GATE – CIVIL ENGINEERING

CONCRETE STRUCTURES (RCC & PSC)
Construction Materials and Management

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Mix design of concrete

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60	–	300	0.55	M 20
iii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

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Mix design of concrete

1. Target mean strength, $f_t = f_{ck} + 1.65\sigma$

f_{ck} : characteristic strength of concrete

σ : standard deviation

Grade of concrete	σ, N/mm^2
M10, M15	3.5
M20, M25	4.0
M30, M35, M40, M45, M50	5.0

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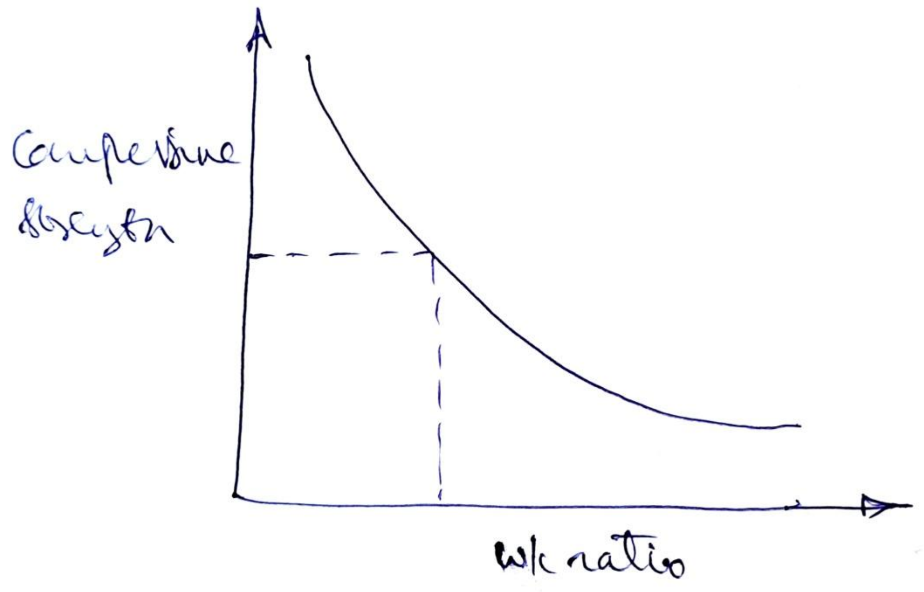
2. Water-cement ratio from the charts available.

Exposure	Minimum cement content, kg/m^2	Maximum w/c ratio
Mild	300	0.55
Moderate	300	0.50
Severe	320	0.45
Very severe	340	0.45
Extreme	360	0.40



3. Determine the water content based on workability requirements.

Water content: 180-200 litres/m^3 of concrete

4. Fine aggregate to coarse aggregate ratio

1:1.5 to 1:2.5 (1:2)

5. Determine the weight of cement

$$\text{w/c ratio} = \frac{\text{weight of water}}{\text{weight of cement}}$$

6. Determine the weight of ingredients per batch based on capacity of concrete mixer.

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7. Compute weight of fine aggregate and weight of coarse aggregate based on absolute volume principle.

$$\frac{W_c}{\rho_c} + \frac{W_{FA}}{\rho_{FA}} + \frac{W_{CA}}{\rho_{CA}} + V_w + V_v = 1.0$$

W_c : weight of cement aggregate

W_{FA} : weight of fine aggregate

W_{CA} : weight of coarse aggregate

ρ_c : mass density of cement

ρ_{FA} : mass density of fine aggregate

ρ_{CA} : mass density of coarse aggregate

V_w : volume of water per m^3 of concrete

V_v : volume of voids per m^3 of cement $\approx$ 2%

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1. Determine the quantities of cement, fine aggregates and coarse aggregates per m^3 of concrete

Void ratio in cement = 62%

Void ratio in fine aggregate = 41%

Void ratio in coarse aggregate = 45%

Mix = 1:2:4

w/c ratio = 0.55

Density of cement = 1440 kg/m^3

Density of fine aggregate = 1700 kg/m^3

Density of coarse aggregate = 1600 kg/m^3

$$\text{Mass density} = \frac{W_d}{V_s}$$

$$\text{Bulk density} = \frac{W_d}{V} = \frac{W_s}{V_v + V_s} = \frac{W_s / V_s}{\frac{V_v}{V_s} + 1} = \frac{\text{Mass density}}{1+e}$$

$$\text{Mass density} = \text{bulk density}(1+e)$$

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$$\text{Mass density of cement}, \rho_c = 1440(1+0.62) = 2332.8 \text{kg/m}^3$$

$$\text{Mass density of fine aggregate}, \rho_{FA} = 1700(1+0.4) = 2391 \text{kg/m}^3$$

$$\text{Mass density of coarse aggregate}, \rho_{CA} = 1600(1+0.45) = 2320 \text{kg/m}^3$$

Let volume of air in concrete = 2% = $0.02m^3$

Let x be the mass of cement in $1m^3$ of concrete

x kg of cement + $2x$ kg of fine aggregates + $4x$ kg of coarse aggregate + $0.55x$ kg of water

$$\frac{x}{2332.8} + \frac{2x}{2397} + \frac{4x}{2320} + \frac{0.55x}{1000} + 0.02 = 1 \Rightarrow x = 277.1kg$$

Weight of cement aggregate = 277.1kg

Weight of fine aggregate = 2×277.1 = 554.2kg

Weight of coarse aggregate = 4×277.1 = 1108.4kg

Weight of water = 0.55×277.1 = 152.4kg

2. Calculate the quantities of the constituent materials required for $1 m^3$ of concrete for mix proportions 1:1.40:2.80 (by volume) with w/c ratio of 0.48 (by weight). Bulk density of cement, fine aggregates and coarse aggregates are 14.7, 16.66 and 15.68 KN/m^3 respectively. Percentage of entrapped air is 2.0%. Specific gravity of cement, fine aggregate and coarse aggregate are 3.15, 2.6 and 2.5 respectively.

Volume of Cement : F.A : C.A = $x : 1.4x : 2.8x$ m^3

Weight of Cement : F.A : C.A = $14.7x : 16.66x : 15.68 \times 2.8x$

Weight of water = $0.48 \times 14.7x$

$$\text{Volume of water} = \frac{0.48 \times 14.7x}{\gamma_w}$$

Volume of air = $0.02 m^3$

$$\frac{14.7x}{3.15\gamma_w} + \frac{1.4 \times 16.66x}{2.6\gamma_w} + \frac{2.8 \times 15.68x}{2.5\gamma_w} + \frac{0.48 \times 14.7x}{\gamma_w} + 0.02 = 1$$

Weight of Cement = 14.7x = 14.7×0.257 = 377.7kg

Weight of F.A = 1.4×16.66x = 1.4×16.66×0.257 = 599.4kg

Weight of C.A = 2.8×16.66x = 1.4×15.68×0.257 = 1128.3kg

Weight of water = 0.48×4.7x = 0.48×14.7×0.257 = 181.3kg

Mix Design of Concrete

PREVIOUS GATE QUESTIONS

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01. A box measuring 50cm×50cm×50cm is filled to the top with dry coarse aggregate of mass 187.5 kg. The water absorption and specific gravity of the aggregate are 0.5 % and 2.5, respectively. The maximum quantity of water (in kg, round off to 2 decimal places) required to fill the box completely is … CE1 2019

Ans. 50.50 to 51.20

50.94

Size of box=0.5m×0.5m×0.5m

Volume of box, $V=0.5\times0.5\times0.5=0.125m^3$

Weight of coarse aggregate, W=187.5kg

Water absorption of coarse aggregate, w=0.5%

Specific gravity of coarse aggregate, G=2.5

Maximum quantity of water required to fill the box, W_w=?

Total volume = Volume of coarse aggregate + Volume of water

$$V = V_c + V_w$$

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Volume of coarse aggregate, $V_c = \frac{W}{G\gamma_w} \Rightarrow V_c = \frac{187.5}{2.5 \times 1000} = 0.075m^3$

$V_w = 0.125 - 0.075 = 0.05m^3$

Weight of water, $W_w = 0.05 \times 1000 = 50kg$

Weight of water absorbed by coarse aggregate $= \frac{0.5}{100} \times 187.5 = 0.09375kg$

Total weight of water =50+0.9375=50.9375kg

(OR)

$V = V_c + V_w$

$$V = \frac{W_c}{G.\gamma_w} + \frac{W_w}{\gamma_w}$$

$$0.125 = \frac{187.5}{2.5 \times 1000} + \frac{W_w}{1000} \Rightarrow W_w = 50kg$$

Water absorption $= \frac{0.5}{100} \times 187.5 = 0.9375$ kg $\therefore$ Total weight of water = 50 + 0.9375 = 50.9375kg

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02. The composition of an air-entrained is given below CE1 2015

Water	184 kg/m^3
Ordinary Portland Cement (OPC)	368 kg/m^3
Sand	606 kg/m^3
Coarse aggregate	1155 kg/m^3

Assume the specific gravity of OPC, sand and coarse aggregate to be 3.14, 2.67 and 2.74, respectively. The air content is………….. litre/m^3

Ans. 50.4

Composition of air entrained concrete:

Water = 184 kg/m^3

Ordinary Portland cement = 368 kg/m^3

Sand = 606 kg/m^3

Coarse aggregate = 1155 kg/m^3

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Specific gravity of OPC, G_c = 3.14
Specific gravity of sand, G_s = 2.67
Specific gravity of coarse aggregate, G_a = 2.74
Air content, a_c=?
Total volume = 1

$$V_c + V_s + V_a + V_w + V_a = 1$$

$$\frac{W_c}{\rho_c} + \frac{W_s}{\rho_s} + \frac{W_a}{\rho_a} + V_w + V_v = 1$$

$$\frac{368}{3.14 \times 1000} + \frac{606}{2.67 \times 1000} + \frac{1155}{2.74 \times 1000} + \frac{184}{1000} + V_v = 1$$

$0.1172+0.2269+0.4215+0.184+V_v=1.0$

V_v = 0.0504

= 0.0504x1000 = 50.4 litre/m^3

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CEMENT

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01. The setting time of cement is determined using CE2 2018

a. Le Chatelier’s apparatus
b. Briquettee’s testing apparatus
c. Vicat’s apparatus
d. Casagrande’s apparatus

Ans. c

Apparatus	**Property of cement**
Le chatelier’s apparatus	Soundness of cement
Briquette’s testing apparatus	Tensile strength of cement
Vicat’s apparatus	Normal consistency of cement setting times of cement
Casagrande’s apparatus	Atterberg’s limits for soil

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02. The Le Chatelier's apparatus is used to determine CE1 2018

a. compressive strength of cement

b. fineness of cement

c. setting time of cement

d. soundness of cement

Ans. d

S. No.	Property of cement	Apparatus
1.	Compressive strength	Cube moulds
2.	Fineness	Sieves, Blaine Air permeability test
3.	Setting time	Vicat apparatus
4.	Soundness	Le chatelier's apparatus

03. Group-I gives a list of test methods and test apparatus for evaluating some of the properties of ordinary Portland cement (OPC) and concrete. Group-II gives the list of these properties. CE2 2017

Group-I		Group-II	
P.	Le Chatelier's test	1.	Soundness of OPC
Q.	Vee-Bee test	2.	Consistency and setting time of OPC
R.	Blaine air permeability test	3.	Consistency or workability of concrete
S.	The Vicat's apparatus	4.	Fineness of OPC

The correct match of the items in Group-I with items in Group-II is

a. P1 Q3 R4 S2 b. P2 Q3 R1 S4 c. P4 Q2 R4 S1 d. P1 Q4 R2 S3

Ans. a

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04. The compound which is largely responsible for initial setting and early strength gain of Ordinary Portland Cement is CE1 2016

a. C_3A **b.** C_3S c. C_2S d. C_4AF

Ans. b

Name of the compound	**Influence**
Tri-calcium silicate $3CaO.SiO_2$ (C_3S)	Early strength gain in OPC
Di-calcium Silicate $2CaO.SiO_2$ (C_2S) Tri-calcium Aluminate $3CaO.Al_2O_3$ (C_3A) Tetra-calcium Aluminoferrite $4CaO.Al_2O_3Fe_2O_3$ (C_4AF)	Initial setting time

AGGREGATE

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01. If the fineness modulus of a sample of fine aggregates is 4.3, the mean size of the particles in the sample is between CE2 2019

a. 150 µm and 300 µm b. 300 µm and 600 µm

c. 1.18 mm and 2.36 mm d. 2.36 mm and 4.75 mm

Ans. c

Fineness modulus of fine aggregate =4.3

The sieves used for the sieve analysis of coarse, fine and combined aggregate as per IS: 2386 (Part I) are: 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 mm, 300 mm, and 150 mm.

Fineness modulus can be considered as a weighted average size of a sieve on which material is retained. The sieves are being counted from the bottom. For fineness modulus of 4.3, mean size of particles lies between 1.18 mm and 2.36 mm.

Sieve size	**Fineness modulus**
0.15 mm	1
0.30 mm	2
0.60 mm	3
1.18 mm	4
2.36 mm	5
4.75 mm	6
10 mm	7
20 mm	8
40 mm	9

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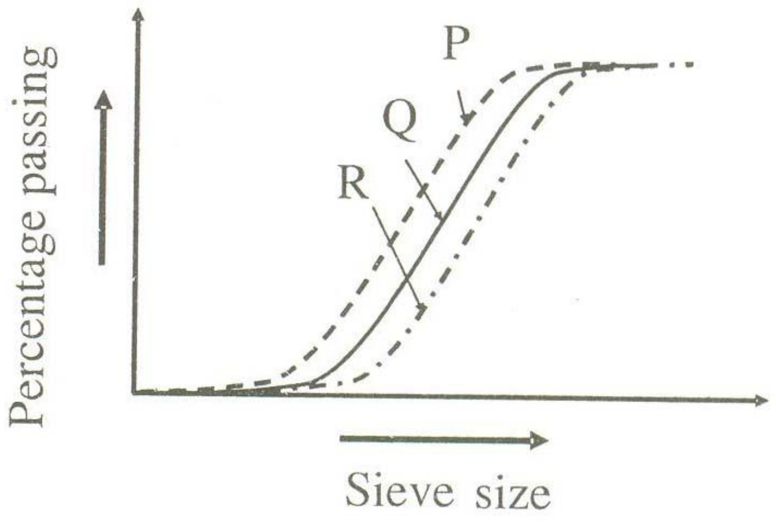
02. The results for sieve analysis carried out for three types of sand P, Q and R, are given in the adjoining figure. If the fineness modulus values of the three sands are given as FM_P , FM_Q and FM_R , it can be stated that 2011



a. $FM_Q = \sqrt{FM_P \times FM_R}$

b. $FM_Q = 0.5(FM_P + FM_R)$

c. $FM_P > FM_Q > FM_R$

d. $FM_P < FM_Q < FM_R$

Ans. d

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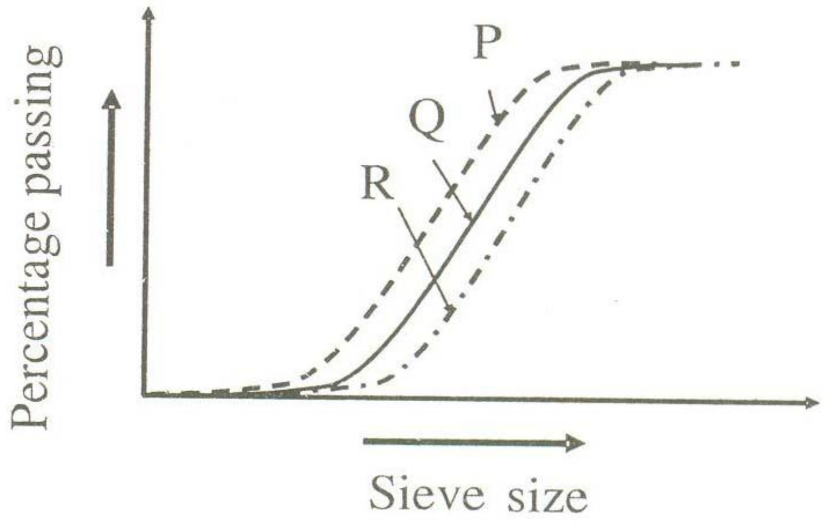
Ans. d

As per the fig, for the same percentage passing, the size of material is large in R than P.



For a given sieve size, the percentage passing through is more for P than for R. Therefore the percentage retained is less in P than in R.

Hence, the fineness modulus is less for P than for R.

$FM_P < FM_Q < FM_R$

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FRESH CONCRETE

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01. Consider the following statements for air-entrained concrete: CE1 2015

i. Air entrainment reduces the water demand for a given level of workability.

ii. Use of air-entrained concrete is required in environments where cyclic freezing and thawing is expected.

Which of the following is TRUE?

a. Both i and ii are true

b. Both i and ii are false

c. i is true and ii is false

d. i is false and ii is true

Ans. a

Air entrainment is the creation of air bubbles in concrete. The primary purpose of air entrainment is: (i) to increase the durability of the hardened concrete in climates subjected to freezing and thawing, and (ii) to increase the workability of concrete while in a plastic state. In conventional concrete, water required beyond all cement particles to hydrate is surplus and is used to make the plastic concrete more workable and easy flowing or less viscous. Excess water evaporates, leaving pores in its place. Environmental water can later fill these voids.

During freeze-thaw cycles, the water occupying these pores expands and creates stresses which leads to tiny cracks. The cracks allow more water and the cracks enlarge. The failure of reinforced concrete is most often due to this cycle, which is accelerated by moisture reaching the reinforcing steel. Steel expands when it rusts and these forces create even more cracks.

In air entrained concrete, the air bubbles compressed so as to reduce or absorb stresses from freezing. The bubbles contribute to workability by acting as a sort of lubricant for all the aggregates and large particles in a concrete mix. For a given level of workability, air entrainment reduces the water demand.

02. Workability of concrete can be measured using slump, compaction factor and Vee-bee time. Consider the following statements for workability of concrete.

i. As the slump increases, the Vee-bee time increases.

ii. As the slump increases, the compaction factor increases.

Which of the following is TRUE? CE1 2015

a. Both i and ii are True
b. both i and ii are False
c. i is True and ii is False
d. i is False and ii is True

Ans. d

As the slump increases, Vee-bee time decreases.

As the slump increases, the compaction factor increases.

03. Maximum possible value of Compacting Factor for fresh (green) concrete is 2013

a. 0.5 **b.** 1.0 c. 1.5 d. 2.0

Ans. b

$$\text{Compaction factor} = \frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}} \leq 1.0$$

Therefore, the maximum value of compacting factor for fresh concrete is 1.0. Compaction factor is defined as the ratio of the density actually achieved in the test to the density of same concrete fully compacted. Its value is always less than 1.0. Therefore, the maximum value of compacting factor of fresh concrete is 1.0.

HARDENED CONCRETE

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01. In the context of provisions relating to durability of concrete, consider the following assertions:

Assertion (1):As per IS 456-2000, air entrainment to the extent of 3% to 6% is required for concrete exposed to marine environment.

Assertion(2):The equivalent alkali content (in terms of Na_2O equivalent) for a cement containing 1% and 0.6% of Na_2O and K_2O, respectively, is approximately 1.4% (rounded to 1 decimal place)

Which one of the following statements is correct? CE2 2019

a. Assertion (1) is false and Assertion (2) is TRUE

b. Assertion (1) is true and Assertion (2) is FALSE

c. Both Assertion (1) and Assertion (2) are FALSE

d. Both Assertion (1) and Assertion (2) are TRUE

Ans. a

Ans. a

As per IS:456-2000, clause 8.2.2.3, air entrainment to the extent of 3% to 6% is required to resist freezing and thawing and not for marine environment.

Hence assertion 1 is false.

Equivalent alkali content in terms of $Na_2O = Na_2O + 0.685K_2O = 1 + 0.685 \times 0.6$

$= 1.41\%$

Hence, assertion 2 is true.

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02. For M25 concrete with creep coefficient of 1.5, the long-term static modulus of elasticity (expressed in MPa) as per the provisions of IS:456-2000 is… CE1 2016

Ans. 10000

Grade of concrete : M25

Creep coefficient, θ =1.5

Long term static modulus of elasticity, $E_{ce} = \dfrac{E_c}{1+\theta}$

$$E_{ce} = \frac{5000\sqrt{f_{ck}}}{1+\theta} = \frac{5000\sqrt{25}}{1+1.5} = 10000$$

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03. The modulus of elasticity, $E_c = 5000\sqrt{f_{ck}}$ where f_{ck} is the characteristic compressive strength of concrete, specified in IS 456-2000 is based on CE2 2014

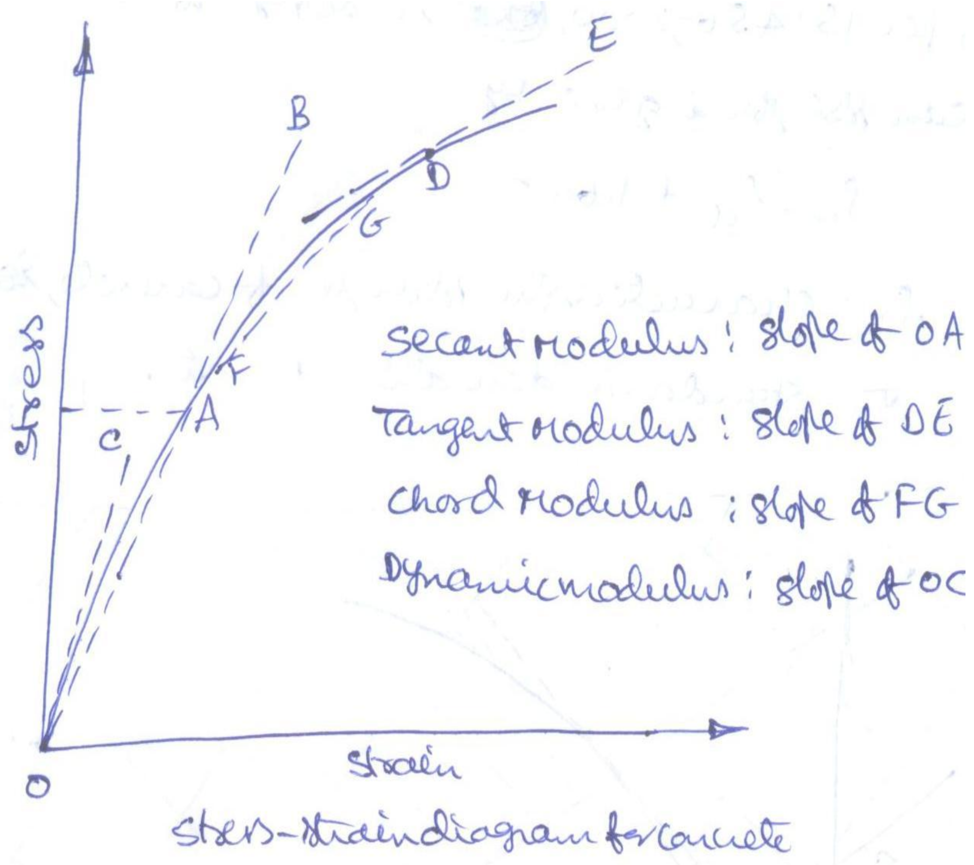
a. tangent modulus

b. initial tangent modulus

c. secant modulus

d. chord modulus

Ans. b



Secant Modulus: The slope of a line drawn from the origin to the point on the stress-strain curve corresponding to 40% of the failure stress.

The modulus of elasticity most commonly used in practice is secant modulus.

Tangent Modulus: The slope of a line drawn tangent to the stress strain curve at any point on the curve.

Chord Modulus: The slope of a line drawn between two points on the stress-strain curve.

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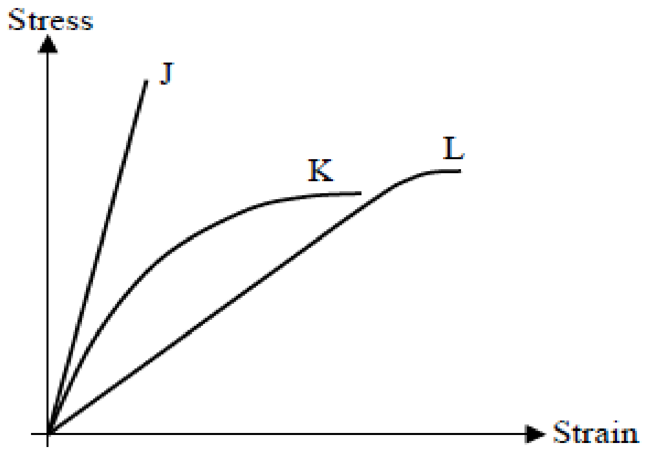
Dynamic Modulus or Initial tangent Modulus: The modulus of elasticity corresponding to a small instantaneous strain. It is equal to the tangent modulus drawn at the origin.

As per IS: 456-2000, $E_c = 5000\sqrt{f_{ck}}$

E_c : Short term static modulus of elasticity in N/mm^2

f_{ck} : Characteristic cube compressive strength of concrete in N/mm^2

04. Group I contains representative stress-strain curves as shown in the figure, while Group II gives the list of materials. Match the stress-strain curves with the corresponding materials. CE2 2014



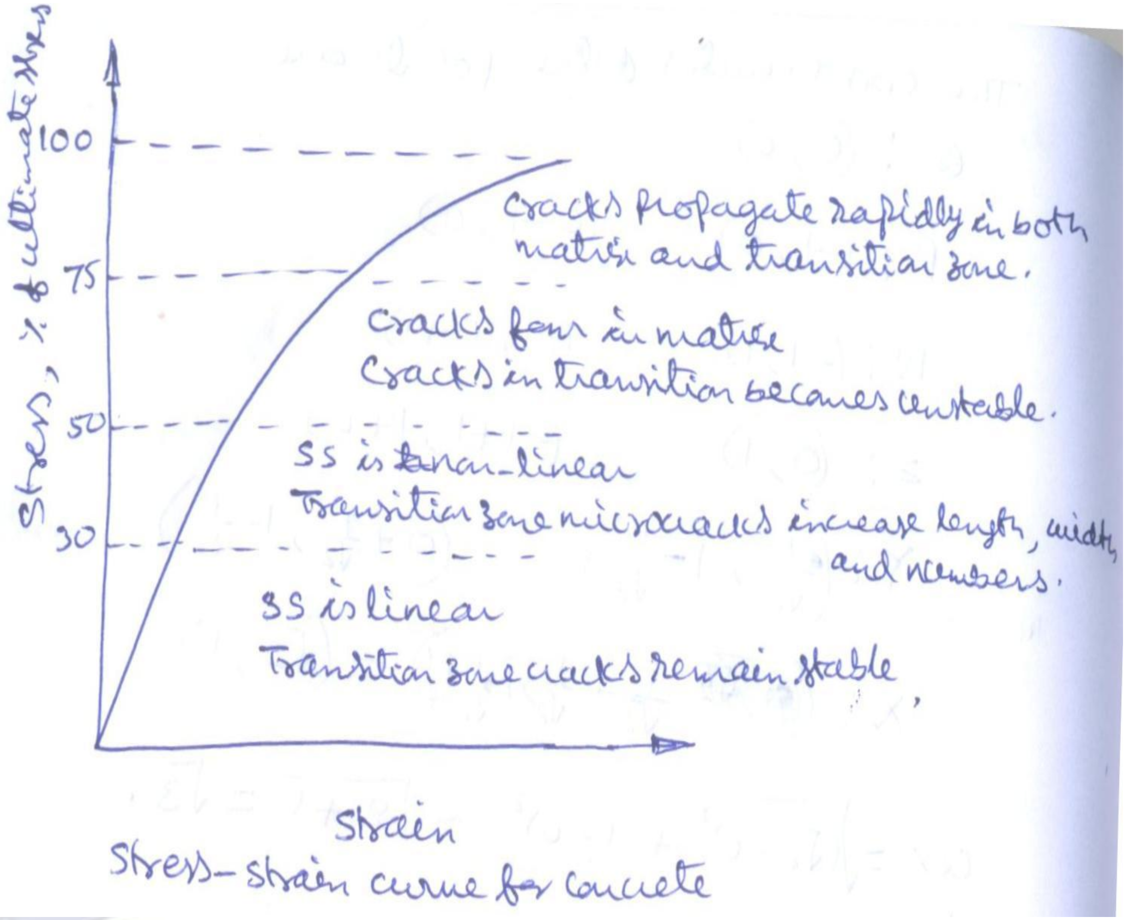
Group I		Group II	
P.	Curve J	1.	Cement paste
Q	Curve K	2.	Coarse aggregate
R.	Curve L	3.	Concrete

a. P1 Q3 R2 **b.** P2 Q3 R1 c. P3 Q1 R2 d. P3 Q2 R1

Ans. b

A typical relationship between stress and strain for normal strength concrete, which is a combination of aggregate and cement paste together shows a non linear relationship is shown in fig. After an initial linear portion lasting up to 30-40% of the ultimate load, the curve becomes non linear with large strains registered for small increments of stress.

The non-linearity is primarily a function of the coalescence of micro-cracks at the paste-aggregate interface. The ultimate stress is reached when large crack network is formed within the concrete consisting of coalesced micro cracks and the cracks in the cement paste matrix. The strain corresponding to ultimate stress is 0.003 for normal strength concrete. The stress strain behavior in tension is similar to that in compression.



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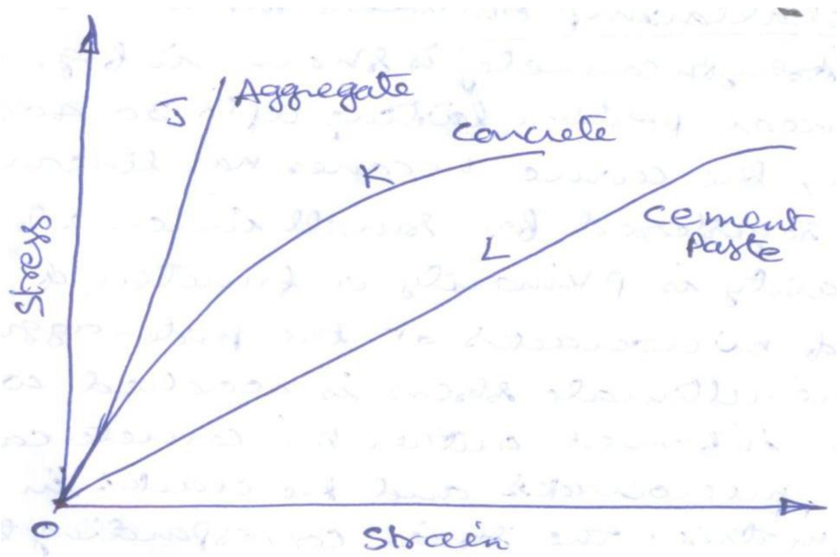

The stress-strain relationship of aggregate alone and cement paste alone shows a fairly good straight line. The rate of increase of strain in aggregate is less than that in cement paste.

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05. The creep strains are 2013

a. caused due to dead loads only

b. caused due to live loads only

c. caused due to cyclic loads only

d. independent of loads

Ans. a

Creep strains are caused due to dead loads only. The progressive inelastic strains due to creep in a concrete member are likely to occur under the sustained loads at ambient temperature.

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06. Column I gives a list of test methods for evaluating properties of concrete and Column II gives the list of properties 2009

Column I		Column II	
P	Resonant frequency test	1	Tensile strength
Q	Rebound hammer test	2	Dynamic modulus of elasticity
R	Split cylinder test	3	Workability
S	Compaction factor test	4	Compressive strength

The correct match of the test with the property is

a. P2 Q4 R1 S3 b. P2 Q1 R4 S3 c. P2 Q4 R3 S1 d. P4 Q3 R1 S2

Ans. a

Ans. a

Methods for evaluating properties of concrete	**Properties**
Resonant frequency test	Dynamic modulus of elasticity
Rebound hammer test	Compressive strength
Split cylinder test	Tensile strength
Compacting factor test	Workability

07. Consider the following statements :

I. The compressive strength of concrete decreases with increase in water-cement ratio of the concrete mix.

II. Water is added to the concrete mix for hydration of cement and workability.

III. Creep and shrinkage of concrete are independent of the water-cement ratio in the concrete mix.

The true statements are 2007

a. I and II b. I, II and III c. II and III d. only II

Ans. a

The compressive strength of concrete decrease with increase in water cement ratio.

08. Group I contains some properties of concrete/cement and Group II contains list of some tests on concrete/cement. Match the property with the corresponding test.

Group I		Group II	
P	Workability of concrete	1	Cylinder splitting test
Q	Direct tensile strength of concrete	2	Vee-Bee test
R	Bond between concrete and steel	3	Surface area test
S	Fineness of cement	4	Fineness modulus test
		5	Pull out test

a. P2 Q1 R5 S3 b. P4 Q5 R1 S3 c. P2 Q1 R5 S4 d. P2 Q5 R1 S4

Ans. a

Ans. a

properties of concrete/cement	Test on concrete/cement
Workability of concrete	Slump cone test, Compaction factor test, Vee-Bee test
Direct tensile strength of concrete	Cylinder splitting test
Bond between concrete and steel	Pull out test
Fineness of cement	Surface area test

09. The cylinder strength of the concrete is less than the cube strength because of 1997

a. the difference in the shape of the cross section of the specimens.

b. the difference in the slenderness ratio of the specimens.

c. the friction between the concrete specimens and the steel plate of the testing machine.

d. the cubes are tested without capping but the cylinders are tested with capping.

Ans. b

The cylinder strength of concrete is less than the cube strength because of the difference in the slenderness ratio of the specimens.

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10. The modulus of rupture of concrete gives 1995

a. the direct tensile strength of the concrete

b. the direct compressive strength of the concrete

c. the tensile strength of the concrete under bending

d. the characteristic strength of the concrete

Ans. c

Modulus of rupture of concrete, $f_{cr} = 0.7\sqrt{f_{ck}}$

f_{ck} : Characteristic strength of concrete, N/mm^2

The modulus of rupture of concrete gives the tensile strength of concrete under bending.

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BRICKS

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01. As per Indian standards for bricks, minimum acceptable compressive strength of any class of burnt clay bricks in dry state is CE2 2016

a. 10.0 MPa b. 7.5 MPa c. 5.0 MPa **d.** 3.5 Mpa

Ans. d

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02. Bull's trench kiln is used in the manufacturing of CE1 2016

a. lime b. cement **c.** bricks d. none of these

Ans. c

Construction Materials

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PROPERTIES OF STEEL

Ductility is a mechanical property of a material where it is capable of sustaining large permanent defamation without fracture.

- Ductility provides an indication of how visible overload damage to a component might become before the component fractures.
- Ductility is used as a quality control measure to assess the level of impurities and proper processing of a material.
- Ductility is characterized by the material's ability to be stretched into a wire.
- Ductility measured in terms of the elongation and the reduction of area at fracture.

$$\text{Elongation (\%)} = \frac{\text{Change in axial length}}{\text{Original length}} \times 100$$

$$\text{Reduction of area (\%)} = \frac{\text{Change in cross-sectional area}}{\text{Original cross-sectional area}} \times 100$$

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Ductile material is the one which undergoes a large defamation before failure.
In ductile materials, some permanent deformation occurs in the specimen and the material is said to react plastically to any further increase in load or stress. The material will not return to its original, unstressed condition when the load is removed.

- Failure is due to bulk yielding causing permanent deformations
- Cause noise, loss of accuracy, excessive vibrations, etc.
- In a ductile material, the elastic deformation is less predominant than plastic defamation

Brittle material is the one which experiences a small defamation before failure and there is no necking.
In brittle materials, little or no plastic deformation occurs and the material fractures near the end of the linear-elastic portion of the curve.

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- Brittleness is a tendency of a material to fracture or fail upon the application of a relatively small amount of force or impact.
- Brittle failure occurs suddenly without warning.
- Failure is due to fracture
- Brittleness is a tendency of a material to fracture or fail upon the application of a relatively small amount of force or impact.
- Brittleness is not an absolute property of a metal, rate of loading influence the behavior of a metal from ductile to brittle at low temperatures
- Brittle failure occurs suddenly without warning.
- Ductile material would fail in a brittle fashion if it is twisted or bent back and forth sufficiently to make it brittle.

Elasticity is the ability of a material to return to its previous shape after stress is released.

Plasticity is the property of the material to deform continuously without much increase of stress.

- Plastic deformation is retained after the release of the applied stress

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Ductility is the ability to be drawn out by tension to a small section without rupture.

Malleability is the property of a material that gives extension in a direction without rupture.

Tenacity is the property of the material to resist fracture under the action of tensile force.

- It is the measure of strength of a fibre or yarn.
- It is the ultimate (or breaking) force of the fibre divided by the denier, a measure of the linear density.
- Tenacity or tensile strength is the resistance offered by material to tension ie., to a stress tending tear it.

Deformation of the material is the change in geometry created when stress is applied.

Elastic deformation is a change in shape of a material at low stress that is recoverable after the stress is removed.

Plastic deformation is a permanent deformation due to the stress beyond elastic limit.

Normal stress strain curve: It is a plot based on original area of cross section of specimen at any instant to calculate stresses.

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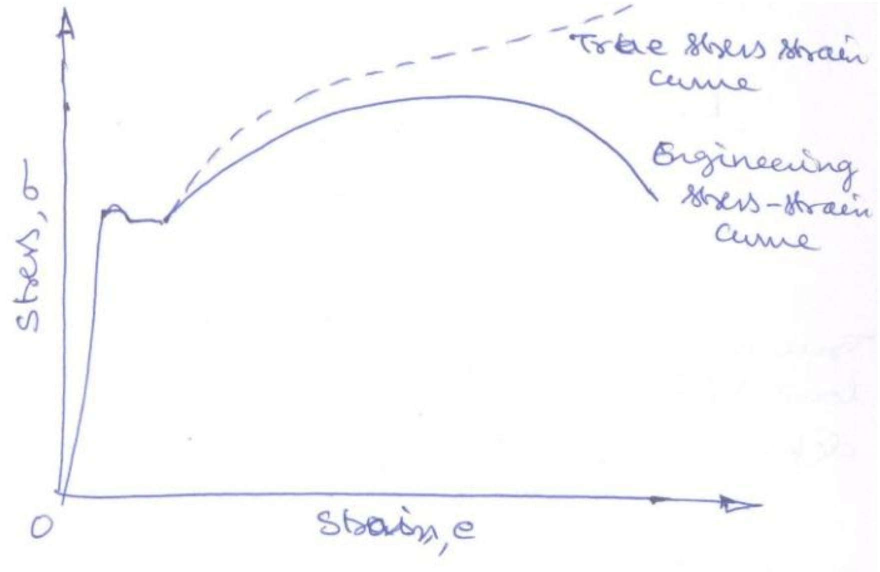
True stress strain curve: It is a plot based on actual area of cross section of specimen for all computations

True or actual stress is obtained by dividing the load by the actual cross sectional area in the deformed specimen.

$$\sigma_{actual} = \frac{P}{A_{actual}}$$

For smaller loads, the difference between true stress and engineering stress is negligible. For larger loads, the true stress is larger than that of the engineering stress.

True or actual strain $= \int_{L_0}^{L} \frac{dL}{L} = \ln\left(\frac{L}{L_0}\right)$



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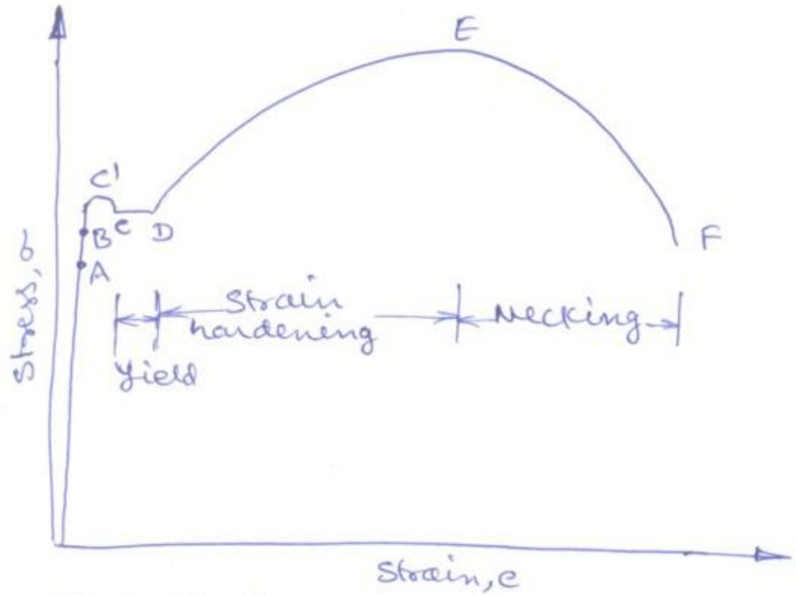
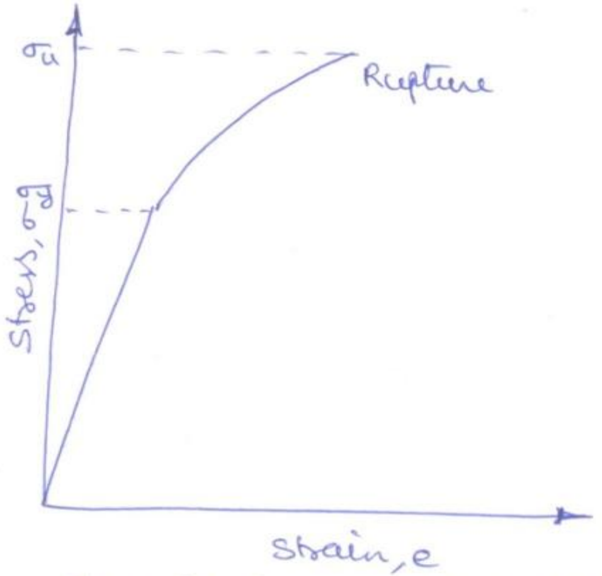
Mechanical Properties of materials:

Stress-strain diagrams of materials vary widely depending upon whether the material is ductile or brittle in nature.

The stress-strain diagram of a mild steel is shown in fig.



Stress-strain curve for mild steel



Stress-strain curve for Brittle material.

A: Proportionality limit | B: Elastic limit | C: Upper yield point

D: Lower yield point | E: Ultimate stress | F: Failure stress

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As the ductile material reaches the yield strength, it starts yielding continuously even though there is no increment in external load/stress.

The flat curve in stress-strain curve is referred as perfectly plastic region.

Engineering stress and **strain** computations are based on the fixed, undeformed cross-sectional area.

- The engineering stress-strain curve does not give a true indication of the deformation characteristics of a metal because it is based entirely on the original dimensions of the specimen, and these dimensions change continuously during the testing used to generate the data.
- Engineering stress and strain data is commonly used because it is easier to generate the data and the tensile properties are adequate for engineering calculations.
- True stress and strain measures account for changes in cross-sectional area by using the instantaneous values for the area.
- Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength and other tensile properties.

- The stress and strain initially increase with a linear relationship. In this region of the curve, when the stress is reduced, the material will return to its original shape.
- The slope of the line where stress is proportional to strain and is called the modulus of elasticity or **Young's modulus.**
- The modulus of elasticity (E) defines the properties of a material as it undergoes stress, deforms, and then returns to its original shape after the stress is removed.
- Modulus of elasticity is a measure of the stiffness of a given material.

Proportionality limit is the point up to which stress is proportional to strain (follows Hooke's law), so the stress-strain graph is a straight line, and the gradient will be equal to the elastic modulus of the material.

- It 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.

Elastic limit is the greatest stress the material can withstand without any measurable permanent strain remaining on the complete release of load.

- It is determined using a tedious incremental loading-unloading test procedure.
- Elastic limit is greater than the proportional limit.
- It is the lowest stress at which permanent deformation can be measured.
- Beyond the elastic limit, permanent deformation will occur.

Yield strength is defined as the stress required to produce a small specified amount of plastic deformation.

- It is a point on the stress-strain curve at which the curve levels off and plastic deformation begins to occur.
- The offset yield strength is 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 of 0.2% for metals and 2% for plastics.
- To determine the yield strength using offset, the point is found on the strain axis of 0.002, and then a line parallel to the stress-strain line is drawn. This line will intersect the stress-strain line slightly after it begins to curve, and that intersection is defined as the yield strength with a 0.2% offset.
- For most engineering design applications, the yield strength is used.

Upper yield point and lower yield point: Some metals, such as mild steel, reach an upper yield point before dropping rapidly to a lower yield point. The material response is linear up until the upper yield point, but the lower yield point is used in structural engineering as a conservative value.

Strain hardening of the material is the zone beyond the yield stress at which the load required for further deformation.

- The material regain its strength and offer more resistance.
- During strain hardening, the material undergoes changes in its atomic and crystalline structures
- In ductile materials like aluminum alloys, the strain hardening occurs immediately after the linear elastic region without perfectly elastic region.
- During strain hardening, the strength of the material is increased and ductility decreased.

Necking is the phenomenon of fast decreasing the diameter of the specimen due to local instability

Ultimate Tensile Strength: The ultimate tensile strength (UTS) is the maximum engineering stress level reached in a tension test. The strength of a material is its ability to withstand external forces without breaking..

Ultimate compressive strength is the stress required to rupture a specimen.

Bearing test is used to determine the deformation of a hole as a function of the applied bearing stress.

- Bearing stress is the average intensity of pressure that can be found by dividing the load *P* by the projected area of the contact surface.

Hardness is defined at the resistance to elastic deformation of the surface.

Creep is a time-dependent deformation of a material while under an applied load that is below its yield strength.

- It is the property of a material by virtue of which it deforms continuously under a steady load.
- Usually creep occurs at high temperatures
- Creep is the gradual increase of a plastic strain with time at constant load

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Toughness is the ability of a metal to deform plastically and to absorb energy in the process before fracture.

- It is the ability to absorb energy before fracture.
- The key to toughness is a good combination of strength and ductility.
- A material with high strength and high ductility will have more toughness than a material with low strength and high ductility.
- Toughness is measured by calculating the area under the stress strain curve from a tensile test.
- Ductility and Toughness decrease as the rate of loading increases.
- Ductility and toughness increases with increase of temperature.
- Ductility is a measure of how much something deforms plastically before fracture, but just because a material is ductile does not make it tough.

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Fatigue is the failure of a material by fracture when subjected to a repeated application of stress to the metal

Factors that affect fatigue strength

- Surface roughness can cause microscopic stress concentrations that lower the fatigue strength.
- Welding, cutting, casting, grinding, and other manufacturing processes involving heat or deformation can produce high levels of tensile residual stress, which decreases the fatigue strength.
- Casting defects can significantly reduce fatigue strength.
- Extreme high or low temperatures can decrease fatigue strength.
- Smaller grains yield longer fatigue lives
- Scratches, dents and identification marks can act as stress raisers and so reduce the fatigue strength.
- Residual stresses on the surface of the material will improve the fatigue strength.
- Stress concentrations reduces the fatigue strength.
- Fatigue strength decreases with increase in temperature.

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Yield strength is the lowest stress that produces a permanent deformation in a material.

Compressive strength is a limit state of compressive stress that leads to failure in a material in the manner of ductile failure or brittle failure.

Tensile strength or ultimate tensile strength is a limit state of tensile stress that leads to tensile failure in the manner of ductile failure or brittle failure.

Fatigue strength is a measure of the strength of a material or a component under cyclic loading, and is usually more difficult to assess than the static strength measures.

It is a strength which can withstand for some specified number of cycles.

Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy.

Fracture is the separation of an object of material into two or more pieces under the action of stress.

Endurance limit is the maximum stress which can be applied to a material for an infinite number of cycle without resulting in failure of the material.

- Endurance limit is the stress level below which a material has a high probability of not failing under reversal of stress.

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Tolerance limit is the permissible limit or limits of variation in a measured value or property of a material.

Isotropic material is said to be isotropic, when the properties of a material are the same in all directions.

Anisotropic material is said to be anisotropic, when the properties of a material vary with different directions.

Orthotropic material has different material properties or strengths in different orthogonal directions.

Homogeneous material is said to be homogeneous if it has identical properties at all points in identical directions.

- Homogeneous material is uniform in composition and character.

Visco-elasticity is the property of the material that exhibit both viscous and elastic characteristics when undergoing deformation.

Inelastic material: The material which cannot regain its original size and shape after removal of the load. ie., strain is not recovered after unloading.

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Rigid plastic material: The material in which strain is zero upto a stress level and then stress remains constant.

Resilience is the ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading.

Proof resilience is defined as the maximum energy that can be absorbed within the elastic limit, without creating a permanent distortion.

Modulus of resilience is defined as the maximum energy that can be absorbed per unit volume without creating a permanent distortion.

Strain is a measure of the amount of deformation that occurs when an object is placed under stress.

Strain rate is defined as the change in strain over the change in time.

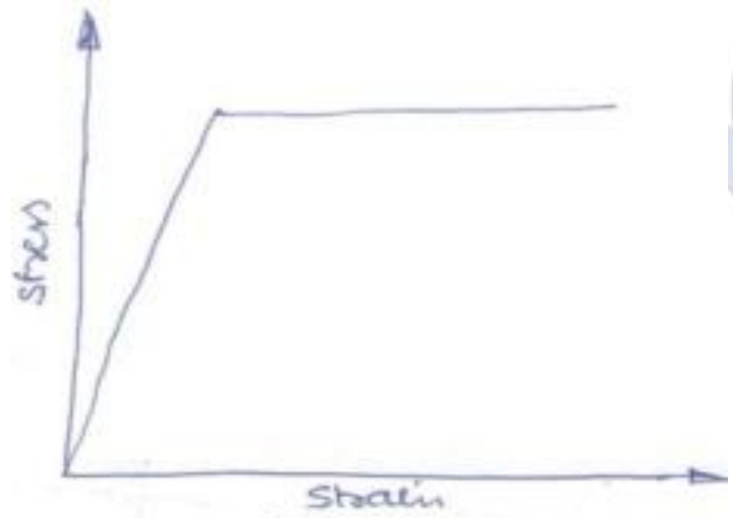
Factor of safety:

$$\text{For ductile materials, } F = \frac{\text{Yield stress}}{\text{Working stress}}$$

$$\text{For brittle materials, } F = \frac{\text{Ultimate stress}}{\text{Working stress}}$$

Margin of safety= Factor of safety - 1

Stress- Strain curves



a. Stress-strain curve for Plastic design

b. Stress strain curve for brittle material

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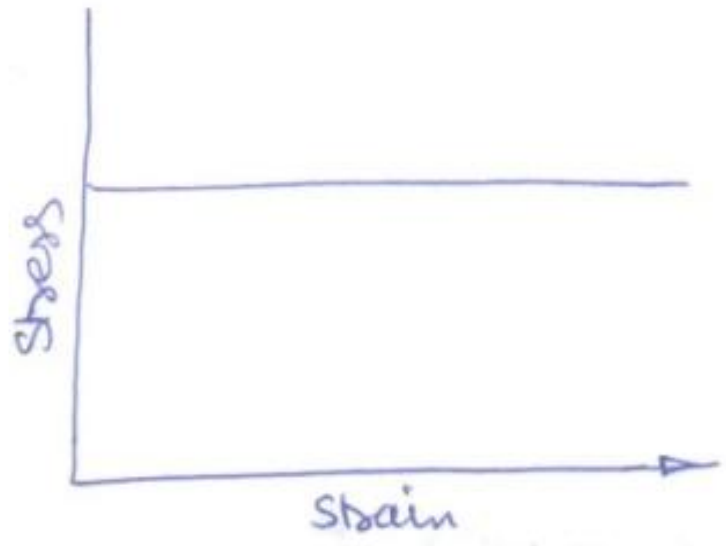
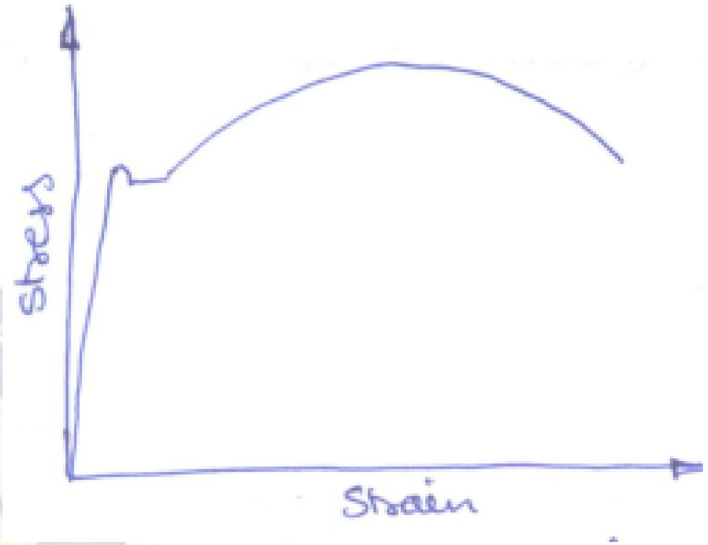


c. Stress-strain curve for ideally plastic material



d. Stress-strain curve for ductile material.

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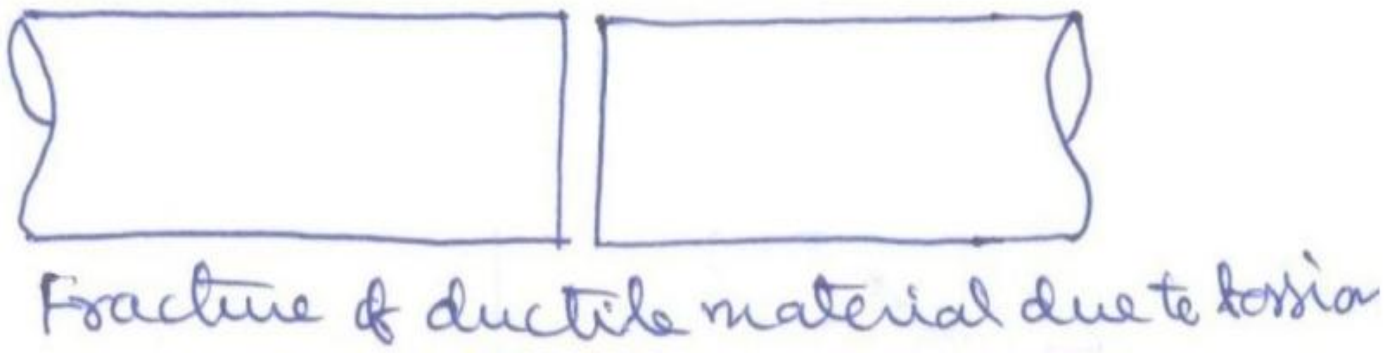
For ductile materials like mild steel subjected to a torque, the plane of fracture will be normal to the longitudinal axis. Mild steel is relatively weaker in shear than in tension and the plane of maximum shear is perpendicular to its axis.



For brittle material of high compressive strength and shear, the twisting will cause fracture along spiral line at to the axis of the member.

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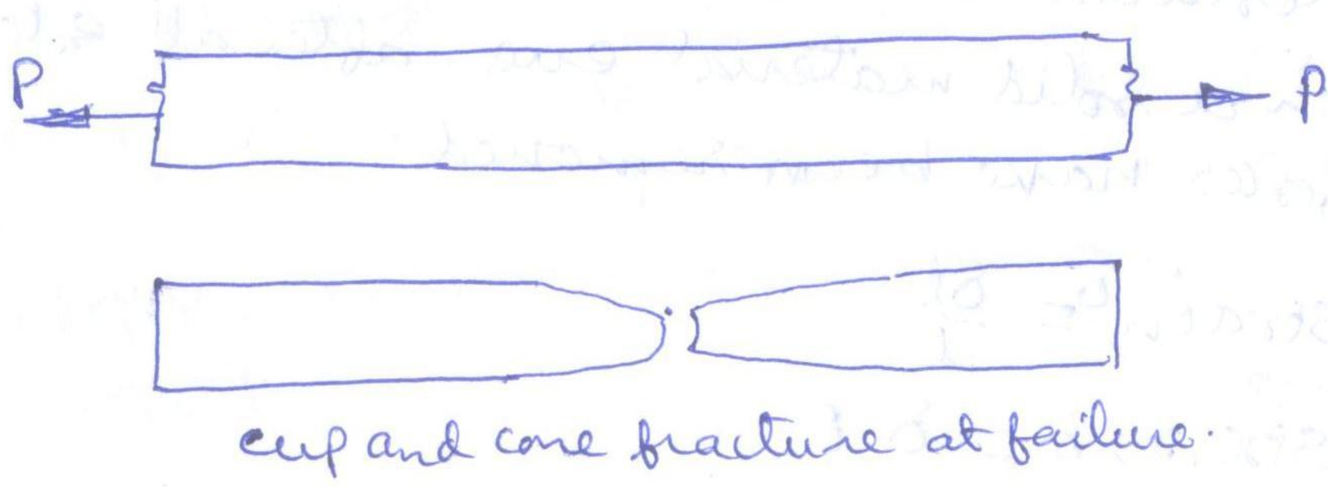
A mild steel specimen in tension has a cup and cone fracture at failure since mild steel is weak in shear and failure of the specimen takes place at to the direction of the applied tensile force. Mild steel specimen is equally strong in tension and compression but it is weak in shear. Therefore, when a mild steel tension specimen subjected to an axial load, cup and cone fracture of mild steel specimen occurs in the plane of maximum shear at to its axis



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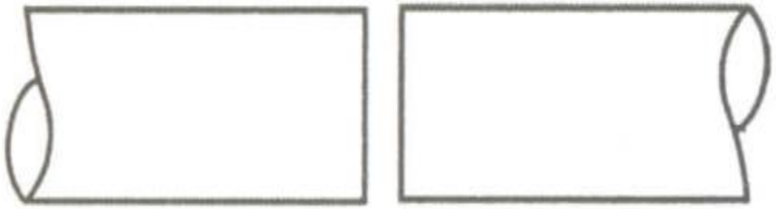
In a tension test on a cast iron specimen, the failure of the specimen is on a cross section perpendicular to the axis of the specimen. The failure of the specimen is on a plane subjected to maximum tensile stress and cast iron is relatively weak in tension.



Gauge length

The total elongation in tension test = uniform extension + local extension due to necking or waisting.

$$\delta = a.L + b\sqrt{A_0} \quad \text{(unwin's formula)}$$

Uniform extension is proportional to gauge length and local extension is proportional to $\sqrt{A}$

Gauge length , $L = 5.65\sqrt{A}$

A: Initial cross sectional area of the bar.

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Cement

- In 1824 Joseph Aspdin from England invented the Portland cement named after the limestone cliffs on the Isle of Portland in England
- Cement is the hydraulic binder (hydraulic = hardening when combined with water) which is used to produce concrete.
- Cement commonly used as binding material in the construction process.
- Cement is an extreme ground Material having adhesive and cohesive properties which provide a binding Medium for the discrete ingredients.

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- Cement: can be manufactured from natural cement stones or artificially by using calcareous and argillaceous materials.

Argillaceous	Calcareous
Shale and clay	Lime stone
Cement rock	Chalk
Blast furnace slag	Marine shells
Marl	

- Two types of Cement based on the type of material.

Natural Cement	Artificial Cement
Roman Cement	Portland cement etc.,
Pozzolona cement	
Medina cement	

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Manufacture of cement

- Cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450 °C in a kiln, in a process known as calcination, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix.
- The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement (often referred to as OPC).
- Manufacturing process of cement include three steps:
    - 1. Mixing and crushing of raw materials

        a. Dry process

        b. Wet process
    - 2. Burning
    - 3. Grinding

Mixing and crushing of raw materials - Dry process:

- In the dry process calcareous material such as lime stone (calcium carbonate) and argillaceous material such as clay are ground separately to fine powder in the absence of water and then are mixed together in the desired proportions.
- Water is then added to it for getting thick paste and then its cakes are formed, dried and burnt in kilns.
- Dry process is usually used when raw materials are very strong and hard.
- In the dry process, the raw materials are changed to powdered form in the absence of water.
- About 75% of cement is produced using the dry process.
- Dry process is considered to be economical as compared to wet process. Because the less consumption of fuel in kiln.

Mixing and crushing of raw materials - Wet process:

- In the wet process, the raw materials are changed to powdered form in the presence of water.
- Raw materials are pulverized by using a Ball mill, which is a rotary steel cylinder with hardened steel balls. When the mill rotates, steel balls pulverize the raw materials which form slurry (liquid mixture).
- The slurry is then passed into storage tanks, where correct proportioning is done.
- Proper composition of raw materials can be ensured by using wet process than dry process.
- Corrected slurry is then fed into rotary kiln for burning.
- Wet process is generally used when raw materials are soft because complete mixing is not possible unless water is added.
- About 25% of cement is produced using the dry process.

Composition of Cement:

Constituents	Percentage	Average	Influence
Lime CaO	60-65%	63%	Control strength and soundness
Silica SiO_2	17-25%	20%	Gives strength, excess it causes slow setting
Alumina Al_2O_3	3-8%	6%	responsible for quick setting time excess causes low strength
Iron Oxide Fe_2O_3	0.5 to 6%	3%	Gives colour
Magnesia MgO	0.1 to 4%	2%	Imparts colour and Hardness
Sulphur Trioxide SO_3	1 to 2%	1.5%	makes cement sound
Soda or Potash	0.5 to 1%	1%	residues excess cause efflorescence cracking

Composition depends on – Ratio of CaO and SiO_2

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Bogue Compounds:

- During the manufacturing of cement, various constituents combine in burning and form certain compounds. When these raw materials are put in kiln, then it fuses and following four major compounds- Bogue compound formed.
- These compounds formed during burning, react with water help in setting and hardening of cement
- These compounds are called bogue compounds they are

Compound	Scientific	Symbol
Tricalcium silicate	Alite	C_3S
Dicalcium silicate	Belite	C_2S
Tricalcium aluminate	Celite	C_3A
Tetracalcium alumino ferrite	Felite	C_4AF

Mineral types	Tricalcium silicate	Dicalcium silicate	Tricalcium aluminates	Tetracalcium aluminoferrite
Abbreviation	C_3S	C_2S	C_3A	C_4AF
Content (%)	25-50%	25-40%	5 to 11%	8-14%
Hydration speed	fast	slow	fastest	fast
Hydration heat	much	little	most	more
Strength	high	early low, later high	low	low
Anti- corrosion	good	fine	poor	excellent
Shrinkage	middle	better	big	small

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Heat of Hydration

- When water is added to cement, chemical reaction starts between active components of cement (C_4AF, C_3A, C_3S and C_2S) and water which is exothermic in nature and liberate a significant amount of heat.
- This is known as hydration and the liberated heat is called heat of hydration
- About an average 23 percent of water by weight of cement is required for complete hydration of Portland cement.
- If excess water is present, it will lead to capillary cavities
- For complete hydration of cement, w/c ratio is more than 0.35 but less than 0.45

Tricalcium silicate (C_3S)

- 25-50% normally 40%
- Well Burnt cement
- Hydrates rapidly generating high strength and high heat and develops an early hardness and strength
- Increase heat of hydration
- Heat of hydration 500 J/gm

Dicalcium silicate (C_2S) 25-40%

- Hydrates and hardens slowly
- It takes long time
- Imparts resistance to chemical attack
- Decreases heat of hydration
- Heat of hydration 260 J/gm
- Normally 32%

Tricalcium aluminate: (C_3A)

- 5 to 11% (normally 10.5%)
- Responsible for initial set
- More heat of hydration (865 j/g) has greater tendency to volume changes causing cracking
- Gypsum slows down the hydration rate of C3A.
- Raising C_3A content
    - Reduces the setting time
    - Weakens resistance to sulphate attack
    - Lowers the ultimate strength

Tetra calcium alumina-Ferrate (C_4AF)

- Responsible for flash set but generate less heat (8-14%) normally 9% has poorest cementing value. Also responsible for grey color of Ordinary Portland Cement
- Raising C_4AF content- Reduces the strength
- Heat of hydration – 420 J/g

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For heat of hydration $C_3A > C_3S > C_4AF > C_2S$

For Rate of Hydration $C_4AF > C_3A > C_3S > C_2S$

- Rapid hardening cement contains more C_3S and less C_2S than OPC not used for mass concrete because due to large quantity of heat of hydration.

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Types of cement:

There are about 19 types of cement are available and under the 19th cement namely High Strength Cement, there are 5 types available.

1. Ordinary Portland Cement
2. Rapid Hardening Cement – IS: 8041-1990
3. Extra Rapid Hardening Cement
4. Low Heat Portland Cement - IS: 12600-1989
5. Portland Slag Cement – IS: 455-1989
6. Portland Pozzolana Cement – IS: 1489-1991 (Part 1 and 2)
7. Sulphate Resisting Portland Cement– IS: 12330-1988
8. White Portland Cement – IS: 8042-1989
9. Coloured Portland Cement - IS: 8042-1989
10. Hydrophobic CeMent - IS: 8043-1991
11. High AluMina Cement - IS: 6452-1989
12. Super Sulphated Cement - IS: 6909-1990
13. Special Cements
14. Masonry Cement
15. Air Entraining Cement
16. Expansive Cement
17. Oil Well Cement

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ORDINARY PORTLAND CEMENT - OPC

- Ordinary Portland Cement (OPC) is considered to be the most important among the types of cement.
- It is being manufactured by the process of burning limestone which is the siliceous material at 1400°C and after burning it is grinded with Gypsum.
- OPC can be classified to a three grades system which usually depending upon on the strength tested at 28 days as per specification of IS 4031-1988
- Grade-33 : If the 33 Grade Cement, if tested at 28 days compressive strength should not be less than $33N/mm^2$ and it is certified by IS 269:1989.
- Grade-43 : When strength of cement tested after 28 days with having not less than $43N/mm^2$, then it is termed as called 43 grade cement.
- Grade-53 : When strength of cement tested for its the strength at 28 days is not less than $53N/mm^2$, This is being certified by IS 12269:1987.

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Days	Grade 33	Grade 43	Grade 53
3 days (Compressive strength)	16	23	27
7 days (Compressive strength)	23	33	37
28 days(Compressive strength)	33	43	53

- **Hydraulic Cement**: Set and harden in water due to chemical action b/w cement and water called as hydration eg., Portland cement
- **Non-hydraulic cement**: derived from calcinations of gypsum or limestone eg., plaster of Paris

RAPID HARDENING CEMENT (RHC):

- The Rapid Hardening Cement is done which almost similar to Ordinary Portland Cement
- it suggests Rapid Hardening leading to higher rate of development of strength, which is done at the age of 3 days, however, the time taken for OPC to develop the similar strength is about 7 days.

EXTRA RAPID HARDENING CEMENT

- It is prepared by adding $CaCl_2$ to the rapidly hardening cement. There should be only 2% of calcium chloride by weight of the Rapid Hardening Cement
- ERHC fastens the setting and hardening process very fast.
- Because of its character of quick hardening, it is mostly recommended in the the process of concreting under the cold weather.
- Also called ultra rapid hardening cement
- Also known as calcium chloride cement
- Manufactured by 2% $CaCl_2$ and Rapid H.C.
- Addition of $CaCl_2$- quick setting – hardening properties.

PORTLAND SLAG CEMENT certification by IS 455:1989.

- It is usually obtained through mixing portland cement clinker, gypsum and granulated blast furnace slag in a suitable proportion and then grinding which leaves as the mixture
- The manufacturing of PSC is process where they utilize the blast furnace slag which is a waste product from blast furnace.

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QUICK SETTING CEMENT

- Set quickly but does not harden quickly
- This quick setting property can be achieved by the reduction of gypsum content during clinker grinding.
- Initial setting time 5 min
- Final setting time 30 min
- These kind of quick setting of cement is to be mixed, placed and compacted.
- It is used mostly in under water construction, where, pumping of water is involved, where it reduces the time taken for pumping and makes it economical.

SULPHATE RESISTING CEMENT (SRC):

- The sulphate resisting cement is certified by IS 12330:1988.
- Generally, Sulphate mixes with both of free calcium hydroxide which sets the cement making calcium sulphate and it reacts with hydrate of calcium aluminate leading the formation of calcium sulphoaluminate.
- < 5% C_3A
- Used for canals and culverts.

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AIR-ENTRAINING CEMENT

- This kind of cement is made by mixing with agent which allows Air-entraining with Ordinary Portland Cement clinker at the time of grinding.
- The given below are the various air-entraining agents can be used:
    - Alkali salts of wood resins.
    - detergents of alkyl- aryl sulphonate type of synthetically made.
    - Calcium lingo sulphate which is obtained during the process of sulphite in paper making.
    - Calcium salts of glues and other some kind of proteins used in the treatment of animal hides.
    - Wetting agents like aluminium powder and hydrogen peroxide can be used.
- It is to be noted that the above agents are used in powder or liquid forms to an extent of Only 0.025-0.1% by weight of cement clinker.
- During the mixing Air-Entraining Cement, it produces tough, which is tiny, a discrete non-coalescing air bubbles on the body of concrete.
- These air bubbles can modify the quality of concrete on its workability, etc

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COLOURED CEMENT (WHITE CEMENT)

- White cement is certified under IS 8042:1989
- Raw Materials needed for the production of white cement are
  - Limestone which contains 96% $CaCo_3$ and iron oxide of less than 0.07%.
  - White cement is ground finer than that of then grey cement.
- As per the ISI standard scale, whiteness of the white cement should not be less than 70%.
- The white cement is considered to be the best for the construction of Architectural Projects, other Decorative Works, structures where vibrant colours are deemed good.

LOW HEAT CEMENT

- LHC is certified by the code of IS 12600:1989.
- LHC is being made by the addition of Tri-calcium aluminates and Silicate in Ordinary Portland Cement
- Low Heat Cement is particularly suited for making concrete for dams
- Low percentage of C_3A (5%) and Higher percentag of C_2S (46%)

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HYDROPHOBIC CEMENT

- This cement is certified by IS 8043-1991.
- Hydrophobic cement is produced by grinding the OPC clinker with substances of water- repellant which forms a film of acid of oleic and stearic.
- The natural properties of hydrophobic cement are the similar to that of OPC except that it contains a small quantity of air bubbles, which increases the work ability of concrete.
- The water repellant film of hydrophobic cement protects from the bad effect of moisture during the storage and transportation.

HIGH ALUMINA CEMENT

- It is certified under the code IS 6452:1989.
- High Alumina Cement is obtained through mixing of alumina with calcareous in proportions followed by grinding which leaves to a fine powder.
- It is highly refractory, which is not easily controlled.
- It has low pH.
- It remains in high durability in sulfuric acid.
- The hardening takes place rapidly.

Field Test on Cement:

- Open the bag and take a good look at the cement, then it should not contain any visible lumps.
- Colour of cement should be greenish grey
- Should get cool feeling when thrusted.
- When we touch the cement, it should give a smooth a gritty feeling.
- When we throw the cement on a bucket full of water before it sinks the particles should flow.

Laboratory Tests on Cement

1. Consistency of cement
2. Setting times of cement
3. Soundness of cement
4. Compressive strength test
5. Fineness of cement
6. Tests for chemical composition of cement

Consistency test

- Normal consistency is defined as the percentage of water required to produce a cement paste of standard consistency.
- Done by Vicat's Apparatus.
- Vicat's Apparatus:
  - Vicat mould is in form of cylinder
  - Three attachments are used

    $10\,mm\phi$ Plunger – consistency test

    $1mm^2$ needle – initial setting time

    $5mm\phi$ annular colur- final setting time
  - Initial setting time-0.85P
  - Initial setting time-30 min
  - Final setting time $\ngtr 10hr$

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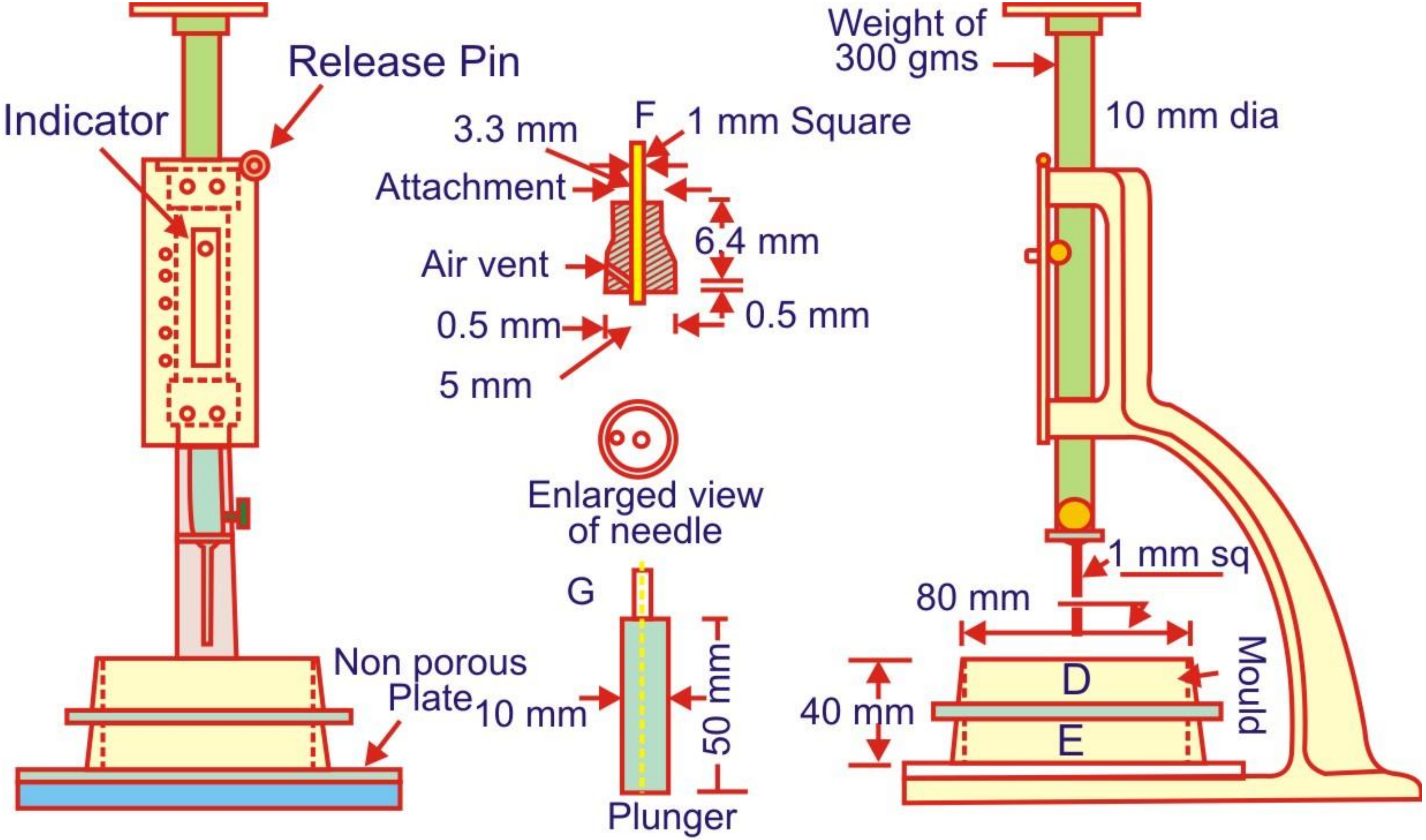
Vicat's Apparatus



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Fineness of cement:

- The fineness of cement has an important bearing on the rate of hydration, rate of gain of strength, evolution of heat.
- Finer cement offers greater surface area.
- Disadvantage of fine grinding is that it is susceptible to air set & early deterioration
- Maximum number of particles in a sample of cement
- Degree of fineness of cement is the measure the size of grain in it.
- 3 methods are used to find out Fineness of cement
    - Sieve method – IS sieve No.9
    - Air permeability method : Nurse Blaines method
    - Sedimentation Method – Wanger turbidimeter

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Soundness of cement:

- It is very important that the cement after setting shall not undergo any appreciable change of volume.
- Purpose to detect the change in volume of cement after setting
- Two methods are used to find out Soundness of cement
    - Lechatelier method
    - Autoclave method
- The unsoundness in cement is due to the presence of excess of lime combined with acidic oxide at the kiln.
- This is due to high proportion of magnesia & calcium sulphate.
- Therefore magnesia content in cement is limited to 6%.
- Gypsum 3-5.

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Cement mortar

- Cement mortar is the mixture of cement and sand.
- For preparing mortar, mixture of cement and sand thoroughly mixing them in dry condition.
- Water is gradually added and mixed with shovels.

Work	Cement: Sand
Masonary works	1:6 to 1:8
Plastering masonary	1:3 to 1:4
Plastering Concrete	1:3
Pointing	1:2 to 1:3

Curing – The process to ensure sufficient moisture for hydration after laying mortar

- Cement gains the strength gradually with hydration

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Hydration of cement

- When cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. This chemical reaction with water is called "hydration".
- Hydration starts as soon as the cement and water are mixed.
- The rate of hydration and the heat liberated by the reaction of each compound is different.
- Each compound produces different products when it hydrates.

- A mix richer than 1:3 is prone to shrinkage.
- Leaner mix is not capable of closing the voids in sand and hence the plastered surface is porous.

Cement : sand	Compressive strength
1:3	10 N/mm^2
1:4	7.5 N/mm^2
1:5	5 N/mm^2
1:6	3 N/mm^2
1:8	0.7 N/mm^2

Uses of cement mortar

- To bind the masonary units like stone, bricks, cement blocks.
- To plaster the slab and walls make them impervious.
- To give neat finishing to walls and concrete works
- For pointing masonary units
- As a filler material in stone masonary.

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Mortars for plastering and masonary

1. Lime Mortar

- Fat lime and hydraulic lime are used for making the lime mortar
- Fat lime→ used sand mixed is normally 2 to 3 times its volume of lime
- Hydraulic lime→ used sand mixed is normally 2 times the volume of lime
- Lime is prepared by pounding or by grinding
- Pounding: Pounding pits are formed in hard grounds
    - Size of pit 1.8m long, 0.4m wide and 0.5m deep
- Grinding: better way of getting good mix
    - Carried out in bullock driven grinding mill or power driven mill.
- Lime mortar is also having good grinding property
- Fat lime mortar is used for plastering while hydraulic lime mortar is used for masonary construction.

2. Mud Mortar

- Clay lumps are collected and wetted with water and allowed to mature for 1 or 2 days.
- Kneeded well
- Sometimes fibrous materials like gobber is added on water
- Prevents cracks in the plaster
- Cheap mortar and Durability less
- Used for temporary works

3. Gauged mortar

- Mortar obtained by adding cement to lime mortar
- Proportion of cement : lime : sand are

  1:1:6

  1:2:9

  1:3:9
- This mortar is to be used within half an hour after maxing the cement
- It is cheaper than cement mortar
- Quality is between that of cement mortar and lime mortar

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4. Clay cement mortar

- Quality of clay mortar can be improved by adding the cement to the mix.
- Normal proportion of clay : cement is 1:1.

5. Decorative mortar

- Obtained by coloured cement adding.

Aggregates

- Aggregates are the important constituents of the concrete which give body to the concrete.
- Aggregates generally occupy 65- 80% of a concrete's volume.
- Aggregates are inert fillers floating in the cement paste matrix for concretes of low strength.
- The strength of aggregates do not contribute to the strength of concrete for low strength concrete.
- The characteristics of aggregates impact performance of fresh and hardened concrete.

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Why use aggregate

- Reduce the cost of the concrete
- Reduce thermal cracking
- Reduces shrinkage
- High aggregate: cement ratio desirable
- Imparts unit weight to concrete.

Aggregate Classification

- **Size:** Coarse Aggregates & Fine Aggregates.
- **Specific Gravity:** Light weight, Normal weight and Heavy weight aggregates.
- **Availability:** Natural Gravel and Crushed Aggregates.
- **Shape:** Round, Cubical, Angular, Elongated and Flaky aggregates.
- **Texture:** Smooth, Granular, Crystalline, honeycombed and Porous.

Aggregate Classification: Size

Fine Aggregate

- Sand and/or crushed stone.
- < 4.75 mm.
- F.A. content usually 35% to 45% by mass or volume of total aggregate

Coarse Aggregate

- Gravel and crushed stone
- >4.75 mm
- Typically between 9.5 and 37.5 mm.

Aggregate Classification: Specific Gravity

Normal weight Aggregate

- Most common aggregates (eg. Sand, Gravel, Crushed stone)
- Produce normal-weight concrete 2200 to 2400 kg/m^3

Light weight Aggregate

- Expanded (Shale, Clay, Slate, Slag)
- Produce structural lightweight concrete: 1350 to 1850 kg/m^3
- eg. Pumice, Scoria, Perlite, Diatomite
- Produce lightweight insulating concrete: 250 to 1450 kg/m^3

Heavy weight Aggregate

- Barite, Limonite, Magnetite, Hematite, Iron
- Produce high-density concrete up to 6400 kg/m^3
- Used for Radiation Shielding

Aggregate Classification : Availability

Natural Gravel

- River or seashore gravels; desert, seashore and windblown sands
- Rounded in nature
- Fully water worn or completely shaped by attrition

Crushed Aggregates

- Crushed rocks of all types; talus; screes
- Angular in nature

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Aggregate Classification : Shape

- The shape of aggregates is an important characteristic since it affects the workability of concrete.

Round Aggregates

Irregular Aggregates

Angular Aggregates

Flaky Aggregates

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Aggregate Classification : Texture

- Surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough.
- Surface texture depends on hardness, grain size, pore structure, structure of the rock.

No	Surface Texture	Examples
1.	Glassy	Black flint
2.	Smooth	Chert, Slate, marble and some rhyolite
3.	Granular	Sandstone, oolites
4.	Crystalline	Fine :Basalt, trachyte Medium : Dolerite, granophyre,granulite, microgranite, some limestones Coarse : Gabbro, gneiss, granite, syenite.
5.	Honeycombed and Porous	Scoria, pumice, trass.

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Physical Prosperities of Aggregate :

1. Grading

- 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. (150 μm, 300 μm, 600 μm, 1.18mm, 2.36mm, 4.75mm)
  - Coarse aggregate: 5 sieves with openings from 4.75 mm to 80 mm. (4.75mm, 10 mm, 12.5 mm, 20 mm, 40 mm)
- 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.

I.S. Sieve Designation	Percentage passing by weight for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90–100	90–100	90–100	95–100
2.36 mm	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 micron	5–20	8–30	12–40	15–50
150 micron	0–10	0–10	0–10	0–15

Fineness Modulus (FM)

- The results of aggregate sieve analysis are expressed by a number called Fineness Modulus.
- Fineness Modulus is obtained by adding the sum of the cumulative percentages by weight of a sample aggregate retained on each of a specified series of sieves and dividing the sum by 100.

$$\text{Fineness modulus} = \frac{\text{Sum of Cumulative Percentage weight retained on standard seives } (\%)}{100}$$

Fine sand: FM: 2.2 - 2.6
Medium sand: F.M: 2.6 - 2.9
Coarse sand: F.M: 2.9 - 3.2

- If sand is having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

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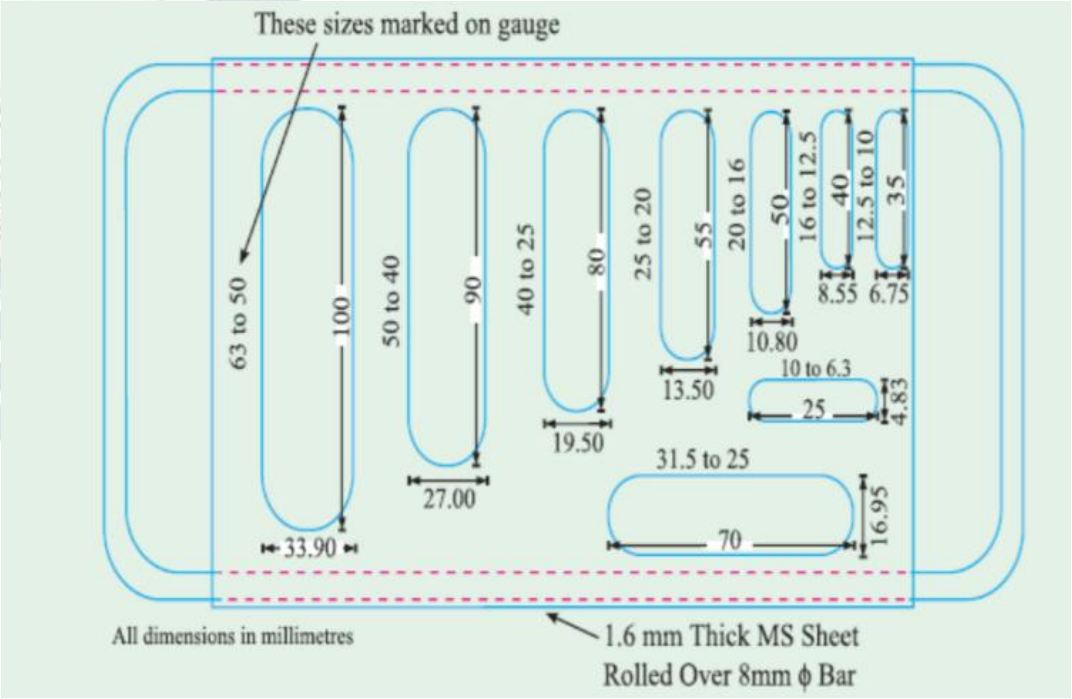
2. Flakiness index

- Flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths or (**0.6** times) of their mean dimension.
- The test is not applicable to sizes smaller than 6.3 mm.
- The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken.



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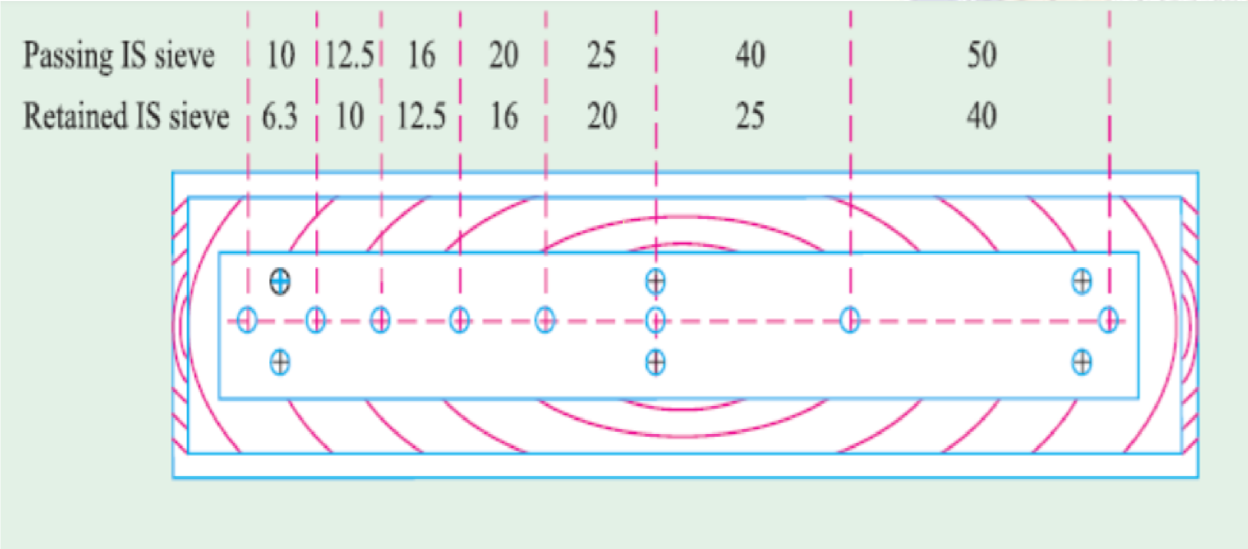
3. Elongation Index

- The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension.
- The elongation index is not applicable to sizes smaller than 6.3 mm.
- The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged.
- The presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable.



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4. Specific Gravity

- Indian Standard Specification IS : 2386 (Part III) gives various procedures to find out the specific gravity of different sizes of aggregates.

$$\text{Specific Gravity} = \frac{C}{A-B}$$

$$\text{Apparent specific gravity} = \frac{C}{B-C}$$

$$\text{Water Absorption} = \frac{(B-C)}{C} \times 100$$

A = Weight of saturated aggregate in water $(A_1 - A_2)$

B = Weight of the saturated surface dry aggregate in air

C = Weight of ovendried aggregate in air

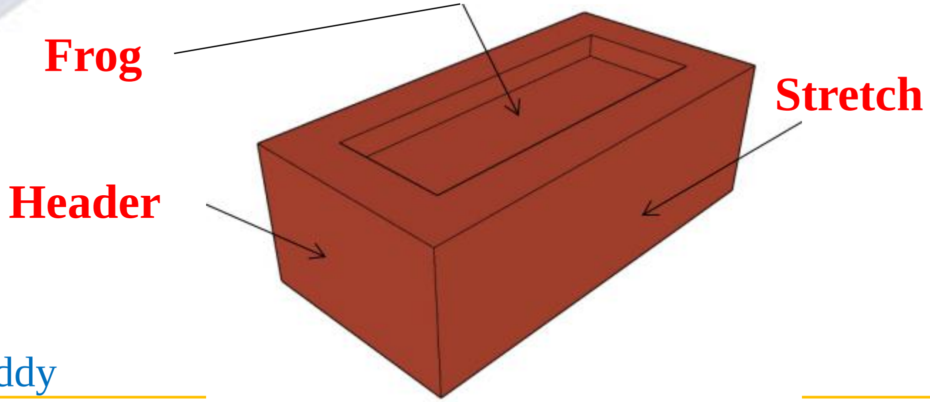
A_1 = Weight of aggregate and basket in water

A_2 = Weight of empty basket in water

Bricks

A brick is building material used to make walls, pavements and other elements in masonary construction. Made of burnt clay or mixture of sand and line

- Clay bricks are commonly used
- Standard size: 19×9×9 cm (without mortar)
- Modular size: 20×10×10 (with mortar)
- Frog- an incident of 1-2 cm deep formed on the top
- Purpose of providing frog – holding the mortar
- Size of frog – 10×4×1 cm
- In many parts of the country, bricks still made in non-standardize. Which are called as traditional bricks of field bricks. Size 23 × 11.4×7.6 cm



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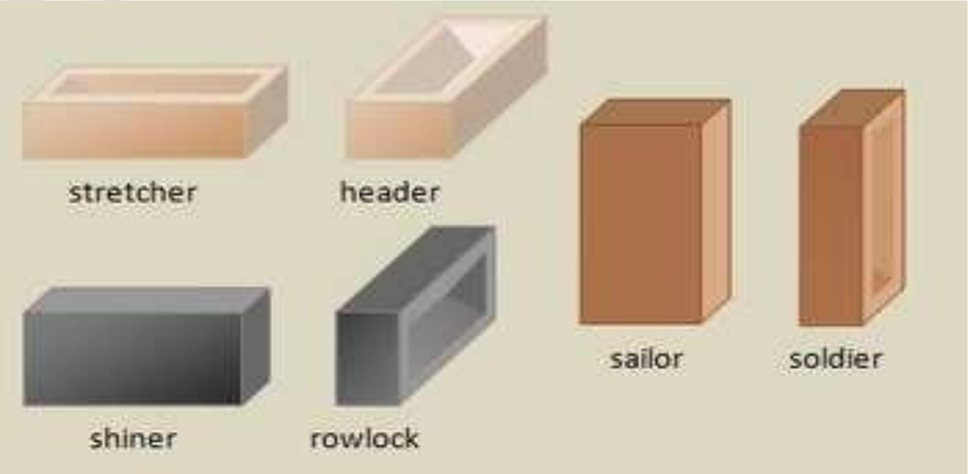
Orientation of brick

A brick is given a classification based on how it is laid, and how the exposed face is oriented relative to the face of the finished wall.

- Stretcher or Stretching brick – A brick laid flat with its long narrow side exposed.
- Header or Heading brick – A brick laid flat with its width exposed.
- Soldier-A brick laid vertically with its long narrow side exposed.
- Sailor-A brick laid vertically with the broad face of the brick exposed.
- Rowlock-A brick laid on the long narrow side with the short end of the brick exposed.
- Shiner or Rowlock Stretcher-A brick laid on the long narrow side with the broad face of the brick exposed.



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Classification of bricks

- Based on their physical and mechanical properties

First class bricks

- These bricks are table moulded
- Burnt in kilns
- Deep red, copper colour
- Should be free from flaws, cracks, stones
- Metallic sound should come when two bricks
- Water absorption 12-15%
- Crushing strength $\geq$ 10 N/mm^2 (10.5 N/mm^2) or 100 kg/cm^2

Second class bricks

- Ground moulded and burnt in kilns
- Small cracks and distortions permitted
- Crushing strength $\geq$ 7.0 N/mm^2
- Water absorption 16-20% by dry weight

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Third class bricks

- Ground moulded and burnt in clamps
- Reddish yellow coloured
- Water absorption 25%
- Rough surface with irregular and distorted edges

Fourth class bricks

- Over burnt and badly distorted in shape size
- Brittle in nature
- Uses-ballast of such bricks for foundation and floors in lime concrete and road metal.

Normal brick work 1:6 (cement : sand)
Plastering works 1:4
Grouting 1:1.5
Gunting 1:3

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On strength

According to Bureau of Indian Standards (BIS) has classified the bricks on the Basis of Compressive Strength

Class	Ave.comp.strength ≥ N/mm^2.
35	≥ 35.0
30	≥ 30
25	≥ 25
20	20
17.5	17.5
15	15
12.5	12.5
10	10
7.5	7.5

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Properties of good brick

- Size and shape-uniform and plane, rectangular surfaces
- A fractured surface should not have show fissures holes grits or lumps of lime
- Hardness hard when scratched by finger nail no impression is made
- Soundness metallic sound
- Water absorption ≤ 20%
- Crushing strength ≥ 10 N/mm^2.

Composition of good brick earth

- Silica 50-60%
- Alumina 20-30%
- Lime 10%
- Magnesia < 1%   < 20%
- Ferric oxide < 7%   < 20%
- Alkalis < 10%   < 20%

Silica (50-60%)

- It prevents cracking and shrinking and warping of raw bricks
- Imparts durability and uniform shape to bricks
- Excess of silica destroy cohesion b/w particles and bricks become break makes brittle

Alumina (20-30%)

- 20-30%
- Absorbs water and imparts plasticity to the earth such that it can be moulded
- Excess of alumina, it causes cracks in bricks on drying and becomes too hard . when burnt.

Lime (< 10%)

- It prevents shrinkage on drying
- Excess of lime causes the brick to melt, and hence brick looses its shape.

Iron oxide < 7%

- Gives red colour
- Improves impermeability and durability
- Gives strength and hardness

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Harmful ingredients in brick earth

- **Lime**
  - Excess of lime-colour changes red to yellow
  - When lime is present in lumps, it absorbs moisture, swells and causes disintegration of the bricks
- Pyrites (Iron pyrites) discolourise the bricks

Manufacture of bricks

- Unsoiling → digging → cleaning → weathering → blending → tempering →Moulding →drying → Burning → **Brick**
- For manufacturing of good brick, tempering is done in pug mills and operation is called pugging
- In pug mill feeding of clay from top and taking out of pugged clay from bottom are done.
- Burning can be done in kiln
- Temp. about 350°C to 1100°C

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- Dehydration (400°C-650°C) also known as water smoking stage
- Oxidation period (650°C to 900°C)
- Vitrification (1000°C to 1250°C) for high melting clay. (900°C to 1100°C) for low melting clay.

Types of continuous kilns.

Bull’s trench kiln

Hoffman’s kiln

Tunnel kiln

Testing of bricks

- **Dimension test:** According to IS:1077 standard size of bricks 19 cm × 9 cm × 9 cm
- **Water absorption test (IS: 3495 part-3)**

Depends on their porosity

By capillary action

% of water absorption indicates gives indication compactness

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Compressive strength test: IS: 3495 Part I

- Specimen placed with flat face horizontal
- Load is applied at a rate of 14 N/mm^2 per minute till failure
- Max. load at which brick fails is recorded for calculation of compressive strength.

$$\text{compresive strength} = \frac{\text{Maximum load at fail}}{\text{loaded area of brick}}$$

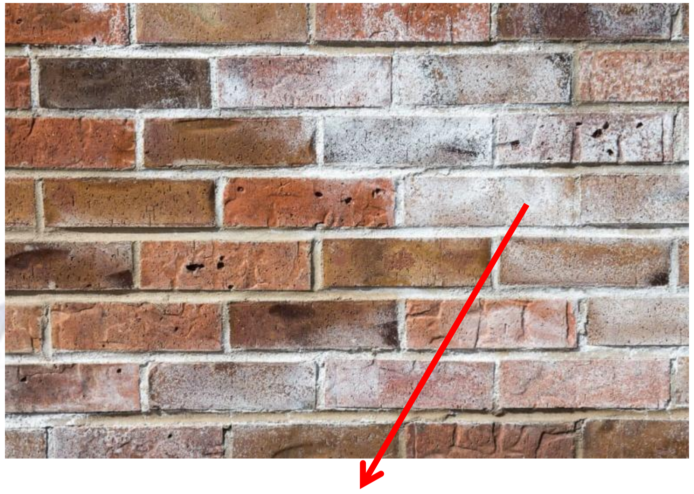
Warping test: (IS 3495 part IV)

- Measured with the help of flat steel or glass surface
- Two types concave and convex
- Largest distance is reported as warpage

Efflorescence < 10% for higher classes

≤ (10-50%) up to class 12.5

- Due to sulphate attack and efflorescence, white patches form on brick masonry
- High class brick masonry-modular bricks



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Important Points:

- A good brick should not absorb water more than 20%
- Presence of weeds in brick earh makes unsound
- The most important purpose of frog in a brick is to form keyed joint b/w brick and mortar
- Bricks are burnt @ 900°C to 1200°C
- The minimum compressive strength of 1^{st} class bricks should be 10 N/mm^2.
- Absorption a brick is to broken for test
- Hardness – two bricks can be struck with each other without breaking
- Soundness – A scratch is easily made on brick surface with the help of a finger nail.
- Refractory bricks resist- high temperature – chemical action – dampness
- Carbon brick is made form crushed coke bonded with air
- Avg. comp. strength < 12.5 N/mm^2- Efflorescence is moderate
- Mobility is used to consistency of mortar

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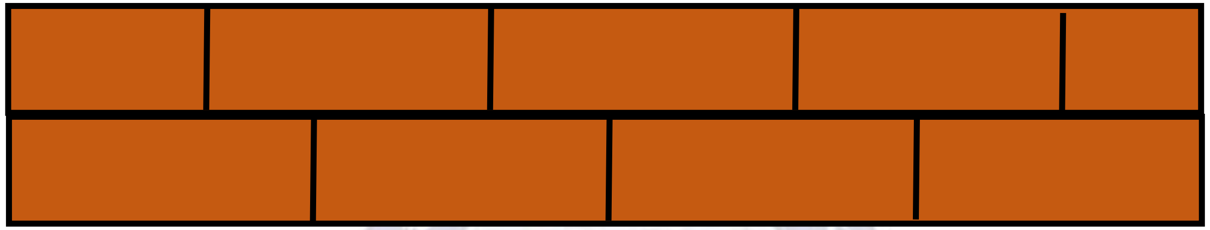
For good bonding in bricks of uniform in size: the vertical joints in alternate course should fall in plumb



- Continuous joints reduces strength
- King closers are used in brick masonry

For one m^3 of brick masonry, the number of modular bricks needed is 500 or 550

- Size 20 × 10 × 10 cm or 19 × 9 × 9 cm

$$\text{For } 1\text{m}^3 = \frac{100^3\text{cm}^3}{20\times10\times10} = \frac{100^3}{2000} = 500\,\text{bricks}$$

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- Bricks bonded together with mortar- brick masonry
- Pug mill is used for preparation of clay
- The process of mixing clay, water and other ingredients to make bricks- kneading
- Alluvial soil is good for making bricks

Lime mortar

- In mortar lime is used as binding material
- Has a high plasticity and can be placed easily
- Hardens slowly
- Lime can be used for mortar can be fat lime or hydraulic lime

Fat lime:

- Has high calcium oxide (CaO) content
- Unsuitable for water logged areas or in damp situations
- It shrinks to a great extent.

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Hydrated lime

- It is a dry powder obtained by treating quick lime with water enough to satisfy its chemical affinity for water under conditions of hydration
- It contains small quantities of Silica and Alumina and Iron oxides with some of Cao, gives mortar
- That mortar has better setting and hardening under water
- Requires proportion of lime to sand by volume 1:2
- More strength in damp conditions
- Slaked fat lime is used to prepare mortar for plastering
- Hydraulic lime for masonry construction

Surkhi mortar:

- Surkhi is a pozzolanic material, all of it passes through 4.75 mm is sieve.
- Mortar is prepared by using fully or partly Surkhi instead of sand in fat lime mortar.
- Cannot used for plastering or pointing because it is likely to disintegrate after some time.

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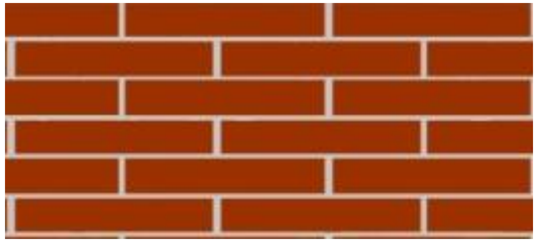
Gauged mortar:

- To improve the quality of lie mortar and to achieve early strength, cement is sometime added to it – gauging
- It makes lime mortar economical, strong
- Also known as composite mortar or lime cement mortar

Stretcher bond

- All bricks are laid as stretchers on the faces of walls.
- Thickness of wall is 9 cm, used in partition walls, sleeper walls.
- Not suitable
- Stretcher lager face of brick (19 cm × 9 cm)
- Header shorter face of brick (9 × 9 cm)
- Arris edge of a brick
- Quoin- It is a corner or their external angle on the face side of a wall. Generally quoins are at right angles.



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Header bond

- All bricks are laid as headers on the faces of the walls
- Unsuitable for load bearing walls

English bond

- Most commonly used wall
- Bond consists of alternate courses of headers and stretchers
- Queen closer is used after first header to break the vertical joints in successive courses
- No continuous vertical joint

Flemish bond

- Made up of alternate header and stretcher
- Every alternative course starts with header at corner

Types of Flemish bond

Double Flemish

Single Flemish bond

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Double Flemish bond

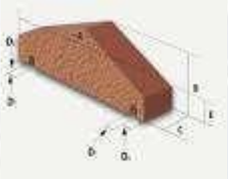
- Back and front face are same in appearance
- Better appearance than English bond
- Front facing –double Flemish bond.
- Back facing – English bond
- English bond is stronger than Flemish bond
- Flemish bond gives better appearance than English bond
- Greater skill required in Flemish bond

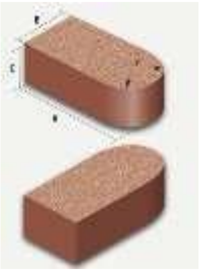
Classification based on shape

The ordinary bricks are rectangular solids. But sometimes the bricks are given different shapes to make them suitable for particular type of construction. Different types of bricks available with various shapes:


1. Bullnose brick

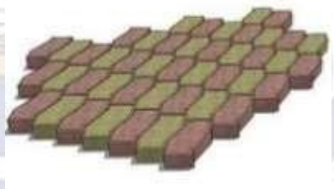

2. Channel bricks


3. Coping bricks


4.Cownose bricks:

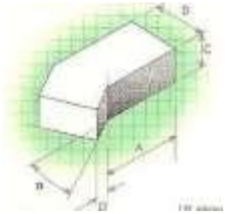

5. Curved sector bricks

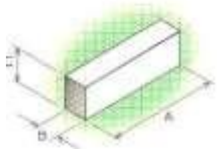

6.Hollow bricks

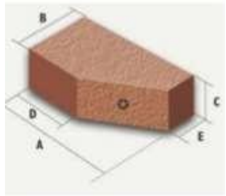

7.Paving bricks


8.Perforated bricks:


9. Purpose-made bricks


10. Dogleg/angle


11. Queen closer.


12. King Closer

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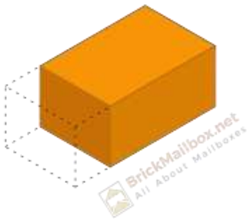
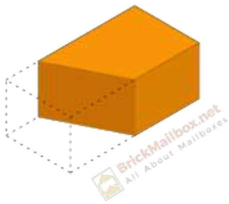
Other Shapes of Bricks:-

Bat:-The portion of brick that is cut across the width.

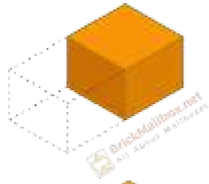
- Three Quarter Bat:- When the length of the bat is equal to three-quarters of the length of the original brick.



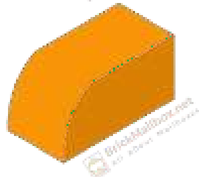
- Beveled Bat:- When a bat has its width beveled. Bevel is the incline surface that meets another of the same body with the angle being anything but a 90- degree angle.



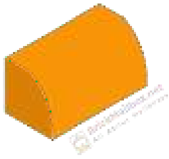
- Half Bat:- When the length of a bat is equal to half of the length of the original brick.



- Single Bull Nose Header:-Top header side corner of the brick is rounded off.



- Single Bull Nose Stretcher :Top stretcher side corner of the brick is rounded off.



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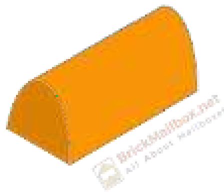
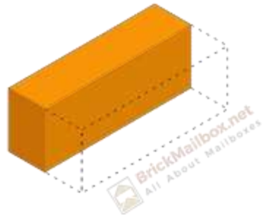
Other Shapes of Bricks:-

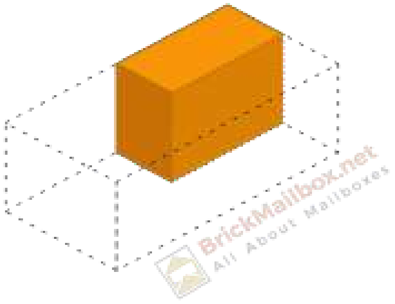
- Bull Nose Double Stretcher:-Both top stretcher side corners of the brick are rounded off.



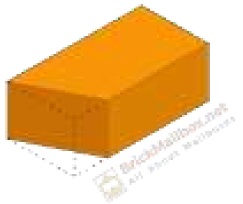
- Queen Closer (Half):-The piece of brick taken by cutting a brick lengthwise into two parts.



- Queen Closer (Quarter):-When the queen closer is cut in half, then it is called a queen closer quarter.



- Mitred Closer:-These are bricks where one end is cut at an angle from 45 to 60 degrees.



Important Points

- Mortar strength should match brick, in brick masonry
- When the corner of a brick is removed along the line joining midjoints- king closer
- English bond is provided for heavy loads on masonry
- For high class brick masonry, modular bricks are proper bricks
- Strength of mortar influence by type of mortar
- Slenderness ratio for masonry walls should not be more than 30
- Max. slenderness ratio for load bearing masonry wall-built in cement mortar. As per ID code shall not exceed-27

Timber

- Timber: Non isotropic material and Brittle material (fails without warning)
- Standard moisture for good timber 12%
- Strength of timber is maximum when load applied is parallel to grain.
- Nail diameter should be within the range a range of 1/4th to 1/6th of least thickness of wooden timber.
- Seasoning of timber is required to remove sap from timber.
- Painting of flush doors

  1) prime coat

  2) putty filling

  3) paint
- Reduces quantity of paint and effort involved in regular coats of paint

  Deciduous→ hard wood

  Confiner→ soft wood

  Endogenous→ Bamboo

  Exogenous→ Eucalyptus

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Conifers:

- Ever green trees having pointed needle like leaves.
  Eg. Deodar, chir, fir, kail, pine
- Show distinct annual rings.
- Have straight fibres.
- Soft, light in colour and light weight
- Resinous.

Deciduous:

- Have flat board leaves
  Eg. Oak, teak, shishum, sal and maple.
- Annular rings are indistinct
- Hard wood, heavy weight, dark colour
- Non-resinous

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- Radial sawing gives strong timber so that layer distribution is uniform.
- Lateral support of timber beam

  $d/b<3$, $L/b<50$

- Moisture content in structural timber – 10 to 20%
- Inner most core of the stem of tree is Pith
- Concentric circles in a stem are annular rings
- CASEIN: name for a family commonly found in milk white in colour.

Components of scaffolding		Function
Putlog	-	Transverse member
Ledge	-	Horizontal member
Brace	-	Diagonal member
Standard	-	Vertical member

Preservation of timber:

1) pressure impregnation : more effective

: all voids by pressure are filled.

2) Dipping: all voids are filled by gravity

3) Spraying (or) Brushing

- Radial splits in timber originating from bark and narrowing towards pith are known as star shakes
- On application of external stress on timber, it behaves like an elastic material.
- Tangential shrinkage of wood is due to reduction in moisture content is 3.1 to 5.1.
- Compressive strength in structural timber is minimum in direction of parallel to grains.
- Timber can be made fire resistant by soaking it in ammonium sulphate.
- Maximum deflection in timber beams or joints $\ngtr \frac{span}{300}$
- For engineering purposes→ hardwood → deciduous
- Log→Trunk of a tree after cutting all the branches.

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- Dry rot is a disease due to fungal effect on timber.
- Wet rot→ where ventilation and air circulation is very less.
- Dry rot is a special form of decay in timber caused by fungus which reduces the wood to powder condition.
- Disease of dry rot in timber is caused by lack of ventilation.
- The age of trees can be understood by counting the number of rings.
- Each year, trees from new cells, arranged in concentric circles called Annular growth rings which are used to understand its age.
- CREOSE oil is impregnated into timber with high pressure to prevent fungal effect.

Product		Use
Fibre board	-	Insulation
Hear wood	-	Scantling
Laminating wood	-	Arches/trusses
Plywood	-	paneling

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- Heart shake: widest at centre diminishing towards outer circumference.
- Knot: Damaged branch of a tree, which causes twists in the grain arrangement.
- Max tensile strength – in direction parallel to grains

Exogenous tress: {Hard wood}

→ grows outward

→distinct consecutive rings are formed in horizontal directions(section)

- Timber mostly used for engineering purposes belong to exogenous trees.

Endogenous Trees:

- Grows inwards and fibrous mass is seen in their longitudinal sections.

Eg. Bamboo, cane, palm

- Soft wood – chir, deodar, fir, pine
- Hard wood – oak, sal, teak

Exogenous trees → Confiners

→ Deciduous.

Min E of timber as per IS → 5600N/mm^2

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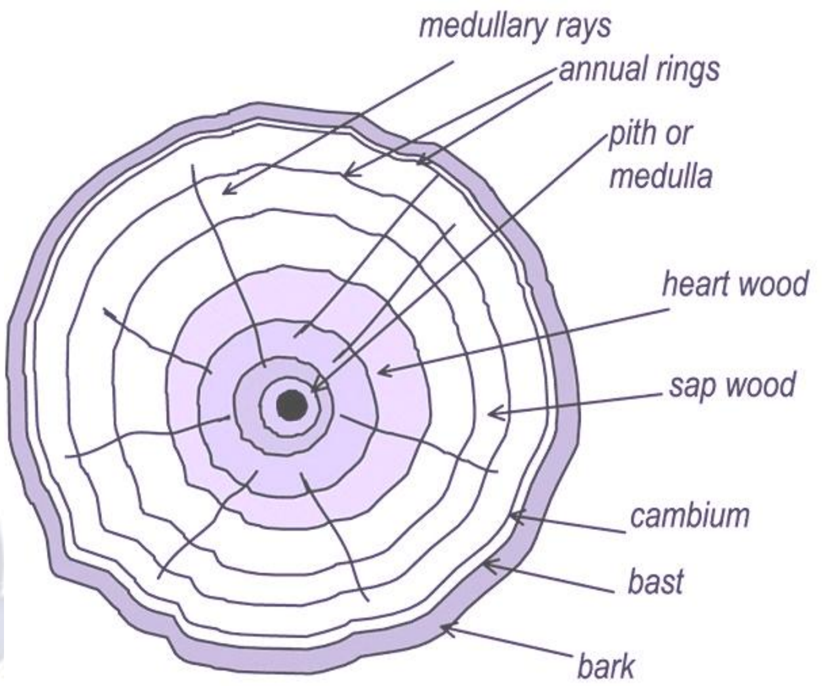
Structure of Timber

- Inner bark gives protection to cambium layer
- Outer bark also known as cortex.
- Sap wood contains living cells and takes active part in growth of tree
- Medullary rays are thin radial fibres extending from pith to cambium layer
- Pith is centre of the timber structure
- Annualar rings are explained the life of the timber.



The tree trunk showing growth rings

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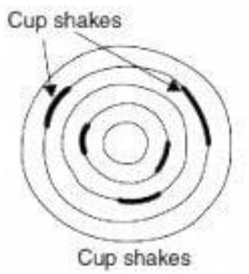
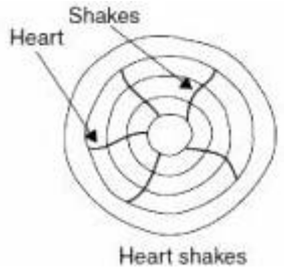
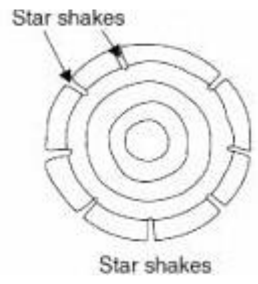
Defects due to natural forces:

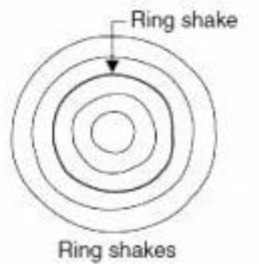
Shakes: cracks which partly or completely separate the fibres of wood.

- Cup shakes: rupture of tissues in circular direction
  Separate one annular ring from the other
- Heart shakes: cracks extend from pith to sap wood
  Due to shrinkage of inner part of tree or heart wood
- Star shakes: cracks extend from bark towards sap wood.
  Due to extreme heat.
- Radial shakes: similar to star shakes but fine irregular and numerous.
  Only occurs when tree is exposed to sun.
- Torn grain – small depression formed due to falling of a tool.
- When moisture content >20% → Fungi
  Defect









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Differences between soft wood and hard wood

Property	**Soft wood**	**Hard wood**
Colour	Lighter	Darker
Growth	Faster	Slower
Density	Low	High
weight	Low	High
Annular rings	Distinct	Indistinct
Heart wood	Cannot	Can be sap wood
Strength	Strong along the grains	Along grains and across

- Recommended moisture content for structural elements
  - For doors - 12 to 20%
  - For windows - 10 to 16%
- Heat conductivity – low
  - Heat conductivity along the fibres is 1.8 times greater than across the fibres.

- Sound conductivity- high

  Velocity of sound in timber is 2 to 17 times greater than that of air.

Tensile strength:

- Timber is stronger in tension along the grain → 80 to 190 N/mm^2
- Across the grain tensile strength is low.
- Tensile strength along the grain is 2 to 4 times stronger than compressive strength.

Bending strength:

- Used for beams, slabs.
- Measured by one point loading test.

Shear strength:

- Low
- 6.5 to 14.5 N/mm^2 along the fibres.

- Modulus of elasticity of timber → 0.5 to 1.0×10^4 N/mm^2
- Unpleasant smell indicates decayed timber.
- For good timber → should have straight fibres

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Ring galls:

- Peculiar curved swellings on the body of a tree and where branches improperly cutoff.
- Timber in this part is very weak and not durable.
- Burls also known as excrescences.
- Knots – bases of branches are broken from tree
  - Form a source of weakness.

Defects due to seasoning

- Bow – curvature in direction of its length.
- Cup – curvature in transverse direcition.
- Twist – spiral distortion along the length
  - Due to wind
- Split – separation of fibres along grain extends from one end to other.
- Honey combing – separation of fibres interior due to drying stress.
- Warp – when a piece of timber out of shape.

Types of preservatives:- Preservation of timber IS-401

1. ASCU Treatment

- ASCU solution prepared by 6 parts by ASCU powder is mixed in 100 parts if water
- Composition

  1 part – hydrated Arsenic pentoxide.

  3 pats – blue vitrol or copper sulphate

  4 parts – potassium dichromate or sodium
- Solution protects against from white ants
- Odour less

2. Chemical salts

3. Coal – tar

4. Creosote oil

- Obtained by distillation of tar
- Also known as bethel's method
- Thoroughly seasoned and drilled

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- **Oil paints**
- **Solignum paints**
  - Highly toxic in nature
  - Applied in hot state with help of brush
- **Charring**
  - Old method
  - No preservative is used
  - Surface to be charred is kept wet for about half an hour
  - Charred portion is then cooled with water
- High quality and durable furniture – teak wood.
- Shear strength of timber depends on alignment of layers of coat lignin with fibres.
- Differential shrinkage of timber causes warping.
- Sap wood – outer most annular rings.
- The moisture content at which all of the free water is removed → fibre saturation point. Strength is higher at fibre saturation point.

Fire resistance of timber:

1. Refractory timber – Do not catch the fire easily.

eg. Sal and Teak

2. Non refractory timber – catches fire easily

eg. Chir, deodar, fir

Methods:

1. Application of special chemicals
   - Chemicals are called Antipyrines.

     eg. Borax and sodium arsenate solutions
   - Treated with antipyrines. Timber does not inflame even at high temperature but burns slowly without flame

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2. Sir Able’s process.

- Timber surface coated with dilute or weak solution of sodium silicate.
- Cream like paste of slaked fat lime is then applied.
- Composition of solution.

Sodium silicate	56 grams
Water	50 grams
Kaolin	75 grams

Seasoning of timber:

- Well seasoned timber should have 10 to 12% of moisture equal to atmosphere humidity.
- Seasoned timber should have be protected from exposure to the rain and excessively high humidity.

Objectives of seasoning:

- Reduce shrinkage, warping and weight.
- Increase strength, durability and workability.
- Make it suitable for painting.

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1. Natural seasoning:

- Rate of drying is very slow.
- Time required – 120 to 180 days
- Reduces moisture content of timber – 10 to 20% depend on climatic condition.
- Cheap and simple.

2. Artificial seasoning:

- Faster drying.

Methods of seas – Boiling

- Chemical seasoning or salt seasoning
- Kiln seasoning
- Water seasoning

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Boiling

- Timber immersed in water and heating.
- Very quick method
- Periods of seasoning and shrinkage are reduced by this method but it affects the elasticity and strength of timber.
- Easy to break and becomes brittle.

Kiln seasoning

- Drying of timber is carried out inside an airtight chamber of oven.
- Heated to temperature about 35^0C to 38^0C.
- Time require 12 to 20 days.
- Temperature is raised till the desired degree of moisture content is attained.

Mc. Neill's process

- No adverse affects
- Best method of seasoning of wood.
- Time required is 15 to 60 days.

Important Points

- According to IS code, the weight of timber to be reckoned at a moisture content of 12%.
- Strength of timber is maximum when load applied parallel to grain.
- Fibre saturation point is reached when
    - Free water is removed
    - Shrinkage of wood is rapid
    - Strength is rapid
- The expansion and shrinkage of plywood are comparatively very low as piles are placed at right angles to each other.
- For structural timber – 10 to 20%
- Timber used for flooring – 7 to 20%
- For building frames – 13 to 20%
- Specific gravity of good timber should be 1.54
- Compressive strength of good timber at 15% moisture is 30 to 80 MPa.
- Tensile strength of good timber is 80 to 190 MPa
- Bending strength 40 to 100 Mpa

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- Seasoning of timber is required to remove sap from timber.

Deciduous	-	hard wood
Conifer	-	Soft wood
Endogenous	-	Bamboo
Exogenous	-	Eucalyptus

- Modulus of elasticity of timber 0.5 to $1\times10^4 N/mm^2$
- During the conversion of timber by sawing, in order to obtain strong timber pieces, the cuts should be made by rapid sawing.
- The moisture content in structural timber should be 10 to 20%
- The inner part of stem of a tree – pith
- The vascular tissue which encloses the pith – medullar rays.
- The thin layer below the bark not converted into sapwood as yet cambium layer.
- Dry rot in sapwood is caused by fungal.
- Brown rot in coniferous woods is a result of fungal attack.
- Alternative wetting and drying of unseasoned timber causes powdery form of decaying wood.

- Heart wood – Deadwood
- Timber used for construction is obtained from heartwood.

Decreasing order of effectiveness of preservation of timber

1. pressure impregnation
2. Dipping
3. brushing (or) spraying

- The moisture content in a properly seasoned timber will be in the range of 10 to 12%
- $\frac{\text{Tangential shrinkage}}{\text{Radial shrinkage}}$ of wood – 3.1 to 5.1
- Compressive strength is minimum in perpendicular to grains
- Advantage in using plywood is that the tensile strength is equal in all directions.
- Timber can be made reasonably fire resistance by soaking it in ammonium sulphate
- Knots – caused by wood limbs encased by the wood of the free trunk
- Cupping – unequal shrinking in radial and tangential direction.
- Wood is impregnated with creosote oil in order to protect against fungi

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- Hardest timber is obtained from the wood grown in
  - → moderately dry climatic conditions
  - →open areas
- Dry rot in timber is due to decomposition of sap

Fibre wood	- Insulation
Heart wood	- scantling
Laminated timber	- aches/ timber
Plywood	- paneling

- Kiln seasoning of timber results in → reduced density
- The timber preservative creosote belongs to the group of tar oil type.
- As a natural material, timber is anistropic
- The defect which develops uncontrolled and non-uniform loss of moisture from wood is warping.
- The treatment for making timber fire resistant is Able's process.

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- Fibre saturation point – no free water exists in cell activities but cell walls are saturated.
- The moisture content of timber in building frames →12 to 18%
- Modulus of elasticity of standard timber [Group B] → 1 to 1.25 MN/cm^2
- IS 399-1963: weight of timber is specified at 12% moisture content.
- Dry rot: fungal effect
- Grey rot: Destruction of cellulose of wood due to fungal attack.
- Wet rot: chemical decomposition of wood.
- White rot: White layer on the surface due to fungus.
- The moisture content for plywood – 8% to 16%
- Heartwood (Dead wood) → nutrients are not transferred.
  → Gives strength only.
- Ply wood →Tensile strength is equal in all directions.

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