by attrition and available in the form of seashore gravel. Rounded aggregates result the minimum percentage of voids (32 – 33%) hence gives more workability. They require lesser amount of water-cement ratio. They are not considered for high strength concrete because of poor interlocking behavior and weak bond strength.

Irregular Aggregates

The irregular or partly rounded aggregates are partly shaped by attrition and these are available in the form of pit sands and gravel. Irregular aggregates may result 35- 37% of voids. These will give lesser workability when compared to rounded aggregates. The bond strength is slightly higher than rounded aggregates but not as required for high strength concrete.

Angular Aggregates

The angular aggregates consist well defined edges formed at the intersection of roughly planar surfaces and these are obtained by crushing the rocks. Angular aggregates result maximum percentage of voids (38-45%) hence gives less workability. They give 10-20% more compressive strength due to development of stronger aggregate-mortar bond. So, these are useful in high strength concrete manufacturing.

Flaky Aggregates

When the aggregate thickness is small when compared with width and length of that aggregate it is said to be flaky aggregate. Or in the other, when the least dimension of aggregate is less than the 60% of its mean dimension then it is said to be flaky aggregate.

Elongated Aggregates

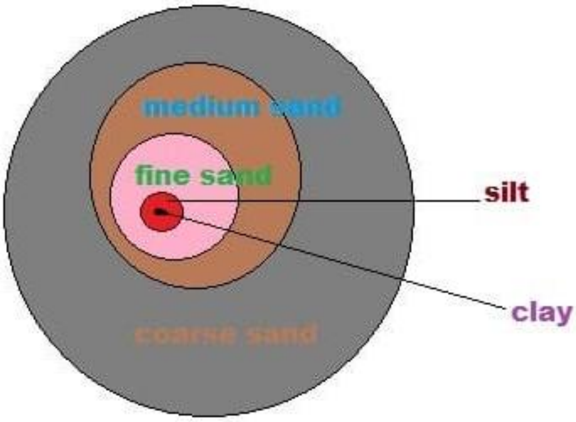
When the length of aggregate is larger than the other two dimensions then it is called elongated aggregate or the length of aggregate is greater than 180% of its mean dimension.

Flaky and Elongated Aggregates

When the aggregate length is larger than its width and width is larger than its thickness then it is said to be flaky and elongated aggregates. The above 3 types of aggregates are not suitable for concrete mixing. These are generally obtained from the poorly crushed rocks.

Classification of Aggregates Based on Size

Aggregates are available in nature in different sizes. The size of aggregate used may be related to the mix proportions, type of work etc. the size distribution of aggregates is called grading of aggregates.



Following are the classification of aggregates based on size:

Aggregates are classified into 2 types according to size

1. Fine aggregate
2. Coarse aggregate

Fine Aggregate

When the aggregate is sieved through 4.75mm sieve, the aggregate passed through it called as fine aggregate. Natural sand is generally used as fine aggregate, silt and clay are also come under this category. The soft deposit consisting of sand, silt and clay is termed as loam. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent.

Coarse Aggregate

When the aggregate is sieved through 4.75mm sieve, the aggregate retained is called coarse aggregate. Gravel, cobble and boulders come under this category. The maximum size aggregate used may be dependent upon some conditions. In general, 40mm size aggregate used for normal strengths and 20mm size is used for high strength concrete. The size range of various coarse aggregates given below.

Grading of Aggregates

Grading is the particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square openings. As per IS:2386(Part-1)

Fine aggregate—6 standard sieves with openings from 150 μm to 4.75 mm.

Coarse aggregate—5 sieves with openings from 4.75mm to 80 mm.

Gradation (grain size analysis)

Grain size distribution for concrete mixes that will provide a dense strong mixture. Ensure that the voids between the larger particles are filled with medium particles. The remaining voids are filled with still smaller particles until the smallest voids are filled with a small amount of fines.

Ensure maximum density and strength using a maximum density curve

Good Gradation:

Concrete with good gradation will have fewer voids to be filled with cement paste (economical mix) Concrete with good gradation will have fewer voids for water to permeate (durability)

Particle size distribution affects:

1. Workability
2. Mixproportioning

Fine Aggregate effect on concrete:

1. Over sanded (More than requiredsand)
    - Over cohesivemix.
    - Water reducers may be lesseffective.
    - Air entrainment may be moreeffective.
2. Under sanded (deficit ofsand)
    - Prone to bleed andsegregation.
    - May get high levels of waterreduction.
    - Air entrainers may be lesseffective.

Shape and surface texture of aggregates:

- The shape of aggregate is an important characteristic since it affects the workability of concrete.
- It is difficult to measure the shape of irregular shaped aggregates. Not only the type of parent rock but also the type of crusher used also affects the shape of the aggregate produced.
- Good Granite rocks found near Bangalore will yield cuboidal aggregates. Many rocks contain planes of jointing which is characteristics of its formation and hence tend to yield more flaky aggregates.
- The shape of the aggregates produced is also dependent on type of crusher and the reduction ratio of the crusher.
- Quartzite which does not possess cleavage planes tend to produce cubical shape aggregates.
- From the standpoint of economy in cement requirement for a given water cement ratio rounded aggregates are preferable to angular aggregates.
- On the other hand, the additional cement required for angular aggregates is offset to some extent by the higher strengths and some times greater durability as a result of greater Interlocking texture of the hardened concrete.
- Flat particles in concrete will have objectionable influence on the workability of concrete, cement requirement, strength and durability.
- In general excessively flaky aggregates make poor concrete.
- While discussing the shape of the aggregates, the texture of the aggregate also enters the discussion because of its close association with the shape.

- Generally round aggregates are smooth textured and angular aggregates are rough textured. Therefore some engineers argue against round aggregates from the point of bond strength between aggregates and cement.
- But the angular aggregates are superior to rounded aggregates from the following two points:
- Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for road and pavements.
- The total surface area of rough textured angular aggregate is more than smooth rounded aggregates for the given volume.
- By having greater surface area, the angular aggregates may show higher bond strength than rounded aggregates.
- The shape of the aggregates becomes all the more important in case of high strength and high performance concrete where very low water/cement ratio is required to be used . In such cases cubical aggregates are required for better workability.
- Surface texture is the property, the measure of which depends upon the relative degree to which particle surface are polished or dull, smooth or rough.
- Surface texture depends upon hardness, grain size, pore structure, structure of the rock and the degree to which the forces acting on it have smoothened the surface or roughened.
- Experience and laboratory experiments have shown that the adhesion between cement paste and the aggregate is influenced by several complex factors in

CEMENT:

In ancient times stones have been invariably used as a construction material with lime as the binder for construction of forts and defense structures. Egyptians have used lime and gypsum as cementing materials in the famous Pyramids. The calcareous rocks used by the Romans were either composed of limestone's burned in Kilns or mixtures of limestone and puzzolanic materials (volcanic ash, tuff) combining into a hard concrete. The natural cement is obtained by burning and crushing the stones containing clay, carbonate of lime (CaCO3) and a little quantity of magnesia (CaMgCO3)2. The natural cement is brown in color and is also known as Roman cement.

Ingredient	Oxide / composition	%	Range	Function
Lime	CaO	62	60 – 65	Controls strength and soundness. Its deficiency reduces strength & setting time
Silica	SiO_2	22	17 – 25	Imparts strength. Excess cause slo setting
Alumina	Al_2O_3	5	3 – 8	Responsible for quick setting, if in excess it lowers the strength / weakness the cement

Calcium sulphate	$CaSO_4$	4	3 – 4	A small amount of sulphurisusefulin making sound cement. If it is in excess , it causes cement to become unsound.
Iron oxide	Fe_2O_3	3	0.5 – 6	Gives colour, hardness & strength to the cement
Magnesia	MgO	2	0.5 – 4	Gives color, hardness. If in excess, it causes cracks in mortar.
Alkalies	(Na_2O+K_2O)	1	0.1 – 0.4	These are residues and if in excess cause efflorescence and cracking

USES OF CEMENT

Cement is widely used in construction of various engineering structures. Following are various possible uses of cement:

- Cement mortar for masonryworks
- Cement Concrete for laying floors, roofs, lintels, beams, stairs, pillarsetc
- Construction of important engineering structures such as Bridges, Culverts, Dams, Tunnels, storage Reservoirs; Docksetc
- Making CementPipes
- Manufacture of precast pipes, dust bins, fencing postsetc..

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Concrete is a construction material composed of cement, fine aggregates (sand) and coarse aggregates mixed with water which hardens with time. Portland cement is the commonly used type of cement for production of concrete.

- Concrete technology deals with study of properties of concrete and its practical applications.
- In a building construction, concrete is used for the construction of foundations, columns, beams, slabs and other load bearing elements.
- There are different types of binding material is used other than cement such as lime for lime concrete and bitumen for asphalt concrete which is used for road construction.
- Various types of cements are used for concrete works which have different properties and applications. Some of the type of cement are Portland Pozzolana Cement (PPC), rapid hardening cement, Sulphate resistant cement etc.

Materials are mixed in specific proportions to obtain the required strength. Strength of mix is specified as M5, M10, M15, M20, M25, M30 etc, where M signifies Mix and 5, 10, 15 etc. as their strength in kN/m2. In United States, concrete strength is specified in PSI which is Pounds per Square Inch.

What is Grade of Concrete?

Grade of concrete denotes its strength required for construction. For example, M30 grade signifies that compressive strength required for construction is 30MPa. The first letter in grade "M" is the mix and 30 is the required strength in MPa.

- Based on various lab tests, grade of concrete is presented in Mix Proportions. For example, for M30 grade, the mix proportion can be 1:1:2, where 1 is the ratio of cement, 1 is the ratio of sand and 2 is the ratio of coarse aggregate based on volume or weight of materials.
- The strength is measured with concrete cube or cylinders by civil engineers at construction site. Cube or cylinders are made during casting of structural member and after hardening it is cured for 28 days. Then compressive strength test is conducted to find the strength.

Regular grades of concrete are M15, M20, M25 etc. For plain cement concrete works, generally M15 is used. For reinforced concrete construction minimum M20 grade of concrete are used.

Fiber Reinforced Concrete

Fiber Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. Fiber reinforced concrete are of different types and properties with many advantages. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers.

Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fiber is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fiber is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150.

Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity.

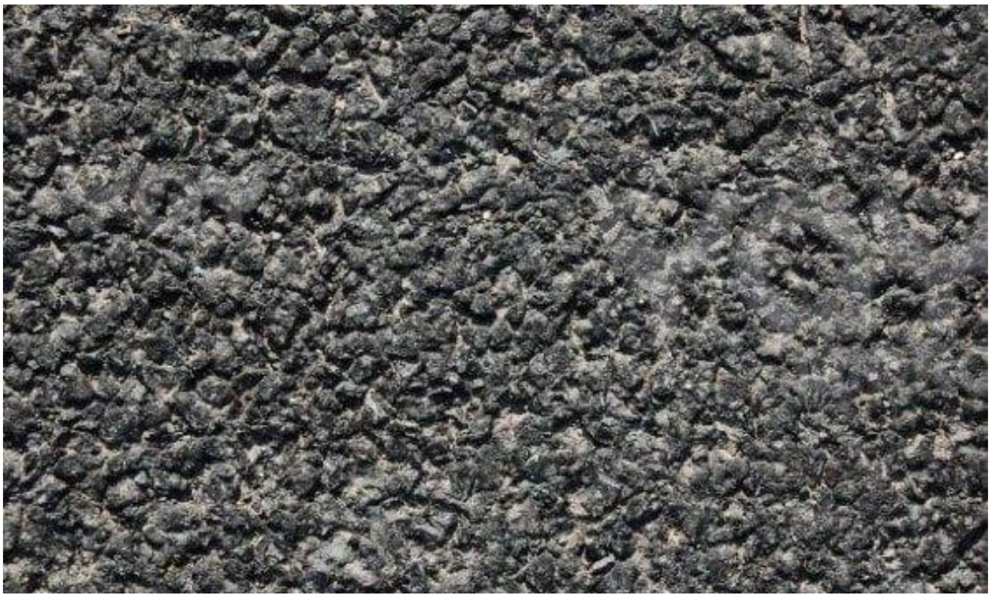
It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers. Within these different fibers that character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation and densities.

Necessity of Fiber Reinforced Concrete

- It increases the tensile strength of the concrete.
- It reduce the air voids and water voids the inherent porosity of gel.
- It increases the durability of the concrete.
- Fibres such as graphite and glass have excellent resistance to creep, while the same is not true for most resins. Therefore, the orientation and volume of fibres have a significant influence on the creep performance of rebars/tendons.
- Reinforced concrete itself is a composite material, where the reinforcement acts as the strengthening fibre and the concrete as the matrix. It is therefore imperative that the behavior under thermal stresses for the two materials be similar so that the differential deformations of concrete and the reinforcement are minimized.
- It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

Asphalt

The asphalt is a mixture which consists alumina, lime, silica and asphaltic bitumen. At low temperatures, it is in solid state and at high temperatures it is in liquid state.



Asphalt is produced in two different ways as follows.

- Natural asphalt
- Residual asphalt

Natural Asphalt

Natural asphalt is obtained directly from the nature especially from the two resources lakes and rocks.

The lake asphalt contains 40 to 70 % of pure bitumen which is boiled in tank and water content evaporates and impurities are separated. The final product is called as asphalt which a=can be used for laying roads etc.

Rock asphalt contains 10 to 15% of pure bitumen and calcareous matter. These rocks are crushed and heated and consolidates by sudden cooling. This asphalt is used for paving tiles etc.

Bitumen

Bitumen is obtained by the partial distillation of crude petroleum. It is also called as mineral tar and is present in asphalt also. It contains 87% carbon, 11% hydrogen and 2% oxygen.

Forms of Bitumen

The forms of bitumen are generally 5 types as follows.

- Cutback bitumen
- Bitumen emulsion
- Plastic bitumen
- Blown bitumen
- Straight run bitumen

Timber

Timber is a naturally occurring material and is used for several engineering purposes. From tall tower blocks and bridges to doors and windows and interior decoration- timber structures find their application everywhere. What becomes extremely essential is the choice of good quality timber for construction. Here in this article, we discuss some factors based on which good timber is characterized.

Characteristics of Good Timber

A timber is said to be good based on the following characteristics :

- Durability
- Strength
- Permeability
- Hardness
- Toughness
- Elasticity
- Workability
- Weight
- Structure
- Defects
- Fire

GLASS

Glass is an inorganic product of fusion, which has been cooled to a solid state condition without crystallizing.
slow cooling process leads to formation of crystal nuclei and crystallization takes place.
If the cooling rate is fast, leaving no time to the formation of crystal nuclei, structure of super cooled liquid state turns to rigid and forms a glass.

Properties

1. Hard and brittle
2. appearance
3. glass can absorb, refracts or transmits light.
4. Glass transmits up to 80% of available natural day light in both directions
5. The glass is fully weather resistance
6. Melting point 1400 to 1500 degree c.

Classification

1. Soda-lime glass.
2. Potash-lime glass.
3. Potash – Lead glass.
4. Common glass.

Uses

1. Soda lime glass: It is used in the manufacture of glass tubes, laboratory apparatus, plate glass, window glass etc.
2. Potash lime glass: It is used in the manufacture of glass articles, which have to with stand high temperatures.
3. Potash – Lead glass: It is used in the manufacture of artificial gems, electric bulbs, lenses, prisms etc.
4. Common Glass: It is mainly used in the manufacture of medicine bottles.

Commercial forms or special types of glass

- Fibre glass
- Float glass
- Ground glass
- Laminated glass
- Wired glass
- Optical glass

Manufacture of glass

1. Batching of fret mixing
2. Furnace melting
    a. Initial stage
    b. Second stage
    c. Third stage
3. Drawing
4. Annealing
5. Cutting

Metal

Metal is used as structural framework for larger buildings such as skyscrapers, or as an external surface covering.

There are many types of metals used for building. Steel is a metal alloy whose major component is iron, and is the usual choice for metal structural construction. It is strong, flexible, and if refined well and/or treated lasts a long time. Corrosion is metal's prime enemy when it comes to longevity.

The lower density and better corrosion resistance of aluminium alloys and tin sometimes overcome their greater cost. Brass was more common in the past, but is usually restricted to specific uses or specialty items today.

Metal figures quite prominently in prefabricated structures such as the Quonset hut, and can be seen used in most cosmopolitan cities. It requires a great deal of human labor to produce metal, especially in the large amounts needed for the building industries.

Ceramics

Ceramics are such things as tiles, fixtures, etc. Ceramics are mostly used as fixtures or coverings in buildings. Ceramic floors, walls, counter-tops, even ceilings. Many countries use ceramic roofing tiles to cover many buildings.

Ceramics used to be just a specialized form of clay-pottery firing in kilns, but it has evolved into more technical areas.

Plastics

Plastic pipes penetrating a concrete floor in a Canadian highrise apartment building.

The term plastics covers a range of synthetic or semi-synthetic organic condensation or polymerization products that can be molded or extruded into objects or films or fibers. Their name is derived from the fact that in their semi-liquid state they are malleable, or have the property of plasticity.

Paints

A wide variety of raw materials are used in the manufacture of paints but they can be grouped according to their function.

Medium, vehicle or binder are terms used to refer to the oils or resins or combinations of the two that form the basis of all paints. Linseed oil is an example of a vegetable oil used as a binder. In al cases it must have the ability to change from a low viscosity liquid into a hard plastic film at the same time binding together the fine particles of pigment. The actual properties of the binder may be modified to a large extent by the pigment. Three main properties are required of the solid film:

a) It must have the correct gloss: All binders are glossy but have considerable variations.
b) It must adhere to the substrate (the surface being painted).
c) It needs the correct mechanical properties, this refers to the qualities of the combined film and substrate and include bending, scratching ad impact.

Pigments are fine insoluble crystalline particles which give colour to the paint. They may be organic or inorganic compounds. If the resulting hardened paint film is to be glossy, the pigment must all be below the surface. The amount of gloss is determined but the ratio of pigment to binder, usually measured on a volume basis. Very glossy paints with less pigment have a poor binding power while very matt ones are under bound. Increasing the pigment proportions increases the hardness but decreases flexibility. Other properties such as corrosion resistance and exterior durability are all affected by the quality and quantity of pigment.

Extenders are used to improve other properties of the paint although they have little or no pigmentary value. They can for instance used to control the amount of gloss.

- A semi-gloss paint might need so much pigment to achieve the correct gloss characteristics that it would not pour and would leave heavy brush marks.
- The addition of a filler such as china clay will considerably reduce cost and at the same time improve viscosity and finish. Only enough pigment to give colour and hiding power is needed.
- The amount of extender used varies depending on the paint but may be as much as 45 percent. Materials used as extenders do not affect the colour because their refractive index is very close to that of the soil.

Solvents are volatile liquids added at a suitable stage to lower the viscosity of the wet paint. They must evaporate very rapidly when the paint is applied to a surface so that high viscosity is obtained and hence freedom from runs.

The solvent can affect the final result and it is vital that the correct type is used for any particular resin system.

Driers are added to oil bound paints to accelerate drying process. Compounds of lead, manganese or cobalt are most common.

TYPES OF PAINTS:

1. Nitrocellulose Lacquers (Non-convertible)
2. Vinyl Lacquers (Non-convertible)
3. Acrylic Lacquers (Non-convertible)
4. Chlorinated Rubber (Non-convertible)
5. Oil Bound Paints (Convertible)
6. Alkyd Resins (convertible)

MODULE-II
INTRODUCTION TO MATERIAL TESTING

TYPES OF STRESSES :

Only two basic stresses exists : (1) normal stress and (2) shear stress.
Other stresses either are similar to these basic stresses or are a combination of this e.g. bending stress is a combination tensile, compressive and shear stresses. Torsional stress, as encountered in twisting of a shaft is a shearing stress. Let us define the normal stresses and shear stresses in the following sections.

Normal stresses : We have defined stress as force per unit area. If the stresses are normal to the areas concerned, then these are termed as normal stresses. The normal stresses are generally denoted by a Greek letter (ζ)

Tensile or compressive Stresses:
The normal stresses can be either tensile or compressive whether the stresses acts out of the area or into the area

Shear Stresses: Let us consider now the situation, where the cross – sectional area of a block of material is subject to a distribution of forces which are parallel, rather than normal, to the area concerned. Such forces are associated with a shearing of the material, and are referred to as shear forces. The resulting stress is known as shear stress.

Principle of Superposition
The principle of superposition states that when there are numbers of loads are acting together on an elastic material, the resultant strain will be the sum of individual strains caused by each load acting separately.

Strain: When a single force or a system force acts on a body, it undergoes some deformation. This deformation per unit length is known as strain.
Mathematically strain may be defined as deformation per unit length. So, Strain=Elongation/Original length

Elasticity: The property of material by virtue of which it returns to its original shape and size upon removal of load is known as elasticity.

Hooks Law
It states that within elastic limit stress is proportional to strain.
Mathematically
E= Stress Strain Where E = Young"s Modulus
Hooks law holds good equally for tension and compression.

Poisson’s Ratio
The ratio lateral strain to longitudinal strain produced by a single stress is known as Poisson‟s ratio. Symbol used for poisson‟s ratio is nu or 1/ m .

Modulus of Elasticity (or Young’s Modulus)
Young‟s modulus is defined as the ratio of stress to strain within elastic limit.

Stress – strain diagram for mild steel
A typical tensile test curve for the mild steel has been shown below

SALIENT POINTS OF THE GRAPH:
(A) So it is evident form the graph that the strain is proportional to strain or elongation is proportional to the load giving a st.line relationship. This law of proportionality is valid uptoa point A.
or we can say that point A is some ultimate point when the linear nature of the graph ceases or there is a deviation from the linear nature. This point is known as the limit of proportionality or the proportionality limit.
(B) For a short period beyond the point A, the material may still be elastic in the sense that the deformations are completely recovered when the load is removed. The limiting point B is termed as Elastic Limit .
(C) and (D) - Beyond the elastic limit plastic deformation occurs and strains are not totally recoverable. There will be thus permanent deformation or permanent set when load is removed. These two points are termed as upper and lower yield points respectively. The stress at the yield point is called the yield strength.
A study a stress – strain diagrams shows that the yield point is so near the proportional limit that for most purpose the two may be taken as one. However, it is much easier to locate the former. For material which do not posses a well define yield points, In order to find the yield point or yield strength, an offset method is applied.
In this method a line is drawn parallel to the straight line portion of initial stress diagram by off setting this by an amount equal to 0.2% of the strain as shown as below and this happens especially for the low carbon steel.
(E) A further increase in the load will cause marked deformation in the whole volume of the metal. The maximum load which the specimen can with stand without failure is called the load at the ultimate strength.
The highest point „E' of the diagram corresponds to the ultimate strength of a material. su = Stress which the specimen can with stand without failure & is known as Ultimate Strength or

Tensile Strength.su is equal to load at E divided by the original cross-sectional area of the bar.

(F) Beyond point E, the bar begins to forms neck. The load falling from the maximum until fracture occurs at F. Beyond point E, the cross-sectional area of the specimen begins to reduce rapidly over a relatively small length of bar and the bar is said to form a neck. This necking takes place whilst the load reduces, and fracture of the bar finally occurs at point F.

True stress – Strain Diagram:

Since when a material is subjected to a uniaxial load, some contraction or expansion always takes place. Thus, dividing the applied force by the corresponding actual area of the specimen at the same instant gives the so called true stress.

Ductile and Brittle Materials:

Based on this behaviour, the materials may be classified as ductile or brittle materials Ductile Materials: It we just examine the earlier tension curve one can notice that the extension of the materials over the plastic range is considerably in excess of that associated with elastic loading. The Capacity of materials to allow these large deformations or large extensions without failure is termed as ductility. The materials with high ductility are termed as ductile materials. Brittle Materials: A brittle material is one which exhibits a relatively small extensions or deformations to fracture, so that the partially plastic region of the tensile test graph is much reduced. This type of graph is shown by the cast iron or steels with high carbon contents or concrete.

Mechanical Properties of material:

Elasticity: Property of material by virtue of which it can regain its shape after removal of external load Plasticity: Property of material by virtue of which, it will be in a state of permanent deformation even after removal of external load. Ductility: Property of material by virtue of which, the material can be drawn into wires. Hardness: Property of material by virtue of which the material will offer resistance to penetration or indentation

Brinell hardness test

The Brinell hardness test is an optical testing method for samples with coarse or inhomogeneous grain structure. This is the best test method for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

The difference between Vickers method and the Brinell method is that the Vickers use pyramid-shaped indenter, whereas the Brinell method uses a spherical indenter.

Equipment Required

- Brinell hardness tester RAB-250
- Brinell microscope
- Indentors (2.5mm and 5mm ball)

Brinell Test Machine Description

1. The Brinell Hardness Tester consists of a loading system, the main screw, and a dial gauge.
2. The loading system consisting of weights, leavers and a hydraulic dashpot and a plunger arrangement is enclosed in the cast iron body of the machine.
3. The main screw is also protected from extraneous elements by a rubber bellow.
4. It carries the test table on its top to hold the specimen and is actuated by a hand at the base.
5. The machine is provided with two ball indenters (of sizes 2.5mm&5mm) to transmit the test load on to the specimen.

Theory and Principle of Brinell Test

The test consists of forcing a steel ball of diameter '**D'** under a load '**P'** into the specimen for a known time and measuring the mean diameter '**d**' of the impression left on the surface after removal of the load. The Brinell Hardness Number (BHN) is then calculated as load (in kg-f) dived by the surface area of indention (in mm^2).
Depth of Indentation (h) is given by,

Test Procedure

1. The surface of the test specimen must be either machined, ground, lapped or polished.
2. Set the machine to the required stage of the test load.
3. Choose the indentor to be used and fasten it to the machine.
4. Place the specimen on the test table and, apply a minor load of 10-kg-f on it by turning the hand wheel and bringing both the pointers on the dial gauge to the 'set' positions.
5. Apply the major load (remaining part of the test load) on the specimen by turning the loading lever backward.
6. Maintain the load on the specimen exactly for the specified dwell time (15 seconds) and then release it by turning the loading lever forwards.
7. Take out the specimen and measure the diameter of the indentation formed on it by using the Brinell Microscope.

Bending test

Bending strength is defined as a material's ability to resist deformation under load, it represents the highest stress experienced within the material at its moment of rupture.

There are two types of bending tests. Three point bending test and four point bending test.
In a three point bending test the area of uniform stress is quite small and concentrated under the centre loading point. In a four point bending test, the area of uniform stress exists between the inner span loading points (typically half the outer span length).

- When a specimen is bent, it experiences a range of stresses across its depth. At the edge of the concave face the stress will be at its maximum compressive value.
- At the convex face of the specimen the stress will be at its maximum tensile value. Most materials fail under tensile stress before they fail under compressive stress, so the maximum tensile stress value that can be sustained before the specimen fails is its flexural strength.
- The flexural strength would be the same as the tensile strength if the material were homogeneous. Therefore the flexural properties of a specimen are the result of the combined effect of all three stresses as well as (though to a lesser extent) the geometry of the specimen and the rate the load applied.

Bend testing provides insight into the modulus of elasticity and the bending strength of a material.

Tension test

Tension test is performed on mild steel, tor steel and high tensile steel to determine the properties like Young's modulus, ultimate strength, and the percentage elongation. In the tension test, a steel rod is subjected to tension load by the means of a Universal testing machine(UTM).
The equipment arrangement and procedure for conducting the tension test on steel rod are explained in this article in detail.

Equipment for Tension Test on Steel

The tension test requires:

1. Universal Testing Machine(UTM)
2. Extensometer
3. Scale VernierCalipers
4. Punching tools

Universal Testing Machine (UTM)

UTM comprises two main units, one is the loading unit and other is the control panel.

Loading unit: The loading of the specimen is conducted in the loading unit. In the figure above, the equipment in the left is called as the loading unit. The loading unit consists of three crossheads, they are **the upper head**, **middle head,** and **lower head.** These crossheads are used depending on the type of load(tensile, compressive or shear) applied on the specimen. When undergoing the tensile test, the upper and lower crossheads are used.

Control Panel:
This unit facilitates the load application on the specimen. The load application is performed by the action of hydraulic pressure. A pendulum dynamometer is fitted to measure and indicate the force coming on the specimen.
A big size load indicating dial fitted with a glass cover is mounted at the side of the control panel. The range indicating dial is to be adjusted for the particular range selected.

Theory
The specimen is subjected to constant tension load and the extension caused in the steel rod is noted against the load within the elastic limit. The load values at yield point, breaking point, and ultimate point are carefully noted.

With the obtained values, the stress and strain are calculated and plotted in a graph. From the data, we get:

1. Modulus of Elasticity, E = Stress/Strain[This is calculated within the elastic limit. The slope of the stress-strain curve provides the modulus of elasticity]
2. Yield Stress = Load at yield Point/Original C/s Area
3. Ultimate Stress = Ultimate Load/Original C/s Area
4. Nominal Breaking Stress = Breaking Load/Nominal Breaking Stress
5. Actual Breaking Stress = Breaking load/Neck Area
6. Percentage elongation = (Change in length/Original Length)/100
7. Percentage reduction in the area = (Change in length/Original Area)/100

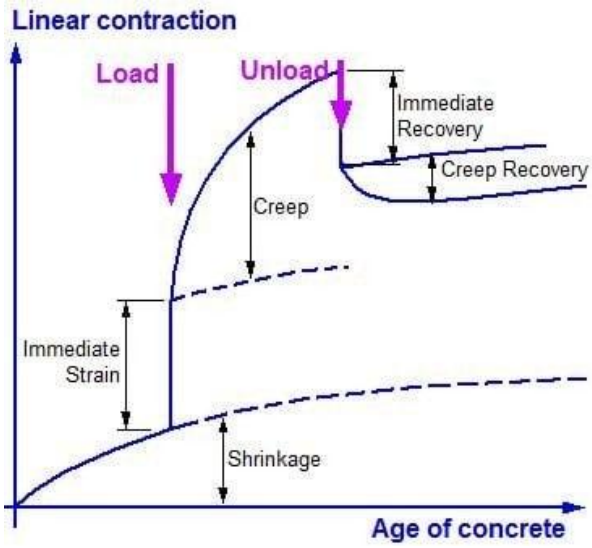
CREEP
Creep is defined as the long term deformation under a sustained load. Water within the hardened cement paste is forced to more as a result of the applied load. This movement of moisture is the primary cause of creep deformation. Some movement also occurs due to the propagation of micro cracks.

The movement due to creep can be greater than the elastic strain on loading. Creep can continue over a long period of time (more than 30 years in some cases) after the application of the load.
Many of the factors that affect shrinkage and modulus of elasticity also affect the creep is a similar way.

Following are the cases, which affect creep in concrete:

- When the aggregate volume is increased, creep will be less as the aggregate is more rigid than the cement paste.
- When the water/cement ratio is increased, the higher water/cement ratio will result in a more porous and weaker cement paste which will deform more under a given load.

- When the natural aggregate is replaced by a lightweight artificial aggregate, the lightweight aggregate will be more porous and less rigid than the natural aggregate.
- If the applied load is increased, the creep also increases.



Factors Affecting Creep

1. Aggregate
2. Mix Proportions
3. Age of concrete

The magnitude of creep strain is one to three times the value of the instantaneous elastic strain, it is proportional to cement-paste content and, thus, inversely proportional to aggregate volumetric content. The magnitude of creep is dependent upon the magnitude of the applied stress, the age and strength of the concrete, properties of aggregates and cementitious materials, amount of cement paste, size and shape of concrete specimen, volume to surface ratio, amount of steel reinforcement, curing conditions, and environmental conditions.

1. Influence of Aggregate

Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. An increase from 65 to 75 % of volumetric content of the aggregate will decrease the creep by 10 %.

The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate.

2. **Influence of Mix Proportions:**

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

3. Influence of Age:

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

Fracture mechanics

Introduction:

Fracture mechanics is all about cracks; stress fields around cracks, stress intensity factors at cracks, failures due to cracks, growth rates of cracks, etc. This website covers all of these topics, beginning with some historical perspective for motivation.

Failures have occurred for many reasons, including uncertainties in the loading or environment, defects in the materials, inadequacies in design, and deficiencies in construction or maintenance. Design against fracture has a technology of its own, and this is a very active area of current research. This module will provide an introduction to an important aspect of this field, since without an understanding of fracture the methods in stress analysis discussed previously would be of little use. We will focus on fractures due to simple tensile overstress, but the designer is cautioned again about the need to consider absolutely as many factors as possible that might lead to failure, especially when life is at risk.

The Module on the Dislocation Basis of Yield (Module 21) shows how the strength of structural metals – particularly steel – can be increased to very high levels by manipulating the microstructure so as to inhibit dislocation motion. Unfortunately, this renders the material increasingly brittle, so that cracks can form and propagate catastrophically with very little warning. An unfortunate number of engineering disasters are related directly to this phenomenon, and engineers involved in structural design must be aware of the procedures now available to safeguard against brittle fracture. The central difficulty in designing against fracture in high-strength materials is that the presence of cracks can modify the local stresses to such an extent that the elastic stress analyses done so carefully by the designers are insufficient. When a crack reaches a certain critical length, it can propagate catastrophically through the structure, even though the gross stress is much less than would normally cause yield or failure in a tensile specimen. The term "fracture mechanics" refers to a vital specialization within solid mechanics in which the presence of a crack is assumed, and we wish to find quantitative relations between the crack length, the material's inherent resistance to crack growth, and the stress at which the crack propagates at high speed to cause structural failure.

The energy-balance approach

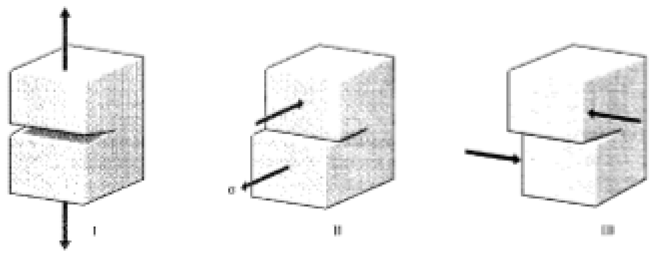
When A.A. Griffith (1893–1963) began his pioneering studies of fracture in glass in the years just prior to 1920, he was aware of Inglis' work in calculating the stress concentrations around elliptical holes2, and naturally considered how it might be used in developing a fundamental approach to predicting fracture strengths. However, the Inglis solution poses a mathematical difficulty: in the limit of a perfectly sharp crack, the stresses approach infinity at the crack tip. This is obviously nonphysical (actually the material generally undergoes some local yielding to blunt the cracktip), and using such a result would predict that materials would have nearzero strength: even for very small applied loads, the stresses near crack tips would become infinite, and the bonds there would rupture. Rather than focusing on the crack-tip stresses directly, Griffith employed an energy-balance approach that has become one of the most famous developments in materials science3.

When a crack has grown into a solid to a deptha, a region of material adjacent to the free surfaces is unloaded, and its strain energy released. Using the Inglis solution, Griffith was able to compute just how much energy this is.

A simple way of visualizing this energy release, illustrated in Fig. 1, is to regard two triangular regions near the crack flanks, of width a and height βa, as being completely unloaded, while the remaining material continues to feel the full stress σ. The parameter β can be selected so as toagree with the Inglis solution, and it turns out that for plane stress loading β = π. The total strain energy U released is then the strain energy per unit volume times the volume in both triangular regions:

$$U = -\sigma^2 /2E \cdot \pi a^2$$

The stress intensity approach



While the energy-balance approach provides a great deal of insight to the fracture process, an alternative method that examines the stress state near the tip of a sharp crack directly has proven more useful in engineering practice. The literature treats three types of cracks, termed mode I, II, and III as illustrated in Fig. 6. Mode I is a normal-opening mode and is the one we shall emphasize here, while modes II and III are shear sliding modes. As was outlined in Module 16, the semi-inverse method developed by Westergaard shows the opening-mode stresses to be:

$$\sigma_x = \frac{K_I}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right) + \ldots$$

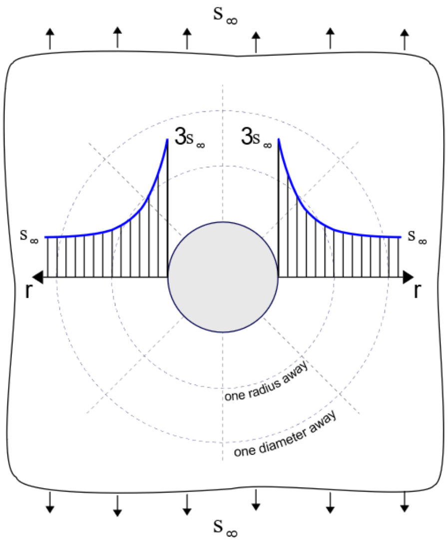
$$\sigma_y = \frac{K_I}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right) + \ldots$$

$$\tau_{xy} = \frac{K_I}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\cos\frac{3\theta}{2}\sin\frac{\theta}{2} \ldots$$

For distances close to the crack tip ($r \leq 0.1a$), the second and higher order terms indicated by dots may be neglected. At large distances from the crack tip, these relations cease to apply and the stresses approach their far-field values that would obtain were the crack not present. The KI in Eqns. 4 is a very important parameter known as the stress intensity factor. The I subscript is used to denote the crack opening mode, but similar relations apply in modes II and III. The equations show three factors that taken together depict the stress state near the crack tip: the denominator factor (2πr) −1/2 shows the singular nature of the stress distribution; σ approaches infinity as the crack tip is approached, with a r−1/2 dependency.

Stress State Schematics

The first sketch here plots the hoop stress, σθθσθθ at θ=±90∘θ=±90∘ as a function of rr. It shows the factor-of-three concentration at the hole's edge and how it quickly dissipates away with increasing rr The stress concentration is small again at one diameter distance from the hole's edge, and indeed negligible at two diameters distance. In finite element analyses, this steep gradient necessitates a very fine mesh in the radial direction in order to accurately model the stress and strain field.



Fracture Toughness

Fracture toughness is an indication of the amount of stress required to propagate a preexisting flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, or service of a material/component. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof. Since engineers can never be totally sure that a material is flaw free, it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the linear elastic fracture mechanics (LEFM) approach to design critical components. This approach uses the flaw size and features, component geometry, loading conditions and the material property called fracture toughness to evaluate the ability of a component containing a flaw to resist fracture.

A parameter called the stress-intensity factor (K) is used to determine the fracture toughness of most materials. A Roman numeral subscript indicates the mode of fracture and the three modes of fracture are illustrated in the image to the right. Mode I fracture is the condition in which the crack plane is normal to the direction of largest tensile loading. This is the most commonly encountered mode and, therefore, for the remainder of the material we will consider KI

The stress intensity factor is a function of loading, crack size, and structural geometry. The stress intensity factor may be represented by the following equation:

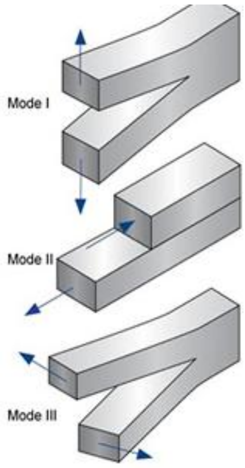
$$K_I = \sigma\sqrt{\pi a \beta}$$

Where: K_I is the fracture toughness in $MPa\sqrt{m}$ $(psi\sqrt{in})$

s is the applied stress in MPa or psi

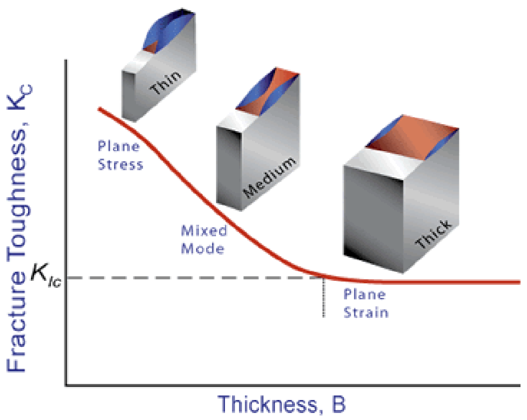
a is the crack length in meters or inches

B is a crack length and component geometry factor that is different for each specimen and is dimensionless.



Role of Material Thickness

Specimens having standard proportions but different absolute size produce different values for K_I. This results because the stress states adjacent to the flaw changes with the specimen thickness (B) until the thickness exceeds some critical dimension. Once the thickness exceeds the critical dimension, the value of K_I becomes relatively constant and this value, K_{IC} , is a true material property which is called the plane-strain fracture toughness. The relationship between stress intensity, K_I, and fracture toughness, K_{IC}, is similar to the relationship between stress and tensile stress. The stress intensity, K_I, represents the level of “stress” at the tip of the crack and the fracture toughness, K_{IC}, is the highest value of stress intensity that a material under very specific (plane-strain) conditions that a material can withstand without fracture. As the stress intensity factor reaches the K_{IC} value, unstable fracture occurs. As with a material’s other mechanical properties, K_{IC} is commonly reported in reference books and other sources.



Plane-Strain and Plane-Stress

When a material with a crack is loaded in tension, the materials develop plastic strains as the yield stress is exceeded in the region near the crack tip. Material within the crack tip stress field, situated close to a free surface, can deform laterally (in the z-direction of the image) because there can be no stresses normal to the free surface. The state of stress tends to biaxial and the material fractures in a characteristic ductile manner, with a 45^o shear lip being formed at each free surface. This condition is called "plane-stress" and it occurs in relatively thin bodies where the stress through the thickness cannot vary appreciably due to the thin section.

However, material away from the free surfaces of a relatively thick component is not free to deform laterally as it is constrained by the surrounding material. The stress state under these conditions tends to triaxial and there is zero strain perpendicular to both the stress axis and the direction of crack propagation when a material is loaded in tension. This condition is called "plane-strain" and is found in thick plates. Under plane-strain conditions, materials behave essentially elastic until the fracture stress is reached and then rapid fracture occurs. Since little or no plastic deformation is noted, this mode fracture is termed brittle fracture.

Plane-Stress and Transitional-Stress States

For cases where the plastic energy at the crack tip is not negligible, other fracture mechanics parameters, such as the J integral or R-curve, can be used to characterize a material. The toughness data produced by these other tests will be dependant on the thickness of the product tested and will not be a true material property. However, plane-strain conditions do not exist in all structural configurations and using KIC values in the design of relatively thin areas may result in excess conservatism and a weight or cost penalty. In cases where the actual stress state is plane-stress or, more generally, some intermediate- or transitional-stress state, it is more appropriate to use J integral or R-curve data, which account for slow, stable fracture (ductile tearing) rather than rapid (brittle) fracture.

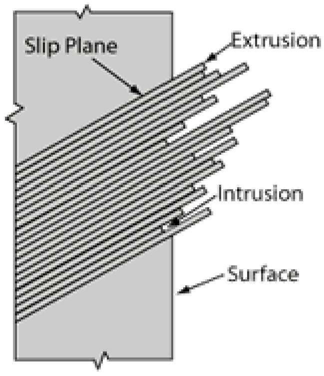
Fatigue Properties

Fatigue cracking is one of the primary damage mechanisms of structural components. Fatigue cracking results from cyclic stresses that are below the ultimate tensile stress, or even the yield stress of the material. The name “fatigue” is based on the concept that a material becomes “tired” and fails at a stress level below the nominal strength of the material. The facts that the original bulk design strengths are not exceeded and the only warning sign of an impending fracture is an often hard to see crack, makes fatigue damage especially dangerous.

The fatigue life of a component can be expressed as the number of loading cycles required to initiate a fatigue crack and to propagate the crack to critical size. Therefore, it can be said that fatigue failure occurs in three stages – crack initiation; slow, stable crack growth; and rapid fracture.

As discussed previously, dislocations play a major role in the fatigue crack initiation phase. In the first stage, dislocations accumulate near surface stress concentrations and form structures called persistent slip bands (PSB) after a large number of loading cycles. PSBs are areas that rise above (extrusion) or fall below (intrusion) the surface of the component due to movement of material along slip planes. This leaves tiny steps in the surface that serve as stress risers where tiny cracks can initiate. These tiny crack (called microcracks) nucleate along planes of high shear stress which is often 45^o to the loading direction.

In the second stage of fatigue, some of the tiny microcracks join together and begin to propagate through the material in a direction that is perpendicular to the maximum tensile stress. Eventually, the growth of one or a few crack of the larger cracks will dominate over the rest of the cracks. With continued cyclic loading, the growth of the dominate crack or cracks will continue until the remaining uncracked section of the component can no longer support the load. At this point, the fracture toughness is exceeded and the remaining cross-section of the material experiences rapid fracture. This rapid overload fracture is the third stage of fatigue failure.



Factors Affecting Fatigue Life

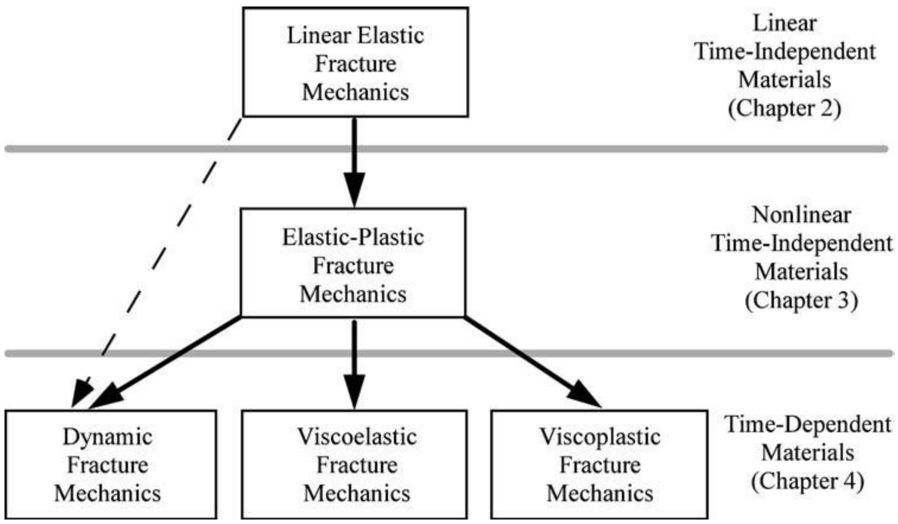
In order for fatigue cracks to initiate, three basic factors are necessary. First, the loading pattern must contain minimum and maximum peak values with large enough variation or fluctuation. The peak values may be in tension or compression and may change over time but the reverse loading cycle must be sufficiently great for fatigue crack initiation. Secondly, the peak stress levels must be of sufficiently high value. If the peak stresses are too low, no crack initiation will occur. Thirdly, the material must experience a sufficiently large number of cycles of the applied stress. The number of cycles required to initiate and grow a crack is largely dependant on the first to factors.

In addition to these three basic factors, there are a host of other variables, such as stress concentration, corrosion, temperature, overload, metallurgical structure, and residual stresses which can affect the propensity for fatigue. Since fatigue cracks generally initiate at a surface, the surface condition of the component being loaded will have an effect on its fatigue life. Surface roughness is important because it is directly related to the level and number of stress concentrations on the surface. The higher the stress concentration the more likely a crack is to nucleate. Smooth surfaces increase the time to nucleation. Notches, scratches, and other stress risers decrease fatigue life. Surface residual stress will also have a significant effect on fatigue life. Compressive residual stresses from machining, cold working, heat treating will oppose a tensile load and thus lower the amplitude of cyclic loading

EFFECT OF MATERIAL PROPERTIES ON FRACTURE

Below figure shows a simplified family tree for the field of fracture mechanics. Most of the early work was applicable only to linear elastic materials under quasistatic conditions, while subsequentadvances in fracture research incorporated other types of material behavior. Elastic-plastic fracturemechanics considers plastic deformation under quasistatic conditions, while dynamic, viscoelastic,and viscoplastic fracture mechanics include time as a variable. A dashed line is drawn betweenlinear elastic and dynamic fracture mechanics because some early research considered dynamiclinear elastic behavior. The chapters that describe the various types of fracture behavior are shownin Figure. Elastic-plastic, viscoelastic, and viscoplastic fracture behavior are sometimesincluded in the more general heading of nonlinear fracture mechanics. The branch of fracturemechanics one should apply to a particular problem obviously depends on material behavior.

Consider a cracked plate that is loaded to failure. Figure is a schematic plotof failure stress vs. fracture toughness KIc. For low toughness materials, brittle fracture is the governing

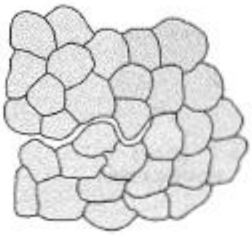


failure mechanism, and critical stress varies linearly with KIc, as predicted by Equation At very high toughness values, EFM is no longer valid, and failure is governed by the flow properties of the material. At intermediate toughness levels, there is a transition between brittle fracture under linear elastic conditions and ductile overload. Nonlinear fracture mechanics bridges the gap between LEFM and collapse. If toughness is low, LEFM is applicable to the problem, but if toughness is sufficiently high, fracture mechanics ceases to be relevant to the problem because failure stress is insensitive to toughness; a simple limit load analysis is all that is required to predict failure stress in a material with very high fracture toughness.

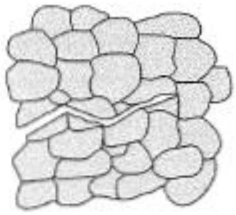
BRITTLE AND DUCTILE FRACTURE

Some materials are known as brittle because a crack moves easily through components made ofsuch materials. If we investigate a fractured surface of a brittle failure to determine the depth upto which the material is affected by the crack growth, we find that material was influenced to avery shallow depth. Rest of the material remains unaffected. On the contrary, a ductile fracturecauses a large amount of plastic deformation to a significant depth.

- Brittle fracture in crystalline metals can be classified into two broad groups- intergranularand trans granular.
- A crack tip of intergranular failure grows along the grain boundaries as shown below. Trans granular fracture, on the other hand, occurs through the crack tip propagatingwithin grains. However, cleavage failure within a grain occurs along a weakcrystallographic plane. In fact, cleavage fracture is the most brittle form of a fracture and it hardly.



(a) Intergranular



(b) Transgranular

Ductile fracture growth occurs due to substantial plastic deformation and creation of micro voids in the vicinity of the crack tip.

- The material deforms plastically due to micro mechanisms, such as nucleation and motion of dislocations, formation of twins, etc.
- Engineering materials generally contain second phase particles. Tiny voids are formed at the sides of these particles under the influence of the tensile field of the crack tip. Dislocation motion helps in the formation of these voids. The ductile crack growth occurs by the coalescence of these voids.
- Fractured surface of a ductile failure shows tiny dimples and gives the surface a rather rough look. In fact, around one such dimple, a second phase particle can be identified.
- The plastic deformation and coalescence of voids absorb a large amount of energy and, therefore, a crack does not grow easily in ductile materials.

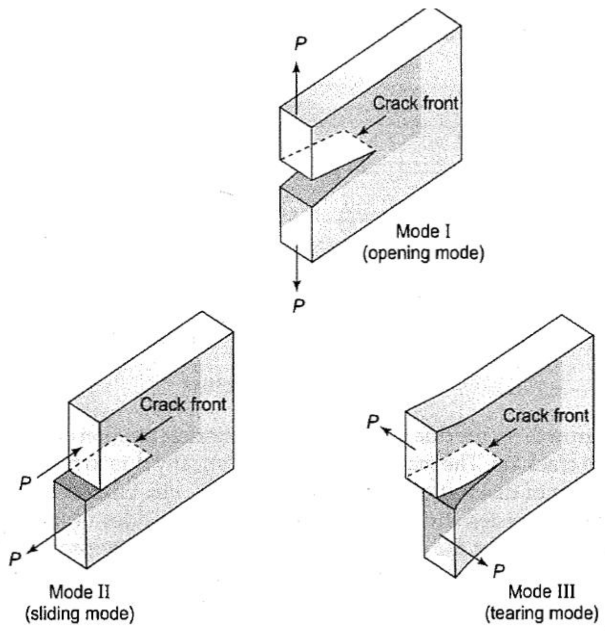
- Often it has been found that materials normally ductile at room temperature in ordinary

Conditions behave as brittle materials under certain special conditions. Steel, which is quite ductile at room temperature, becomes brittle at low temperatures. This explains why welded structures of Liberty ships in World War II failed in the cold waters of the North Atlantic Ocean. Also, the toughness of certain materials is affected considerably by the rate of loading (strain rate).

A thick plate of a regular ductile material may also allow the growth of a crack in a brittle manner. The portion that is deep inside the thick plate (away from free surfaces) is constrained from all sides and large plastic deformations are not possible in the vicinity of the crack-tip. In comparison to thick plates, thin plates are more resistant to crack growth. These aspects will be discussed in detail in subsequent chapters.

MODES OF FRACTURE FAILURE

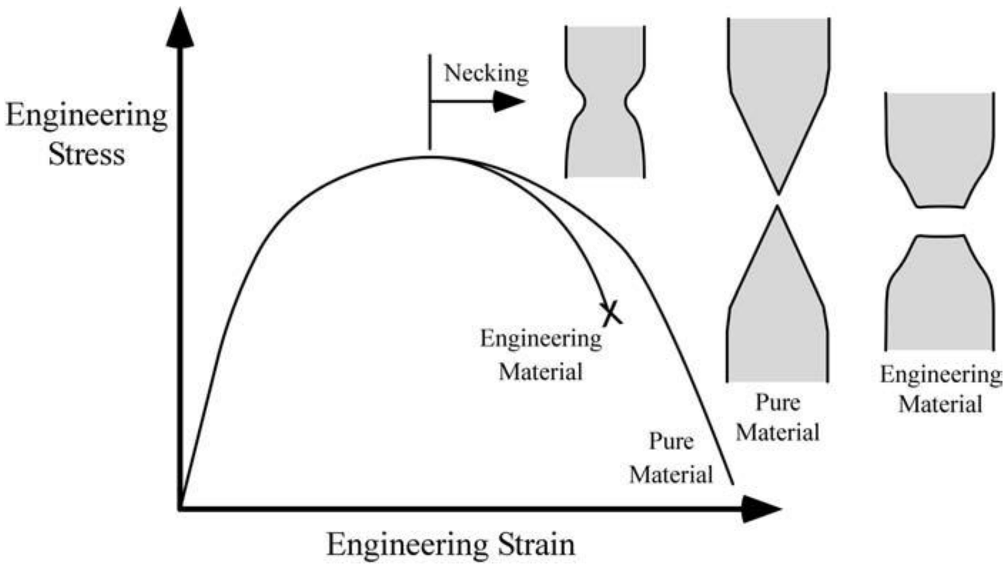
A crack front in a structural component is a line usually of varying curvature. Thus, the state of stress in the vicinity of the crack front varies from one point to another. A segment of the crack front can be divided into three basic modes as shown in Figure. Mode I is the opening mode and the displacement is normal to the crack surface. Mode II is a sliding mode and the displacement is in the plane of the plate-the separation is antisymmetric and the relative displacement is normal to the crack front. Mode III also causes sliding motion but the displacement is parallel to the crack front, thereby causing tearing.



An inclined crack front in a component can be modelled as a superposition of the three basic modes and then, the effect of loading by each mode can be analysed separately. Mode I usually plays a dominant role in many engineering applications and is considered to be the most dangerous. However,in certain applications, components fail through the dominant roles played by Mode II or Mode III. Mode I has been analysed most so far. Also, elaborate experimental methods have been developed to determine toughness in Mode I; in fact, detailed codes havebeen prepared for these experimental methods and they are internationally accepted. ·

DUCTILE FRACTURE

Belo figure schematically illustrates the uniaxial tensile behavior in a ductile metal. The material eventually reaches an instability point, where strain hardening cannot keep pace with the loss in the cross-sectional area, and a necked region forms beyond the maximum load. In very high purity materials, the tensile specimen may neck down to a sharp point, resulting in extremely large local plastic strains and nearly 100% reduction in area. Materials that contain impurities, however, fail at much lower strains. Micro voids nucleate at inclusions and second-phase particles; the voids grow together to form a macroscopic flaw, which leads to fracture.



The commonly observed stages in ductile fracture are as follows:

1. Formation of a free surface at an inclusion or second-phase particle by either interface decohesion or particle cracking.
2. Growth of the void around the particle, by means of plastic strain and hydrostatic stress.
3. Coalescence of the growing void with adjacent voids.

In materials where the second-phase particles and inclusions are well-bonded to the matrix, void nucleation is often the critical step; fracture occurs soon after the voids form. When void nucleation occurs with little difficulty, the fracture properties are controlled by the growth and coalescence of voids; the growing voids reach a critical size, relative to their spacing, and a local plastic instability develops between voids, resulting in failure.

THE DUCTILE-BRITTLE TRANSITION

The fracture toughness of ferritic steels can change drastically over a small temperature range. At low temperatures, steel is brittle and fails by cleavage. At high temperatures, the material is ductile and fails by micro void coalescence.

- Ductile fracture initiates at a particular toughness value, as indicated by the dashed line. The crack grows as the load is increased. Eventually, the specimen fails by plastic collapse or tearing instability.

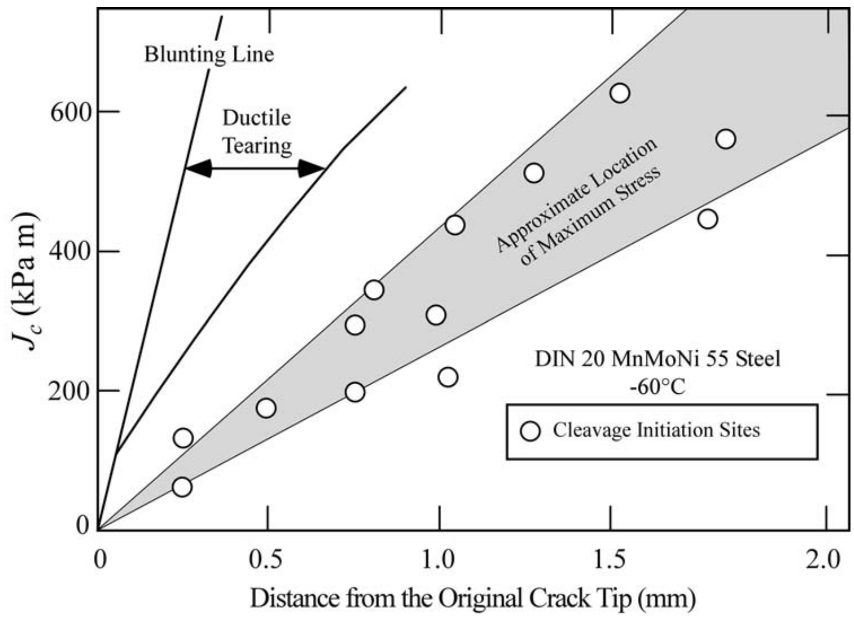
- In the transition region between ductile and brittle behavior, both micro mechanisms of fracture can occur in the same specimen.
- In the lower transition region, the fracture mechanism is pure cleavage, but the toughness increases rapidly with temperature as cleavage becomes more difficult.
- In the upper transition region, a crack initiates by micro void coalescence but ultimate failure occurs by cleavage. On initial loading in the upper transition region, cleavage does not occur because there are no critical particles near the crack tip.
- As the crack grows by ductile tearing, however, more material is sampled. Eventually, the growing crack samples a critical particle and cleavage occurs. Because the fracture toughness in the transition region is governed by these statistical sampling effects, the data tend to be highly scattered.
- Wallin has developed a statistical model for the transition region that incorporates the effect of prior ductile tearing on the cleavage probability.

Recent work by Heerens and Read demonstrates the statistical sampling nature of cleavage fracture in the transition region. They performed a large number of fracture toughness tests on a quenched and tempered alloy steel at several temperatures in the transition region.

1. As expected, the data at a given temperature were highly scattered. Some specimens failed without significant stable crack growth, while other specimens sustained high levels of ductile tearing prior to cleavage.

2. Heerens and Read examined the fracture surface of each specimen to determine the site of cleavage initiation. The measured distance from the initiation site to the original crack tip correlated very well with the measured fracture toughness.

3. In specimens that exhibited low toughness, this distance was small; a critical nucleus was available near the crack tip. In specimens that exhibited high toughness, there were no critical particles near the crack tip;

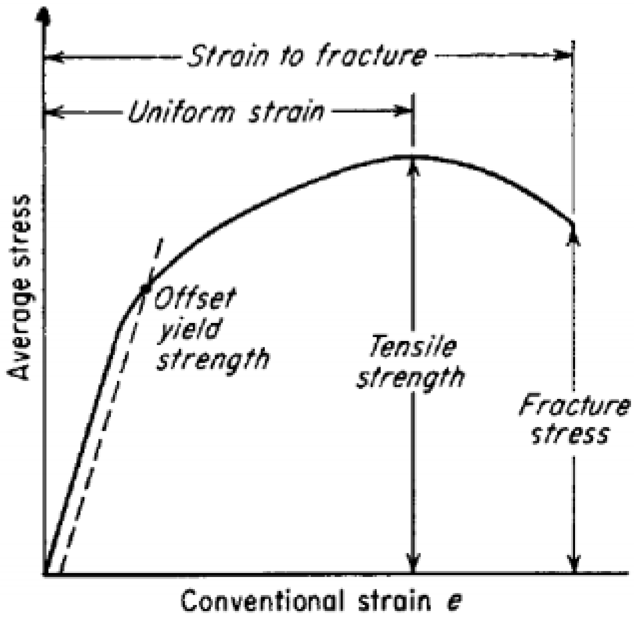

Blunting Line
Ductile
Tearing
Approximate Location
of Maximum Stress
DIN 20 MnMoNi 55 Steel
-60°C
Cleavage Initiation Sites
J_c (kPa m)
0
200
400
600
0
0.5
1.0
1.5
2.0
Distance from the Original Crack Tip (mm)

MOULE-III
STANDARD TESTING & EVALUATION PROCEDURES

TENSION TEST

ENGINEERING STRESS-STRAIN CURVE

- The engineering tension test is widely used to provide basic design information on the strength of materials and as an acceptance test for the specification of materials.
- In the tension test a specimen is subjected to a continually increasing uniaxial tensile force while simultaneous observations are made of the elongation of the specimen.
- An engineering stress-strain curve is constructed from the load-elongation measurements
- The stress used in this stress-strain curve is the average longitudinal stress in the tensile specimen. It is obtained by dividing the load by the original area of the cross section of the specimen.



The engineering stress-strain curve

The strain used for the engineering stress-strain curve is the average linear strain, which is obtained by dividing the elongation of the gage length of the specimen, δ, by its original length.

$$e = \frac{\delta}{L_0} = \frac{\Delta L}{L} = \frac{L - L_0}{L_0}$$

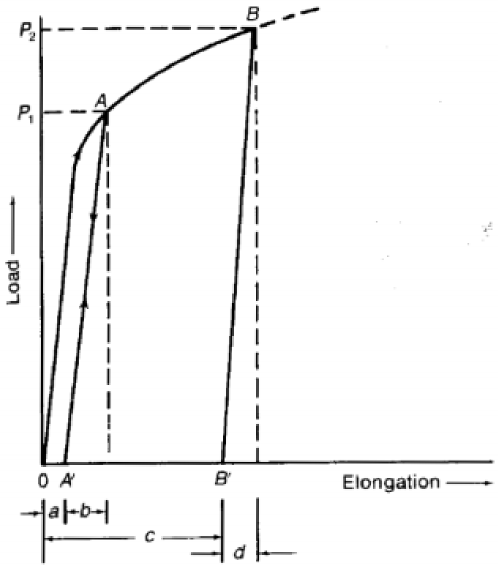
- Since both the stress and the strain are obtained by dividing the load and elongation by constant factors, the load-elongation curve will have the same shape as the engineering stress-strain curve. The two curves are frequently used interchangeably.

- The shape and magnitude of the stress-strain curve of a metal will depend on its composition, heat treatment, prior history of plastic deformation, and the strain rate, temperature, and state of stress imposed during the testing.

- The parameters which are used to describe the stress-strain curve of a metal are the tensile strength, yield strength or yield point, percent elongation, and reduction of area. The first two are strength parameters; the last two indicate ductility.
- The general shape of the engineering stress-strain curve requires further explanation.
- In the elastic region stress is linearly proportional to strain. When the load exceeds a value corresponding to the yield strength, the specimen undergoes gross plastic deformation.
- It is permanently deformed if the load is released to zero. The stress to produce continued plastic deformation increases with increasing plastic strain, i.e., the metal strain-hardens.
- The volume of the specimen remains constant during plastic deformation, AL = A0L0, and as the specimen elongates, it decreases uniformly along the gage length in cross-sectional area

.

- Initially the strain hardening more than compensates for this decrease in area and the engineering stress (proportional to load P) continues to rise with increasing strain.
- Eventually a point is reached where the decrease in specimen cross-sectional area is greater than the increase in deformation load arising from strain hardening.
- This condition will be reached first at some point in the specimen that is slightly weaker than the rest.
- All further plastic deformation is concentrated in this region, and the specimen begins to neck or thin down locally.
- Because the cross-sectional area now is decreasing far more rapidly than the deformation load is increased by strain hardening, the actual load required to deformthe specimen falls off and the engineering stress by Eq. likewise continues todecrease until fracture occurs.



Loading and unloading curves showing elastic recoverable strain and plastic deformation.

Tensile Strength

- The tensile strength, or ultimate tensile strength (UTS), is the maximum load divided by the original cross-sectional area of the specimen.

$$s_u = \frac{P_{max}}{A_0}$$

- The tensile strength is the value most often quoted from the results of a tension test; yet in reality it is a value of little fundamental significance with regard to the strength of a metal. For ductile metals the tensile strength should be regarded as a measure of the maximum load which a metal can withstand under the very restrictive conditions of uniaxial loading.

- It will be shown that this value bears little relation to the useful strength of the metal under the more complex conditions of stress which are usually encountered. For many years it was customary to base the strength of members on the tensile strength, suitably reduced by a factor of safety.

- The current trend is to the more rational approach of basing the static design of ductile metals on the yield strength. However, because of the long practice of using the tensile strength to determine the strength of materials, it has become a very familiar property, and as such it is a very useful identification of a material in the same sense that the chemical composition serves to identify a metal or alloy.

- Extensive empirical correlations between tensile strength and properties such as hardness and fatigue strength are often quite useful. For brittle materials, the tensile strength is a valid criterion for design.

Measures of Yielding

- The stress at which plastic deformation or yielding is observed to begin depends on the sensitivity of the strain measurements.

- With most materials there is a gradual transition from elastic to plastic behavior, and the point at which plastic deformation begins is hard to define with precision.
- Various criteria for the initiation of yielding are used depending on the sensitivity of the strain measurements and the intended use of the data.
  1. True elastic limit based on micro strain measurements at strains on order of 2 x 10 6.This elastic limit is a very low value and is related to the motion of a few hundred dislocations
  2. Proportional limit is the highest stress at which stress is directly proportional to strain. It is obtained by observing the deviation from the straight-line portion of the stress-strain curve.
  3. Elastic limit is the greatest stress the material can withstand without any measurable permanent strain remaining on the complete release of load. With increasing sensitivity of strain measurement, the value of the elastic limit is decreased until at the limit it equals the true elastic limit determined from micro strain measurements. With the sensitivity of strain usually employed in engineering studies (10 -4), the elastic limit is greater than the proportional limit. Determination of the elastic limit requires a tedious incremental loading unloading test procedure.
  4. The yield strength is the stress required to produce a small specified amount of plastic deformation. The usual definition of this property is the offset yield strength determined by the stress corresponding to the intersection of the stress-strain curve and a line parallel to the elastic part of the curve offset by a specified strain (Fig. 8-1). In the United States the offset is usually specified as a strain of 0.2 or 0.1 percent (e = 0.002 or 0.001).

$$s_0 = \frac{P_{(\text{strain offset} = 0.002)}}{A_0}$$

Measures of Ductility

At our present degree of understanding, ductility is a qualitative, subjective property of a material. In general, measurements of ductility are of interest in three ways:

(1) To indicate the extent to which a metal can be deformed without fracture in metalworking operations such as rolling and extrusion.
(2) To indicate to the designer, in a general way, the ability of the metal to flow plastically before fracture. A high ductility indicates that the material is "forgiving" and likely to deform locally without fracture should the designer err in the stress calculation or the prediction of severe loads.
(3) To serve as an indicator of changes in impurity level or processing conditions. Ductility measurements may be specified to assess material "quality" even though no direct relationship exists between the ductility measurement and performance in service.

Modulus of Elasticity

- The slope of the initial linear portion of the stress-strain curve is the modulus of elasticity, or Young's modulus.
- The modulus of elasticity is a measure of the stiffness of the material.
- The greater the modulus, the smaller the elastic strain resulting from the application of a given stress.
- Since the modulus of elasticity is needed for computing deflections of beams and other members, it is an important design value.
- The modulus of elasticity is determined by the binding forces between atoms.
- Since these forces cannot be changed without changing the basic nature of the material, it follows that the modulus of elasticity is one of the most structure-insensitive of the mechanical properties.
- It is only slightly affected by alloying additions, heat treatment, or cold-work.
- However, increasing the temperature decreases the modulus of elasticity. The modulus is usually measured at elevated temperatures by a dynamic method.

Resilience

- The ability of a material to absorb energy when deformed elastically and to return it when unloaded is called resilience.
- This is usually measured by the modulus of resilience, which is the strain energy per unit volume required to stress the material from zero stress to the yield stress σ0.
- Referring to Eq. (2-80), the strain energy per unit volume for uniaxial tension is

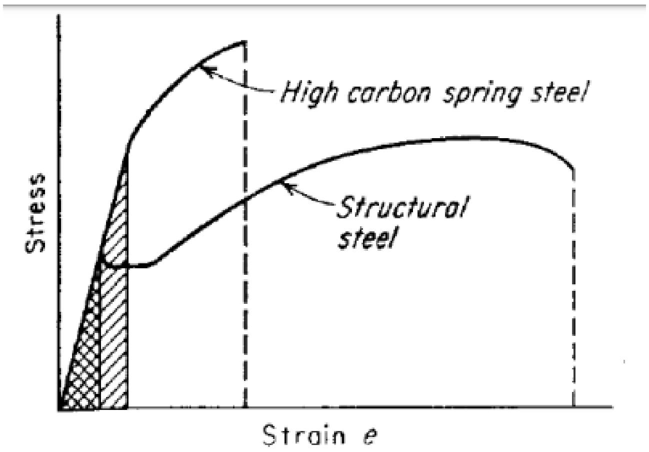
$$U_0 = \tfrac{1}{2}\sigma_x e_x$$

From the above definition the modulus of resilience is

$$U_R = \frac{1}{2}s_0 e_0 = \frac{1}{2}s_0\frac{s_0}{E} = \frac{s_0^2}{2E}$$

Toughness

- The toughness of a material is its ability to absorb energy in the plastic range. The ability to withstand occasional stresses above the yield stress without fracturing is particularly desirable in parts such as freight-car couplings, gears, chains, and crane hooks.
- Toughness is a commonly used concept which is difficult to pin down and define. One way of looking at toughness is to consider that it is the total area under the stress-strain curve.



Comparison of stress-strain curves for high Strain e and low-toughness materials.

- This area is an indication of the amount of work per unit volume which can be done on the material without causing it to rupture.
- Figure shows the stress-strain curves for high- and low-toughness materials.
- The high-carbon spring steel has a higher yield strength and tensile strength than the medium-carbon structural steel.
- However, the structural steel is more ductile and has a greater total elongation. The total area under the stress-strain curve is greater for the structural steel, and therefore it is a tougher material.
- This illustrates that toughness is a parameter which comprises both strength and ductility.
- The crosshatched regions in Fig. 8-3 indicate the modulus of resilience for each steel. Because of its higher yield strength, the spring steel has the greater resilience.
- Several mathematical approximations for the area under the stress-strain curve have been suggested.

True Fracture Stress

- The true fracture stress is the load at fracture divided by the cross-sectional area at fracture.
- This stress should be corrected for the triaxial state of stress existing in the tensile specimen at fracture. Since the data required for this correction are often not available, true-fracture-stress values are frequently in error.

True Fracture Strain

The true fracture strain ef is the true strain based on the original area A0 and the area after fracture Af.

$$\varepsilon_f = \ln \frac{A_0}{A_f}$$

- This parameter represents the maximum true strain that the material can withstand before fracture and is analogous to the total strain to fracture of the engineering stress strain curve.
- Since Eq. is not valid beyond the onset of necking, it is not possible to calculate ef from measured values of However, for cylindrical tensile specimens the reduction of area q is related to the true fracture strain by the relationship

$$\varepsilon_f = \ln \frac{1}{1-q}$$

TORSION TEST

INTRODUCTION

- The torsion test has not met with the wide acceptance and the use that have been given the tension test.
- However, it is useful in many engineering applications and also in theoretical studies of plastic low.
- Torsion tests are made on materials to determine such properties as the modulus of elasticity in shear, the torsional yield strength, and the modulus of rupture.
- Torsion tests also may be carried out on full-sized parts, such as shafts, axles, and twist dills, which are subjected to torsional loading in service.
- It is frequently used for testing brittle materials, such as tool steels, and has been used in the form of a high temperature twist test to evaluate the forgeability of materials.
- The torsion test has not been standardized to the same extent as the tension test and is rarely required in materials specifications.
- Torsion-testing equipment consists of a twisting head, with a chuck for gripping the specimen and for applying the twisting moment to the specimen, and a weighing head, which grips the other end of the specimen and measures the twisting moment, or torque.
- The deformation of the specimen is measured by a twist-measuring device called a troptometer.
- Determination is made of the angular displacement of a point near one end of the test section of the specimen with respect to a point on the same longitudinal element at the opposite end.
- A torsion specimen generally has a circular cross section, since this represents the simplest geometry for the calculation of the stress.

- Since in the elastic range the shear stress varies linearly from a value of zero at the centre of the bar to a maximum value at the surface, it is frequently desirable to test a thin-walled tubular specimen.
- This results in a nearly uniform shear stress over the cross section of the specimen

HARDNESS TEST

INTRODUCTION

- The hardness of a material is a poorly defined term which has many meanings depending upon the experience of the person involved.
- In general, hardness usually implies a resistance to deformation, and for metals the property is a measure of their resistance to permanent or plastic deformation.
- To a person concerned with the mechanics of materials testing, hardness is most likely to mean the resistance to indentation, and to the design engineer it often means an easily measured and specified quantity which indicates something about the strength and heat treatment of the metal.
- There are three general types of hardness measurements depending on the manner in which the test is conducted. These are
    1. Scratch hardness,
    2. Indentation hardness, and
    3. Rebound, or Dynamic, hardness.
- Only indentation hardness is of major engineering interest for metals.
- Scratch hardness is of primary interest to mineralogists.
- With this measure of hardness, various minerals and other materials are rated on their ability to scratch one another.
- Scratch hardness is measured according to the Mohs' scale. This consists of 10 standard minerals arranged in the order of their ability to be scratched.
- The softest mineral in this scale is talc (scratch hardness 1), while diamond has a hardness of 10. A fingernail has a value of about 2, annealed copper has a value of 3, and martensite a hardness of 7.

BRINELL HARDNESS

- The first widely accepted and standardized indentation-hardness test was proposed by J. A. Brinell in 1900.
- The Brinell hardness test consists in indenting the metal surface with a 10-mmdiameter steel ball at a load of 3,000 kg. For soft metals the load is reduced to 500

kg to avoid too deep an impression, and for very hard metals a tungsten carbide ball is used to minimize distortion of the indenter.

- The load is applied for a standard time, usually 30 s, and the diameter of the indentation is measured with a low-power microscope after removal of the load.
- The average of two readings of the diameter of the impression at right angles should be made. The surface on which the indentation is made should be relatively smooth and free from dirt or scale.
- The Brinell hardness number (BHN) is expressed as the load P divided by the surface area of the indentation.

ROCKWELL HARDNESS TEST

- The most widely used hardness test in the United States is the Rockwell hardness test. 45
- Its general acceptance is due to its speed, freedom from personal error, ability to distinguish small hardness differences in hardened steel, and the small size of the indentation, so that finished heat-treated parts can be tested without damage.
- This test utilizes the depth of indentation, under constant load, as a measure of hardness.
- A minor load of 10 kg is first applied to seat the specimen.
- This minimizes the amount of surface preparation needed and reduces the tendency for ridging or sinking in by the indenter.
- The major load is then applied, and the depth of indentation is automatically recorded on a dial gage in terms of arbitrary hardness numbers.
- The dial contains 100 divisions, each division representing a penetration of 0.002 mm.
- The dial is reversed so that a high hardness, which corresponds to a small penetration, results, in a high hardness number.
- This is in agreement with the other hardness numbers described previously, but unlike the Brinell and Vickers hardness designations, which have units of kilograms per square millimetre (kgf mm-2), the Rockwell hardness numbers. are purely arbitrary.
- One combination of load and indenter will not produce satisfactory results for materials with a wide range of hardness.
- A 120° diamond cone with a slightly rounded point, called a Brale indenter, and 1.6- and 3.2 mm diameters steel balls are generally used as indenters.

FRACTURE

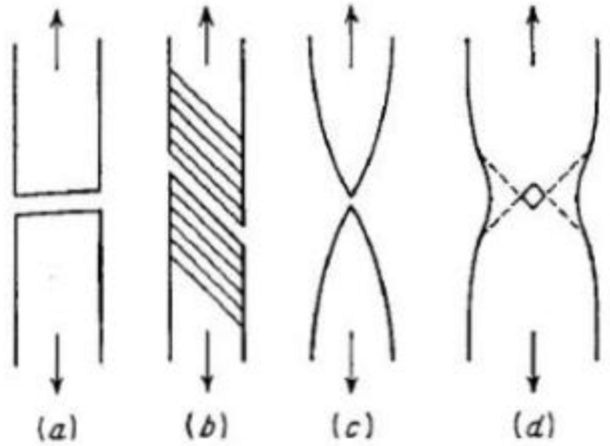
INTRODUCTION

- Fracture is the separation, or fragmentation, of a solid body into two or more parts under the action of stress.
- The process of fracture can be considered to be made up of two components, crack initiation and crack propagation.
- Fractures can be classified into two general categories, ductile fracture and brittle fracture.
- A ductile fracture is characterized by appreciable plastic deformation prior to and during the propagation of the crack. An appreciable amount of gross deformation is usually present at the fracture surfaces.
- Brittle fracture in metals is characterized by a rapid rate of crack propagation, with no gross deformation and very little micro deformation. It is akin to cleavage in ionic crystals.
- The tendency for brittle fracture is increased with decreasing temperature, increasing strain rate, and triaxial stress conditions (usually produced by a notch).
- Brittle fracture is to be avoided at all cost, because it occurs without warning and usually produces disastrous consequences.

TYPES OF FRACTURE IN METALS

- Metals can exhibit many different types of fracture, depending on the material, temperature, state of stress, and rate of loading.
- The two broad categories of ductile and brittle fracture have already been considered.
- Figure schematically illustrates some of the types of tensile fractures which can occur in metals.
- A brittle fracture (fig a) is characterized by separation normal to the tensile stress. Outwardly there is no evidence of deformation, although with x-ray diffraction analysis it is possible to detect a thin layer of deformed metal at the fracture surface.
- Brittle fractures have been observed in bcc and hcp metals, but not in fcc metals unless there are factors contributing to grain-boundary embrittlement.
- Ductile fractures can take several forms. Single crystals of hcp metals may slip on successive basal planes until finally the crystal separates by shear (Fig. b).

- Polycrystalline specimens of very ductile metals, like gold or lead, may actually be drawn down to a point before they rupture (Fig. c).
- In the tensile fracture of moderately ductile metals the plastic deformation eventually produces a necked region (Fig. d).



Types of fractures observed in metal subjected to uniaxial tension, (a) Brittle fracture of single crystals and polycrystals; (b) shearing fracture in ductile single crystals; (c) completely ductile fracture in polycrystals; (d) ductile fracture in polycrystals.

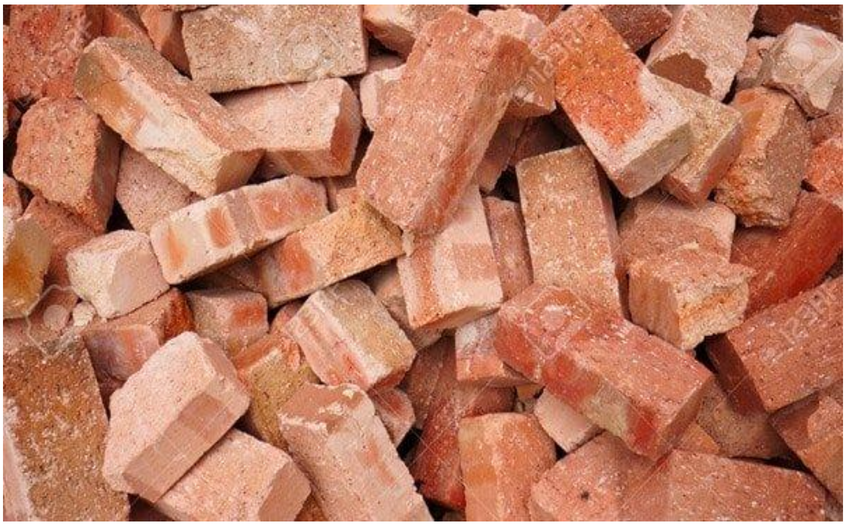
Mechanical property	**Testing method**
Elasticity Stiffness, material behaviour under static load	Tensile test, compression test, bending test, torsion test
Creep behaviour	Creep rupture test
Hardness	Brinell, Rockwell, Vickers
Toughness	Impact test
Fatigue behaviour, fatigue strength	Wöhler fatigue test

MODULE –IV
STANDARD TESTING PROCEDURES

TYPES OF TESTS ON BRICKS:

Various types of tests on bricks are conducted to check the qualities of bricks for construction purposes. Tests on bricks are conducted at construction site as well as in laboratory. Bricks are oldest and important construction materials because of their durability, reliability, strength and low cost.

To produce good quality of structure, good quality materials are required. To decide the quality of the materials some tests are to be conducted on bricks. The tests which are required to find the suitability of bricks for construction purposes are discussed below.



Types of Tests On Bricks for Construction Purpose

Following tests are conducted on bricks to determine its suitability for construction work.

1. Absorption test
2. Crushing strength test
3. Hardness test
4. Shape and size
5. Color test
6. Soundness test
7. Structure of brick
8. Presence of soluble salts (Efflorescence Test)

1. Absorption Test on Bricks

- Absorption test is conducted on brick to find out the amount of moisture content absorbed by brick under extreme conditions. In this test, sample dry bricks are taken and weighed.

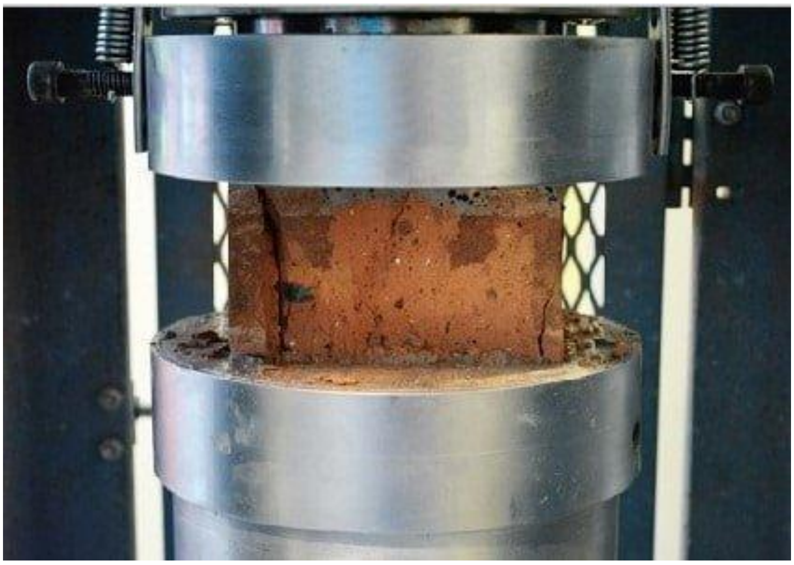
- After weighing these bricks are placed in water with full immersing for a period of 24 hours. Then weigh the wet brick and note down its value.

- The difference between dry and wet brick weights will give the amount of water absorption. For a good quality brick the amount of water absorption should not exceed 20% of weight of dry brick.

2. Crushing Strength or Compressive Strength Test on Bricks

Crushing strength of bricks is determined by placing brick in compression testing machine. After placing the brick in compression testing machine, apply load on it until brick breaks. Note down the value of failure load and find out the crushing strength value of brick.

Minimum crushing strength of brick is 3.50N/mm^2.if it is less than 3.50 N/mm^2, then it is not useful for construction purpose.



3. Hardness Test on Bricks

A good brick should resist scratches against sharp things. So, for this test a sharp tool or finger nail is used to make scratch on brick. If there is no scratch impression on brick then it is said to be hard brick.

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4. Shape and Size Test on Bricks

Shape and size of bricks are very important consideration. All bricks used for construction should be of same size. The shape of bricks should be purely rectangular with sharp edges. Standard brick size consists length x breadth x height as 19cm x 9cm x 9cm.

To perform this test, select 20 bricks randomly from brick group and stack them along its length , breadth and height and compare. So, if all bricks similar size then they are qualifiedfor construction work.

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5. Color Test of Bricks

A good brick should possess bright and uniform color throughout its body.

6. Soundness Test of Bricks

Soundness test of bricks shows the nature of bricks against sudden impact. In this test, 2 bricks are chosen randomly and struck with one another. Then sound produced should be clear bell ringing sound and brick should not break. Then it is said to be good brick.

7. Structure of Bricks

To know the structure of brick, pick one brick randomly from the group and break it. Observe the inner portion of brick clearly. It should be free from lumps and homogeneous.

8. Efflorescence Test on Bricks

A good quality brick should not contain any soluble salts in it. If soluble salts are there, then it will cause efflorescence on brick surfaces.

To know the presence of soluble salts in a brick, placed it in a water bath for 24 hours and dry it in shade. After drying, observe the brick surface thoroughly. If there is any white or grey color deposits, then it contains soluble salts and not useful for construction.

TESTING OF SAND QUALITY AT CONSTRUCTION SITE:

There are different methods for testing of sand quality at construction site for concrete construction. Quality of sand is as much of importance as other materials for concrete.

Aggregate most of which pass through 4.75 mm IS sieve is known as fine aggregate. Fine aggregate shall consists of natural sand, crushed stone sand, crushed gravel sand stone dust or arable dust, fly ash and broken brick (burnt clay).

It shall be hard, durable, chemically inert, clean and free from adherent coatings, organic matter etc. and shall not contain any appreciable amount of clay balls or pellets and harmful impurities e.g. iron pyrites, alkalis, salts, coal, mica, shale or similar laminated materials in such form or in such quantities as to cause corrosion of metal or affect adversely the strength, the durability or the appearance of mortar, plaster or concrete.

The sum of the percentages of all deleterious material shall not exceed 5%. Fine aggregate must be checked for organic impurities such as decayed vegetation humps, coal dust etc.

Testing of Sand Quality at Construction Site

Following are the tests for sand at construction site:

1. **Organic impurities test** – this test is conducted at the field, for every 20 cum or part thereof.
2. **Silt content test** – this is also a field test and to be conducted for every 20 cum.
3. **Particle size distribution** – this test can be conducted at site or in laboratory for every 40 cum of sand.
4. **Bulking of sand** – this test is conducted at site for every 20 cum of sand. Based on bulking of sand, suitable water cement ratio is calculated for concrete at site.

1. Test for Silt Content Test of Sand

The maximum quantity of silt in sand shall not exceed 8%. Fine aggregate containing more than allowable percentage of silt shall be washed so as to bring the silt content within allowable limits.

2. Test for Grading of sand

On the basis of particle size, fine aggregate is graded into four zones. Where the grading falls outside the limits of any particular grading zone of sieves, other than 600 micron IS sieve, by a total amount not exceeding 5 percent, it shall be regarded as falling within that grading zone.

IS Sieve	Percentage passing for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10mm	100	100	100	100
4.75mm	90 – 100	90 – 100	90 – 100	90 – 100
2.36mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100
600 micron	15 – 34	35 – 59	60 – 79	80 – 100
300 microns	5 – 20	8 – 30	12 – 40	15 – 50
150 microns	0 – 10	0 – 10	0 – 10	0 – 15

3. Test for Deleterious materials in sand

Sand shall not contain any harmful impurities such as iron, pyrites, alaklies, salts, coal or other organic impurities, mica, shale or similar laminated materials, soft fragments, sea shale in such form or in such quantities as to affect adversely the hardening, strength or durability of the mortar.

The maximum quantities of clay, fine silt, fine dust and organic impurities in the sand / marble dust shall not exceed the following limits:

(a) Clay, fine silt and fine dust when determined in accordance within not more than 5% by mass in IS 2386 (Part-II), natural sand or crushed gravel sand and crushed stone sand.

(b) Organic impurities when determined in colour of the liquid shall be lighter in lighter in accordance with IS 2386 (Part –II) than that specified in the code.

4. Test for Bulking of sand

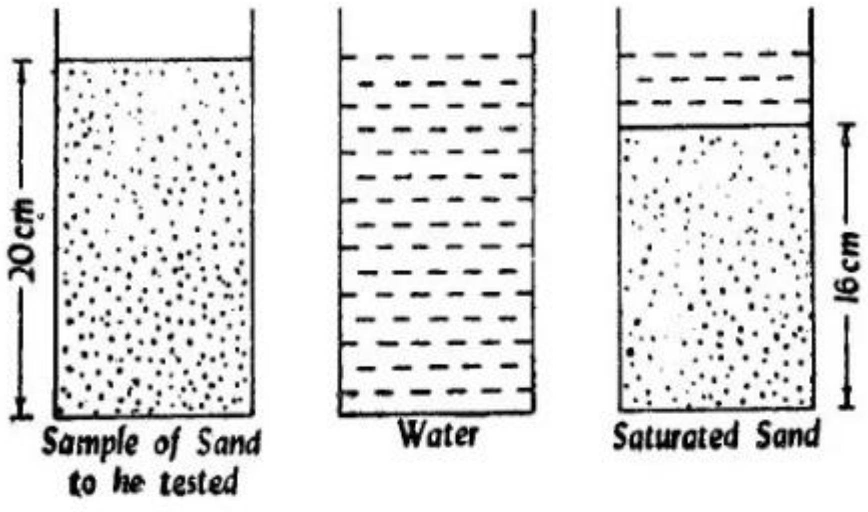

Fig: Bulking of sand test

Fine aggregate, when dry or saturated, has almost the same volume but dampness causes increase in volume. In case fine aggregate is damp at the time of proportioning the ingredients for mortar or concrete, its quantity shall be increased suitably to allow for bulkage.

Table below gives the relation between moisture content and percentage of bulking for guidance only.

Moisture content (%)	Bulking percentage (by volume)
2	15
3	20
4	25
5	30

TESTS ON CONCRETE:

Quality tests on concrete are performed as a part of quality control of concrete structures. Different quality tests on concrete such as compressive strength tests, slump tests, permeability tests etc.are used to assure the quality of the concrete that is supplied for a given specification.

These quality tests on concrete give an idea about the properties of concrete such as strength, durability, air content, permeability etc.

Tests for Concrete Quality Check

Each quality test conducted on concrete determines their respective quality result of concrete. Hence, it is not possible to conduct all the test to determine the quality of concrete. We have to choose the best tests that can give good judgment of the concrete quality.

The primary quality test determines the variation of the concrete specification from the required and standard concrete specification. The quality tests ensure that the best quality concrete is placed at the site so that concrete structural members of desired strength are obtained.

Below mentioned are the quality tests conducted on fresh and hardened concretes.

Quality Tests on Fresh Concrete

Most Common Quality Tests on Fresh concrete are:

1**. Workability Tests**

Workability of concrete mixture is measured by, Vee-bee consistometer test, Compaction factor Test, and Slump test.

2. Air content

Air content measures the total air content in a sample of fresh concrete but does not indicate what the final in-place air content is, because a certain amount of air is lost in transportation Consolidating, placement, and finishing.

3. Setting Time

The action of changing mixed cement from a fluid state to a solid state is called “Setting of Cement”.

Initial Setting Time is defined as the period elapsing between the time when water is added to the cement and the time at which the needle of 1 mm square section fails to pierce the test block to a depth of about 5 mm from the bottom of the mould.

Final Setting Time is defined as the period elapsing between the time when water is added to cement and the time at which the needle of 1 mm square section with 5 mm diameter attachment makes an impression on the test block.

Other tests conducted on fresh concrete are:

1. Segregation resistance
2. Unit weight
3. Wet analysis
4. Temperature
5. Heat generation
6. Bleeding

Tests on Hardened Concrete

Most Common Quality Tests on hardened concrete are:

1. Compressive strength

The compressive strength of concrete cube test provides an idea about all the characteristics of concrete.

2. Tensile strength

The tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. Moreover, the concrete is very weak in tension due to its brittle nature. Hence.it is not expected to resist the direct tension. So, concrete develops cracks when tensile forces exceed its tensile strength. Therefore, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack.

3. Modulus of elasticity

Modulus of elasticity of concrete is the ratio of stress to the strain of the concrete under the application of loads.

4. Permeability Tests on Concrete

When concrete is permeable it can cause corrosion in reinforcement in presence of oxygen, moisture, CO^2, SO^{3-} and Cl^- etc. This formation of rust due to corrosion becomes nearly 6 times the volume of steel oxide layer, due to which cracking develops in reinforced concrete and spalling of concrete starts.

5. In situ test on concrete

There are various in-situ test conducted on hardened concrete, both destructive and non-destructive. Some of them are concrete pull out tests, Break off tests, Schmidt Hammer test. Other quality tests are conducted to test the following

1. Modulus of rupture
2. Density
3. Shrinkage
4. Creep
5. Freeze/thaw resistance
6. Resistance to aggressive chemicals
7. Resistance to abrasion
8. Bond to reinforcement
9. Absorption

Compression Test and Slump Test for Quality Tests

Among the tests mentioned above, the two major tests mainly considered as quality tests are the compression tests and slump tests. If necessary, it is desired to conduct fresh concrete temperature and hardened concrete density determination tests.

The reasons for the selection of compressive strength test and slump test in practice for quality control testing of concrete are:

1. Most of the concrete properties are related to the compressive strength that is obtained by compressive strength test.
2. Compressive strength test is the easiest, most economical or most accurately determinable test.
3. The variability of concrete is best studied by means of compressive strength tests.

4. The quality of the mix is judged by the slump test. This studies the variation of construction materials in the mix. These tests focus on the water-cement ratio of the concrete mix.
5. The slump test is easy to conduct. It determines the quality of concrete very fastly before its placement. The placement standards are as recommended by the respective concrete practice codes.
6. Slump test is conducted at the site which does not require any lab arrangement or expensive testing machines. Hence this test is economical.
7. We conduct the slump test before pouring into the formwork. Hence if there is an issue with the concrete quality, the tested batch can be rejected. This would help in bringing up a defective structural member and avoiding future dismantling and repair.

TYPES ON SOIL TESTS:

Types of Soil tests for building construction works depend on properties of soil. Design of foundation is based on soil test report of construction site.

Soil tests for construction of buildings or any structure is the first step in construction planning to understand the suitability of soil for proposed construction work.

Soil which is responsible for allowing the stresses coming from the structure should be well tested to give excellent performance. If soil shouldn't tested correctly then the whole building or structure is damaged or collapsed or leaned like leaning tower of Pisa. So, soil inspection or testing is the first step to proceed any construction.

Types of Soil Tests for Building Construction

Various tests on soil are conducted to decide the quality of soil for building construction. Some tests are conducted in laboratory and some are in the field. Here we will discuss about the importance of various soil tests for building construction. The tests on soil are as follows.

1. Moisture content test
2. Atterberg limits tests
3. Specific gravity of soil
4. Dry density of soil
5. Compaction test (Proctor's test)

Moisture Content Test on Soil

Moisture content or water content in soil is an important parameter for building construction. It is determined by several methods and they are

- Oven drying method
- Calcium carbide method
- Torsion balance method
- Pycnometer method
- Sand bath method
- Radiation method
- Alcohol method

Of all the above oven drying method is most common and accurate method. In this method the soil sample is taken and weighed and put it in oven and dried at $110^{o} \pm 5^{o}C$. After 24 hours soil is taken out and weighed. The difference between the two weights is noted as weight of water or moisture content in the soil.

<u>Specific Gravity Test on Soil</u>:

Specific gravity of soil is the ratio of the unit weight of soil solids to that of the water. It is determined by many methods and they are:

- Density bottle method
- Pycnometer method
- Gas jar method
- Shrinkage limit method
- Measuring flask method

Density bottle method and Pycnometer method are simple and common methods. In Pycnometer method, Pycnometer is weighed in 4 different cases that is empty weight (M1), empty + dry soil (M2), empty + water + dry soil (M3) and Pycnometer filled with water (M4) at room temperature. From these 4 masses specific gravity is determined by below formula.

$$G = \frac{(M2-M1)}{(M2-M1)-(M3-M4)}$$

Dry Density Test on Soil

The weight of soil particles in a given volume of sample is termed as dry density of soil. Dry density of soil depends upon void ratio and specific gravity of soil. Based on values of dry density soil is classified into dense, medium dense and loose categories.

Dry density of soil is calculated by core cutter method, sand replacement method and water-displacement method.

Core Cutter Method for Soil Dry Density Testing

In this methods a cylindrical core cutter of standard dimensions is used to cut the soil in the ground and lift the cutter up with soil sample. The taken out sample is weighed and noted. Finally water content for that sample is determined and dry density is calculated from the below relation.

$$\rho = \frac{(M/V)}{1+w}$$

Sand Replacement Method for Soil Dry Density Testing

In this method also, a hole is created in the ground by excavating soil whose dry density is to be find. The hole is filled with uniform sand of known dry density. So by dividing the mass of sand poured into the hole with dry density of sand gives the volume of hole. So we can calculate the soil dry density from above formula.

Atterberg Limits Test on Soil :

To measure the critical water content of a fine grained soil, Atterberg provided 3 limits which exhibits the properties of fine grained soil at different conditions. The limits are liquid limit, plastic limit and shrinkage limit. These limits are calculated by individual tests as follows.

Liquid Limit Test on Soil :

In this test, Casagrande's liquid limit device is used which consist a cup with moving up and down mechanism. The cup is filled with soil sample and groove is created in the middle of cup with proper tool. When the cup is moved up and down with the help of handle the groove becomes closed at some point.

Note down the number of blows required to close the groove. After that water content of soil is determined. Repeat this procedure 3 times and draw a graph between log N and water content of soil. Water content corresponding to N=25 is the liquid limit of soil.

<u>Plastic Limit Test on Soil</u> :

Take the soil sample and add some water to make it plastic enough to shape into small ball. Leave it for some time and after that put that ball in the glass plate and rolled it into threads of 3mm diameter.

If the threads do not break when we roll it to below 3mm diameter, then water content is more than the plastic limit. In that case reduce water content and repeat the same procedure until crumbling occurs at 3mm diameter. Finally find out the water content of resultant soil which value is nothing but plastic limit.

Shrinkage Limit Test on Soil :

In case of shrinkage limit, the water content in the soil is just sufficient to fill the voids of soil. That is degree of saturation is of 100%. So, there is no change in volume of soil if we reduce the shrinkage limit. It is determined by the below formula for the given soil sample.

$$Ws = \frac{(M1-M2)n-(V1-V2)Pw}{M2}$$

Where M1 = initial mass

V1= initial volume

M2= dry mass

V2= volume after drying

Pw = density of water.

Proctor's Compaction Test on Soil :

Proctor's test is conducted to determine compaction characteristics of soil. Compaction of soil is nothing but reducing air voids in the soil by densification. The degree of Compaction is measured in terms of dry density of soil.

In Proctor’s Compaction Test, given soil sample sieved through 20mm and 4.75 mm sieves. Percentage passing 4.75mm and percentage retained on 4.75mm are mixed with certain proportions.

Add water to it and leave it in air tight container for 20hrs. Mix the soil and divide it into 6 – 8 parts. Position the mold and pour one part of soil into the mold as 3layers with 25 blows of ramming for each layer.

Remove the base plate and Weight the soil along with mold. Remove the soil from mold and take the small portion of soil sample at different layers and conduct water content test. from the values find out the dry density of soil and water content and draw a graph between them and note down the maximum dry density and optimum water content of the compacted soil sample at highest point on the curve.

MODULE-V

TESTING PROCEDURES OF SPECIAL MATERIALS

POLYMER CEMENT CONCRETE – PROPERTIES AND USES:

Polymer cement concrete is a composite concrete that consist of synthetic polymer within the binding material. Polymer concrete has advantages of higher properties, low energy requirements and low labor costs. It is also called as Polymer Portland cement concrete (PPCC) or latex-modified concrete (LMC).

The composition, properties and applications of polymer cement concrete are explained below.

Composition of Polymer Cement Concrete (PCC)

To the Portland cement a prepolymer (monomer) of a dispersed polymer is incorporated to make PCC. This combination creates a polymer network in situ during the curing process of the concrete.

The use of typical vinyl monomers can interfere with the hydration process or can get degraded. So the use of prepolymers are found more effective as perform the function required. In order to improve the mechanical properties of the PCC, these prepolymers can be added in higher proportions.

As this concrete property is based on the incorporation of a polymer, special care and attention is taken while adding the latex. The emulsion employed increases the lubrication properties of the mix. Hence, only less amount of water is required for workability of the mix.

Requirements of Polymers used in PCC

1. The latex under ambient conditions must be able to form a film so that it properly coats the cement and the aggregate particles. This helps to create a strong bond between the aggregate and the cement matrix.
2. A growing micro rack must be intercepted by the polymer network formed. This is done by dissipating energy through the formation of a micro fibril.

Polymer Latex used in PCC

1. Poly (Vinyl esters)
2. Poly Epoxies (Vinylidene – chloride)
3. Copolymers

4. Styrene Utadiene

Properties of Polymer Cement Concrete

1. Highly Impermeable

The polymer phase in the concrete will help reduce the porosity and micro cracks that are formed in cement matrix. This acts as an additional binding material other than the Portland cement used.

2. High Durability

A dense and water tight concrete is obtained by the use of PCC. This prevents chemical attacks, water penetration and hence no chance of corrosion. The internal micro cracks in cement matrix too is prevented. This increases the life of the structure.

3. Resistance to weathering Conditions

The PCC structure being impermeable they are less affected by the changing weather conditions.

Considerations in Polymer Cement Concrete Construction

1. PCC overlays have excellent long-term performance.
2. Mixing of PCC must be done in a concrete mobile mixer.
3. Handling, placing, and finishing of PCC is to be completed in less than 30 min.
4. PCC requires one to two days of moist curing followed by air drying.
5. Styrene-butadine PCC has excellent durability for exterior exposures or environments where moisture is present.
6. Surface discoloration occurs when the concrete is exposed to UV light, except for acrylic polymers.
7. It is used as overlay of bridge decks, floors, and patching of any concrete surfaces ranging in thickness from 4 to 100 mm for concretes.
8. Acrylic latexes are used for floor repair and patching and in cases where color retention is important.
9. These overlays produce high-strength wearing surface that is very durable against weathering.
10. PCC must be placed and cured at 7 to 30 °C.

11. Mobile, continuous mixers, fitted with an additional storage tank for the latex must be used for large applications of polymer modified concrete.
12. The mixing time is limited to 3 min for small batches or for mortar mixers.
13. PMC has a tendency for plastic shrinkage cracking during placement and special precautions are necessary when the evaporation rate exceeds 0.5 kg/m2/h.
14. The modulus of elasticity is generally lower compared to conventional concrete and hence its use in axially loaded members must be evaluated accordingly.
15. Polyvinyl acetate mixtures must not be exposed to moisture.
16. Epoxy emulsions are more expensive.

Applications of Polymer Cement Concrete

1. Bridge deck coverings

The use of PCC helps to provide highly impermeable and water tight surface that will prevent the ingress of moisture and chlorides thus avoiding reinforcement corrosion, spalling and microcracks.

2. Floor construction

Increased chemical resistance properties, high physical and mechanical properties make it best choice for industrial floor construction. These are also used in pavement construction where the area is subjected to heavy traffic.

3**. Precast construction**

Good workability and heat curing characteristics demand it for precast operations. PCC units with a less water cement ratio can be obtained.

4. Used as patching compounds

PCC can be used for patching and repair works of ordinary Portland cement concrete. This increases the strength and life of existing structure. PCC must be applied only after the removal of old material.

TESTING OF METALS :

Metal testing is a process or procedure used to check composition of an unknown metallic substance. There are destructive processes and non-destructive processes. Metal testing can also include, determining the properties of newly forged metal alloys. With many chemical-property databases readily available, identification of unmarked pure, common metals can be a quick and easy process. Leaving the original sample in complete, re-usable condition. This type of testing is non-destructive. When working with alloys (forged mixtures) of metals however, to determine the exact composition, could result in the original sample being separated into its starting materials, then measured and calculated. After the components are known they can be looked up and matched to known alloys. The original sample would be destroyed in the process. This type of testing is destructive.

Destructive Testing :

In this kind of testing, the material undergoes mechanical testing and is discarded thereafter. Test results are compared with specifications. Subtypes include:

- Bend test
- Impact test – Further categorised as Charpy test and Izod test
- Hardness test
- Tensile test
- Fatigue test
- Corrosion resistance test
- Wear test

Non-Destructive Testing :

Raw and finished material undergoes testing according to code specifications such as ASME Boiler and Pressure Vessel Code Section V. The tested material is not damaged by the test. Subtypes include:

- Visual testing
- Dye penetrate inspection
- Magnetic particle inspection
- Radiographic testing
- Ultrasonic testing
- Leak testing
- Eddy current testing
- Remote field electromagnetic testing
- LR UT

Composite Materials

Composites are combinations of two more separate materials on a microscopic level, in a controlled manner to give desired properties. The properties of a composite will be different from those of the constituents in isolation.

When two materials are combined together to form a composite, one of the materials will be in “Reinforcing phase” and the other material will be in “Matrix phase”. Typically, reinforcing material in the form of fibres, sheets or particles are strong with low densities while the matrix is usually a ductile or tough material.

Eg.: Glass -> Reinforcing material

Polyester -> Matrix material

Glass + Polyester -> GRP (Glass fibre reinforced plastic)

Classification

Composites can be broadly classified in to two groups. They are,

1. Natural composites

2. Man-made composites

Several natural materials can be grouped under natural composites.

Eg.: Bone, Wood etc.,

Man-made composites are produced by combining two or more materials in definite proportions under controlled conditions.

Eg.:

1. Mud mixed straw to produce stronger mud mortar and bricks.

2. Ferro-cement

3. Concrete and RCC

4. Plywood, Chipboards, Decorative laminates