

Introduction to Concrete and Concrete Materials:

Concrete: Concrete is defined as the composite material consisting of binding medium and aggregate particles. The binding medium is the product of reaction between hydraulic cement & water. So, the main constituents of concrete are cement, sand, aggregate and water.

$$\text{Concrete} = \text{Binding Medium} + \text{Aggregates} + \begin{matrix} \text{Admixtures} \\ \cancel{\text{Additives}} \\ (\text{if required}) \end{matrix}$$

Binding medium = hydraulic cement + water.

- * Hydraulic cement: → starts to harden instantly and can be completed in few hours → fastens construction process
 - Hydraulic cement can harden while in contact with water.
 - is a mixture of limestone, clay and gypsum are burned together under extreme temperatures
 - Mostly used in current time's construction
 - almost all construction.
- * Non-hydraulic cement:
 - takes longer time to harden → which delays construction process
 - needs dry conditions to strengthen.
 - materials used include lime, gypsum plasters & oxychlorides
 - It was created first, but its limitations due to longer time to harden → delay construction → generally not used these days.

Use of Concrete in structure!

Concrete is widely used construction material due to following reasons:

- High compressive strength
- Versatility in shape and forms → many forms can be moulded easily
- Excellent resistant to water and comparatively less prone to corrosive and weathering effect.
- Cheapest and most readily available ingredient materials.
- Durability
- fire resistant
- Consideration of energy and resource conservation.

[Note: Maximum concrete used in a single project is 16 million cubic meter of concrete in "Three Gorges Dam" in China.

→ Hydroelectric gravity dam with world's largest power station having installed capacity of 22,500 MW.

Work started → 1994-December
Work completed & fully functional → July, 2012.]

Types of Concrete:

Concrete can be classified on various basis:

i) Based on binding material:

- Cement Concrete → cement as binding material.
- Lime Concrete → lime "
- Asphalt Concrete → asphalt "

ii) Based on purpose of use/design purpose:

a.) Plain Cement Concrete (PCC):

→ Concrete without reinforcement.

→ Strong in compression but very weak in tension.

b) Reinforced Cement Concrete (R.C.C.)

→ Reinforcement is embeded to bear tension

→ Bear both compressive and tensile forces along with shear force.

c) pre-stressed cement concrete:

→ Compressive stress is artificially induced before its actual use.

→ Strong enough to bear both high compressive force and high tensile force in comparison to R.C.C.

Special type of concrete based on purpose of use/new construction technology/ various types of aggregates, admixtures, polymer etc.

a) light weight concrete

→ prepared to decrease self weight.

→ prepared by using light weight aggregates.

b) fibre reinforced concrete

→ fine fibrous materials used for reinforcing.

c) vacuum concrete:

→ excess of water is removed by vacuum treatment.

d) Aerated concrete:

→ concrete formed by mixing expansion agent and treated in such a way as to reduce its density without reducing its strength.

e) Non-cracking concrete:

→ for using in structure exposed to fireworks or very high temperature, waterproof structures, exposed to chemical attacks etc.

f) fire resistance concrete:

→ for using in structure exposed to very high temp.r.

g) concrete containing polymer:

h) chemical resistant concrete

- (4)
- i) High strength concrete.
 - j) Heavy weight concrete.
 - k) Bacterial concrete → presence of material which can successfully remediate cracks in concrete.
 - l) jet cement concrete.
 - m) Self compacting concrete.
 - n) Rolled cement concrete etc.

These various types of concrete are made by

- i) New construction technique.
- ii) Use of various types of aggregates.
- iii) Use of admixtures.
- iv) Use of polymer etc.

1.2) Concrete Materials - Role of different materials (aggregates, cement, water and admixtures):

1.2.1) Aggregates - properties of aggregates and their gradations:

i) Aggregates are chemically inert, granular, inexpensive materials dispersed throughout the cement paste so as to produce a large volume of concrete. Such as sand, gravel, slag, crushed stone etc.

In other words; aggregates are inert granular materials which are used to make concrete.

ii) Aggregates acts as filler only. They do not react with cement and water.

iii) Normally; volume occupied by constituents are as below:

Aggregates — 70-75%.

Water — 15-25%.

Cement — 10-15%.

Role of aggregate:

- It provides a mass of particles, which resist the action of applied loads, abrasion, percolation of moisture and the action of weather.
- It reduces the volume changes resulting from setting and hardening process and from moisture changes in the cement paste i.e. provide volume stability.
- It provides relatively cheap filler for the cementing material.

Types of aggregates:

* According to source:

a) Natural aggregate

- ④ → Igneous rock.
- Sedimentary rock.
- Metamorphic rock

b) Artificial aggregate:

→ for some special purpose, due to the influence of manufacturing method, artificial aggregates are made.

* According to sizes:

a) Coarse aggregate

→ aggregates retained on 4.75 mm IS sieve is called coarse aggregates.

b) Fine aggregate (Sand)

→ aggregates passed through 4.75 mm IS sieve is known as fine aggregate (Sand.)

* According to density:

→ light weight aggregates ($\approx 1120 \text{ kg/m}^3$)

→ medium " " " ($\approx 1520 \text{ kg/m}^3$)

→ Heavy " " " ($\approx 2080 \text{ kg/m}^3$ or more.)

Properties of aggregate

The various properties of aggregates play a vital role in the strength of concrete. The different properties of concrete can be categorized as:

Properties of Aggregate

Physical properties

- shape
- size
- texture
- specific gravity
- apparent sp. gr.
- bulk density
- porosity
- bulking of sand

Mechanical properties

- Bond & Bond strength
- Abrasion strength (hardness)
- Impact value (Toughness)
- crushing strength

Chemical properties → Alkali aggregate reaction.

Thermal properties

- specific heat
- coefficient of expansion
- Thermal conductivity.

* Physical Properties of aggregates:

a) shape:

- i) rounded → considered best for economy point of view
↳ river bed aggregates.

→ ii) Irregular

- iii) Flaky Particles → makes poor concrete when used in excess.
A particle is said to be flaky if its least dimension is less than 0.6 times the mean ~~size~~ size.

Mean size: If particle pass through 40 mm sieve and retain on 20 mm sieve then

$$\text{mean size} = \frac{40+20}{2} = 30 \text{ mm.}$$

iv) Elongated particles:

→ If the largest dimension of particle is 1.8 times the mean size, then the particle is called elongated.

v) Angular particle:

→ If the dimension of particle possess well defined edge, it is called angular particle.

b) Size:

i) Size is important factor considered while making concrete.

ii) Max. size of aggregate $\leq \frac{1}{4}$ of minimum thickness of member.

iii) Maximum size of aggregate depends upon:

→ Workability.

→ Reinforcement spacing

→ Cover provided to reinforcement

→ Section thickness.

c) Texture:

i) It is surface appearance of the particles.

- smooth

- rough

- Granular

- Crystalline

- Honey-combed (visible pores & cavity)

ii) For smooth surface \rightarrow less contact area \rightarrow less bonding strength.

For rough surface \rightarrow more contact area \rightarrow high bonding strength.

d) specific gravity:

i) Specific gravity =
$$\frac{\text{Weight of material}}{\text{Weight of same volume of water}}$$

ii) indicates heavy, medium, light weight aggregates.

iii) used for compaction factor calculation, workability measurement and calculation of theoretical yield of concrete per unit volume.

iv) low sp. gr. indicates \rightarrow porous, weak & absorptive materials.

v) High sp. gr. indicates \rightarrow good quality materials.

vi) A range of sp. gr. may be 2.6 to 2.8.

e) Apparent specific gravity:

It is the ratio of mass of aggregate dried to over to the mass of water occupying the volume equal to that of the solid including intermediate pores.

f) Bulk density:

→ Actual mass of aggregate that would fill a container per unit volume. The volume is considered as the occupied by both aggregates and voids. So, ~~the~~ Bulk density depends on the how densely the aggregates are compacted and the size distribution & shape of the particles.

g) Porosity:

porosity = $\frac{\text{Volume of pores}}{\text{total volume}}$ of a aggregate particle.

→ less porous aggregates are good for strength.

h) Bulking of sand:

→ The increase in volume of sand due to presence of the moisture content is called bulking of sand.

→ bulking is caused by films of water pushing the sand particles apart due to surface tension.

→ Bulking phenomenon occurs much more in case of fine sands rather than in coarse ones.

→ if the mix design is done for volume batching, bulking of sand affects the mix proportion.

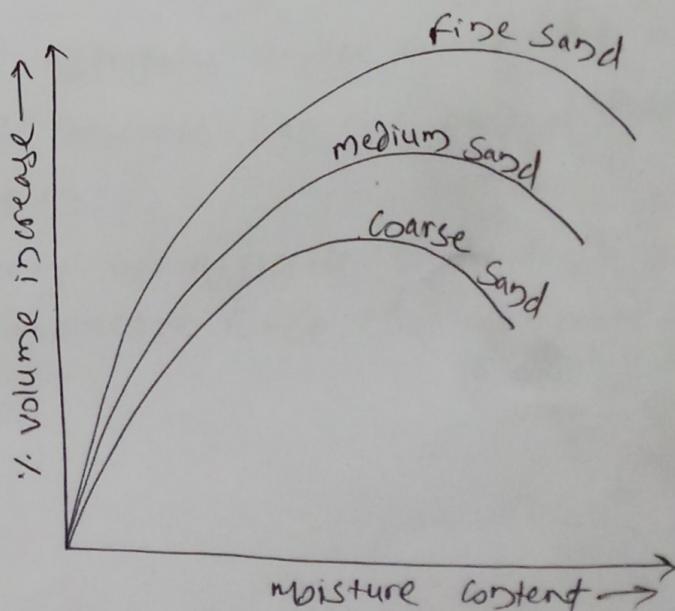


Fig. Bulking of sand

* Mechanical Properties of Aggregates:

a) Bond and Bond strength:

- Bond is the interlocking capacity of a aggregate and adhesion between aggregates and cement paste.
- Bond strength is the resistance developed to split the aggregate particle from hardened cement paste.

b) Abrasion strength (Hardness):

- Resistance of aggregate towards wearing & tearing effect.
- It is generally expressed as percentage loss of weight after abrasion.
- It is determined by the following methods:
 - * Los Angle's Abrasion test
 - * Darry Abrasion test
 - * Deval Attrition test.

c) Impact value (Toughness):

- ability of aggregate to resist the effect of sudden impact or shock or repeating loads.
- It is expressed as percentage loss of weight after impact.
- It is determined by impact value test.

d) Crushing strength (Compressive strength):

- It is the strength of aggregates under compressive loads.
- Compressive strength of concrete can not exceed that of the aggregate used there is.
- It is the major property of aggregate to be dealt, as later it relates to the compressive force that concrete can bear.

Chemical properties of aggregates:1.) Alkali aggregate reaction:

- Although, the aggregates are generally called as inert materials; it may contain silica, which is reactive and reacts with alkali present in cement.
- The expansive alkali-silicate gels are formed due to the reaction. This gel swells by absorbing water and internal pressure is created which results cracking in concrete.
- These cracks results in subsequent strength loss and elasticity loss.
- Later solution of dissolved carbon dioxide converts $\text{Ca}(\text{OH})_2$ to CaCO_3 resulting high volume increase which results to deteriorate the concrete.
- The factors promoting alkali-aggregate reaction are
 - reactive type of aggregate
 - high alkali content in cement
 - availability of moisture in the paste.
 - optimum temperature conditions (10°C to 40°C)

* Alkali-aggregate reaction mechanism:

- The soluble alkalis in the cement dissolves in the mixing water turning it into a highly caustic liquid which reacts with the reactive silica present in the reactive aggregates to form highly expansive alkali-silica gel.
- Silica gel exerts internal hydraulic pressure ~~generated~~
~~through~~ on surrounding set-cement gel to cause pattern cracking with subsequent loss in strength and elasticity.
- The formation of cracks due to alkali-aggregate reaction accelerates other processes of deterioration like carbonation.

* Control of alkali-aggregate reaction/preventive measures: (2)

→ avoid the use of reactive aggregates.

→ use of low-alkali cement

→ use of admixtures like pozzolana.

→ controlling moisture condition & temperature condition.

Thermal properties of aggregates:

The thermal properties of the aggregates affect the durability and the other qualities of concrete

a) Coefficient of thermal expansion:

→ The coefficient of thermal expansion of the concrete increases with increase in coefficient of thermal expansion of aggregate.

→ If the coefficient of thermal expansion of coarse aggregate and cement paste differs too much, a large change in temp. may introduce differential movement which may break the bond between the aggregate and the paste. If the coefficients of the two materials differ by more than 5.4×10^{-6} per °C, the durability of concrete subjected to freezing and thawing may be affected.

b) specific heat & thermal conductivity:

→ The specific heat of the aggregate is a measure of its heat capacity, whereas the thermal conductivity is the ability of the aggregate to conduct the heat.

→ These properties of the aggregates influence the specific heat and thermal conductivity of concrete, and are important in the case of mass concrete and where insulation is required.

Gradation of aggregates & Sieve Analysis:

- The particle size distribution of an aggregate by sieve analysis is termed as grading of aggregate.
- If all particles of an aggregate are of uniform size, the compacted mass will contain more voids whereas an aggregate comprising particles of various sizes will give a mass containing lesser voids.
- The particle size distribution of a mass of aggregate should be such that the smaller particles fill the voids between larger particles.
- The proper grading of an aggregate produces dense concrete and needs less quantity of fine aggregate and cement paste. It is essential that the coarse and fine aggregates to be well graded to produce quality concrete.

* Sieve Analysis:

- The process of dividing a sample of aggregate into various fractions of different particle size is known as sieve analysis. and its purpose is to determine the grading or size distribution of the aggregate.
- Grading pattern of coarse aggregate or fine aggregate sample is achieved by sieving sample successively through all sieves mounted one over another in order of size, with largest opening on top & smallest opening at bottom.
- The material retained on a particular sieve after shaking/ sieving represents fraction of aggregates coarser than sieve size on which it retained and finer than sieve size just above.

use / significance of grading / sieve analysis:

(4)

- By using well graded aggregates; volume of air voids decreases resulting dense concrete and hence strength & durability increases.
- Well graded aggregates results in good workability and minimizes segregation also.

* Fineness Modulus:

- It is an index number used to indicate the average size of particles in the aggregate and defined as the sum of the cumulative percentages retained on the sieves of the standard series divided by 100.
- The standard series of IS Sieves (IS 383: 2016)

For coarse aggregates \rightarrow 80mm, 63 mm, 40 mm, 20 mm, 16 mm,
(Table 7; IS 383: 2016) 12.5 mm, 10 mm, 4.75 mm, 2.36 mm.

for all in aggregates \rightarrow 80 mm, 40 mm, 20 mm, 4.75 mm,
(Table 10; IS 383: 2016) 600 μm, 300 μm, 150 μm.
(Nominal sizes)

for fine aggregates \rightarrow 10 mm, 4.75 mm, 2.36 mm, 1.18 mm,
(Table 9; IS 383: 2016) 600 μm, 300 μm, 150 μm.
(Sand 2025)

* How to calculate fineness modulus:

Example (for fine aggregate)

IS sieve	wt retained (kg)	% retained	cum. % retained	% passing (finer)
10 mm	0	0	0	100%
4.75 mm	0.150	12%	12%	88%
2.36 mm	0.300	24%	36%	64%
1.18 mm	0.450	36%	72%	28%
600 μm	0.200	16%	88%	12%
300 μm	0.100	8%	96%	4%
150 μm	0.050	4%	100%	0%
	1.25 kg		404	

Hence,

$$\text{fineness modulus (F.M.)} = \frac{404}{100} = 4.04$$

→ High value of FM represents coarser particle and low value of FM represents the presence of finer materials.

Grading Curves:

- A curve plotted for % of materials passing through a particular sieve size on ordinate vs sieve size on abscissa to logarithmic scale is termed as grading curve.
- The grading curve indicates whether the grading of a sample confirms the requirements, or it is too coarse or too fine or deficient in a particular size than required.
- * Comparison of standard grading curve for required with actual grading curve of sample:

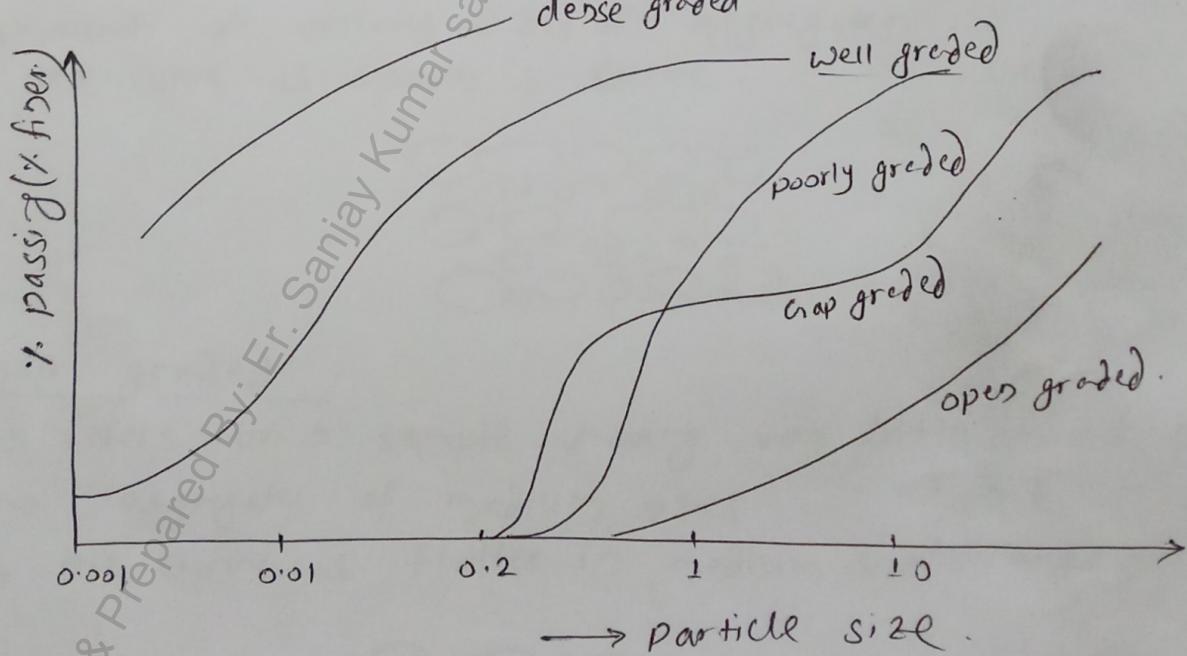
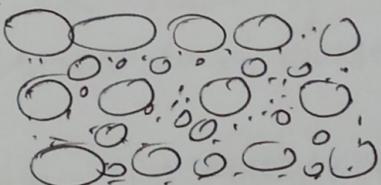


Fig. different grading of aggregates:

- In case of actual grading curve is lower than the specified grading curve (generally well graded.) the aggregate is coarser and segregation of mix might take place. (open, poorly grad'd)
- In case of actual grading curve lies well above the specified curve → indicates aggregate is finer and more water will be required, thus increasing the quantity of cement for a constant water-cement ratio. Hence, uneconomical. (dense grad'd)
- If the actual curve is steeper than specified (poorly graded) → indicates an excess of middle-sized particles and leads to harsh mix. (unpleasantly rough)
- If the actual grading curve is flatter than specified (gap grad'd.)
- indicates aggregate has deficiency of middle sized particles.

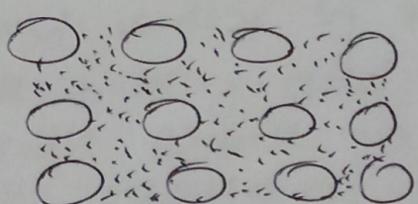
* well graded aggregate:

- refers to a sample having approximately uniform/equal amount of various sizes of aggregates.
- the curve is smooth S-curve.



* Gap graded:

- refers to a sample having very little amount or no aggregate of medium sizes.
- the curve is flatter in medium size range.



* Poorly / Narrow / Uniform graded aggregate:

- refers to sample having aggregate of approximately the same size.
- the curve is very steep and occupies small ranges of aggregates.

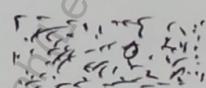


* Open graded aggregates:

- refers to sample of aggregates with high proportions of particles of larger sizes → resulting many air voids due to absence of fine particles.
- the curve will be well below the specified.

* Rich / dense graded aggregate:

- refers to sample of aggregate with high proportion of particles of small sizes.



* Concrete batching:

- Batching means the measuring of different ingredients of concrete (i.e. cement, sand, coarse aggregate and water) accurately.
- Two types viz. (i) mass/weight batching.
(ii) volume batching.

* importance of bulking of sand

- Bulk sand occupies more volume than dry sand.
- the bulking of sand has importance role when batching of sand is done by volume.
- to compensate bulking effect; extra sand has to be added. otherwise concrete mix becomes deficient for sand and results segregation.

Cement:

- Cement is an extremely ground material having adhesive and cohesive properties, which provide a binding medium for the discrete ingredients.
- It is obtained by burning together, in a definite proportion, a mixture of naturally occurring agrillaceous (containing alumina) and calcareous (containing calcium carbonate or lime) materials to a partial fusion at high temperature (about $1400-1500^{\circ}\text{C}$)
- The product obtained from burning, called "dinker" is cooled and ground to the required fineness to produce a material known as "cement".
- Its inventor, Joseph Aspdin, called it Portland cement because when it hardened, it produced a material resembling stone from the quarries near Portland in England.
- During grinding of dinker, gypsum or plaster of Paris (CaSO_4) is added to adjust the setting time. The amount of gypsum is about 3% by weight of dinker. It also improves the soundness of cement.

* Ingredients / Composition of raw materials of cement:

- Raw materials of cement consist mainly of lime, silica, alumina and iron oxide. Depending upon the wide variety of raw materials used in manufacture of cements, the oxide composition of cement may be expressed as below:

Lime (CaO) → 60-65%.

Silica (SiO_2) → 17-25%.

Alumina (Al_2O_3) → 3-9%.

Iron Oxide (Fe_2O_3) → 0.5-6%.

Magnetia (MgO) → 0.5-4%.

Sulphur trioxide (SO_3) → 1-2%.

Alkalies ($\text{Na}_2\text{O}, \text{K}_2\text{O}$) → 0.4-1.5%.

Manufacturing of cement / Portland cement:

source of calcium

Lime stone
or chalk

Clay & shales

source of silica.

Raw materials → (crushing & blending)

Rotary Kiln (1400-1500°C)

clinker

allowed to cool.

Ball mill

Grinding
with gypsum

clinker store

Portland
cement

Fig: Flow diagram for manufacturing process of portland cement.

Step 1 : making clinker

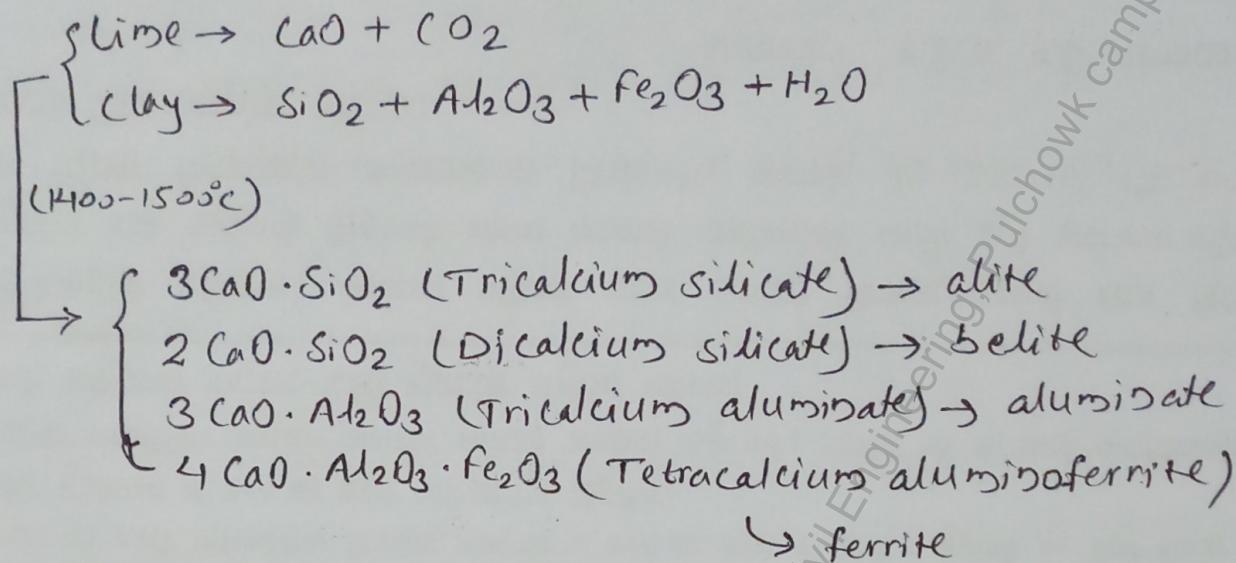
- The raw materials (limestone & clay) crushed to size of 7.5 cm. and homogenized into a mixture. (making uniform)
- The mixture feed into rotary kiln where it is heated to a temperature of 1400°C - 1500°C. where material fused in the form of ball or lumps known as clinker.

Step 2 : Grinding of clinker

- The cooled clinker then ground in ball mill to required fineness to get portland cement. During grinding in ball mill, a small amount of gypsum is mixed to retard the setting time of cement.

* Chemical reactions in the Rotary Kiln

(2)



Compound Composition of Portland Cement:

* The raw materials used for the manufacture of cements consists of mainly following compounds:

<u>Compound</u>	<u>Symbol</u>
Lime $\rightarrow \text{CaO}$	C
Silica $\rightarrow \text{SiO}_2$	S
Alumina $\rightarrow \text{Al}_2\text{O}_3$	A
Iron oxide $\rightarrow \text{Fe}_2\text{O}_3$	F
H_2O	H
SO_3	S

* Though the composition of portland cement is complicated; basically following four complex compounds are formed during burning in kiln.

Tricalcium silicate (C_3S) $\rightarrow 3\text{CaO} \cdot \text{SiO}_2 \rightarrow$ alite

Dicalcium silicate (C_2S) $\rightarrow 2\text{CaO} \cdot \text{SiO}_2 \rightarrow$ belite

Tricalcium aluminate (C_3A) $\rightarrow 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \rightarrow$ Aluminate

Tetra Calcium aluminoferrite (C_4AF) $\rightarrow 4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 \rightarrow$ ferrite

* These four complex compounds of cement are also called as "Bogue's Compound."

* Depending upon the wide variety of raw materials used in manufacture of cements, typical ranges of these compounds in ordinary portland cements may be expressed as given in Table below: (3)

Compound	% by mass in cement
C_3S	25-50
C_2S	20-45
C_3A	5-12
C_4AF	6-12

* In addition to above mentioned main compounds; there exists some minor compounds also in cement such as MgO , TiO_2 , Mn_2O_3 , K_2O and Na_2O .

* Among these minor compounds also; K_2O & Na_2O are of interest, known as alkalis which are found as responsible for Alkali-Aggregate reaction leading to deterioration/disintegration of concrete.

Bogue's equation:

The composition of main four compounds i.e. Bogue's compound are given by the following equations called as Bogue's equation:

$$C_3S = 4.07(C) - 7.60(S) - 6.72(A) - 1.43(F) - 2.85(\bar{S})$$

$$C_2S = 2.87(S) - 0.754(C_3S)$$

$$C_3A = 2.65(A) - 1.69(F)$$

$$C_4AF = 3.04(F)$$

Structure and Reactivity of cement compounds:

* Structure:

- a) Alite (C_3S) \rightarrow light grey crystals in the backscattered SEM image (SEM-scanning electron micrograph.)
 \rightarrow brown crystals in optical microscope image.

b) Belite (C_2S)

- dark grey crystal in backscattered SEM image.
- blue crystals in optical microscope image.

c) ferrite (C_4AF)

- bright interstitial material in both backscattered SEM image and optical microscope image.
- (Interstitial — situated within but ~~not~~ not ~~with~~ with particular characteristics.)

d) Aluminate (C_3A)

- small dark inclusions

* Properties and Reactivity of Cement Compounds:

i.) Tricalcium silicate (C_3S):

- Hydrates and hardens rapidly.
- Responsible for early strength of cement
- generates higher heat of hydration.
- less resistant to chemical attack.
(sulphate)

ii.) Dicalcium silicate (C_2S)

- hydrates and hardens slowly.
- Responsible for ultimate final strength of cement.
- generates less heat of hydration.
- greater resistance to chemical attack.

⇒ C_3S and C_2S are mainly responsible for strength giving properties of cement. C_3S is responsible for gaining initial strength with high heat of hydration whereas C_2S is responsible for ultimate strength with lesser heat of hydration. Finally we can say that both C_3S & C_2S are equally responsible

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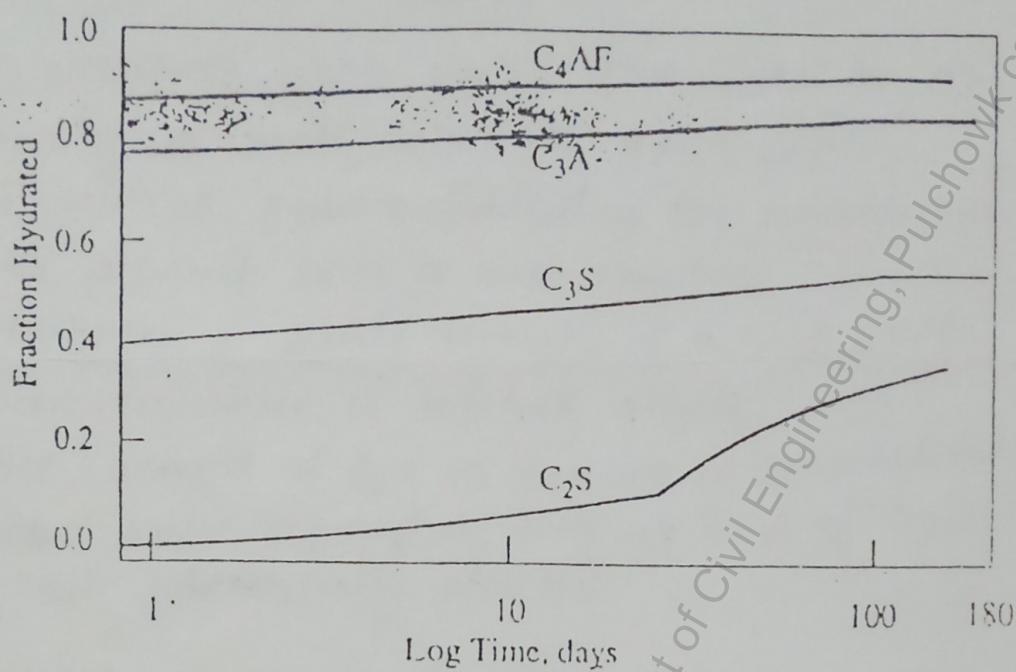


Fig. 2.1 Rate of hydration of pure cement compounds. (setting)

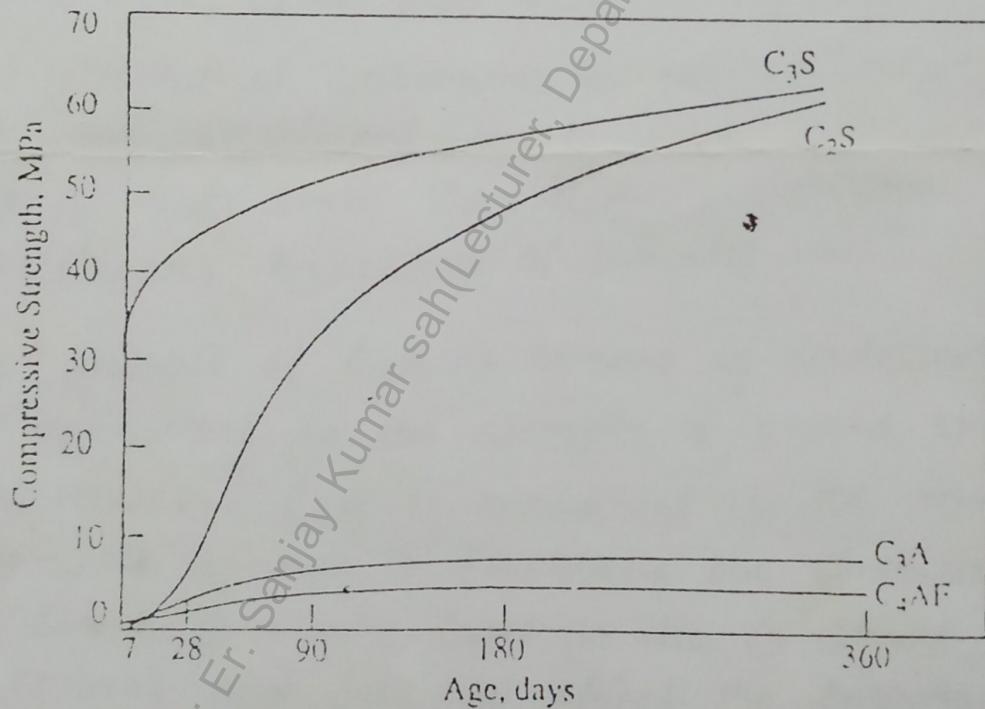


Fig: strength criteria of cement Compounds:

Collected & Prepared By: Er. Sanjay Kumar sah(Lecturer, Department of Civil Engineering, Pulchowk campus)

for final strength of cement paste.

iii.) Tricalcium aluminate (C_3A):

- fast-reacting with water and lead to an immediate stiffening of paste, called as flash set.
- The role of gypsum added in the manufacture of cement is to prevent such a fast reaction.
- contributes a little strength of cement paste.
- weak resistance to sulphate attack.
- Since, amount of C_3A in cement is comparatively small, the set water required as well as heat of hydration generated are not substantially affected.

iv.) Tetra calcium alumino ferrite (C_4AF)

- like C_3A ; C_4AF also hydrates rapidly.
 - its individual contribution to overall strength of cement is not significant.
 - It is more stable than C_3A .
 - accelerates hydration of silicates
- ⇒ The presence of C_3A in cement is undesirable, it contributes little or nothing to the strength of cement except at early ages. However C_3A is beneficial in the manufacture of cement because it facilitates the combination of lime and silica. Similarly C_4AF is also in small quantities in cement and does not affect the behaviour significantly; however, it reacts with gypsum to form calcium Sulphoferite and its presence may accelerate the hydration of silicates.

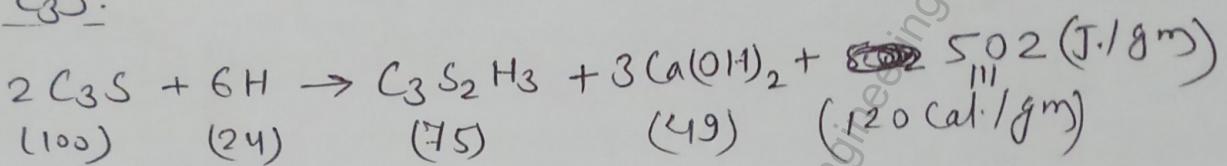
* Other compounds (oxides & alkalis):

- a high lime content generally increases the setting time and results in higher strengths. A decrease in lime content

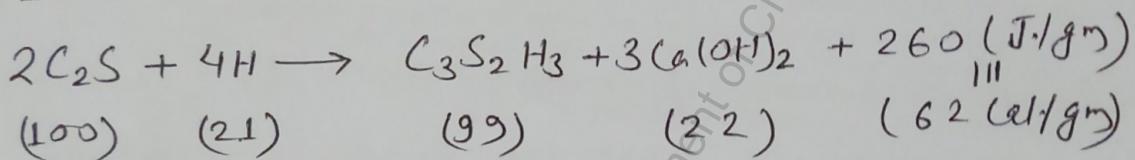
Hydration of Cement:

→ Anhydrous cement i.e. cement is powder form doesn't bind fine and coarse aggregate. It acquires adhesive property only when mixed with water. The reaction between cement and water is called as hydration of cement.

* For C_3S :



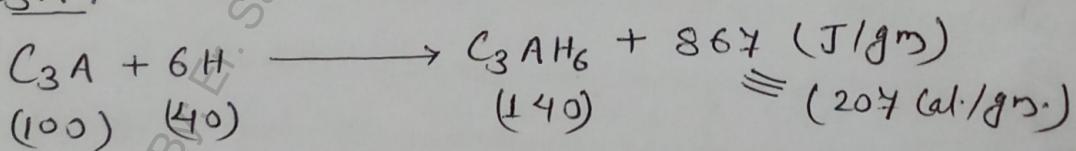
* For C_2S :



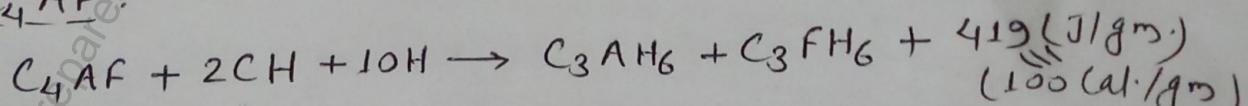
The nos. in brackets are corresponding masses

- Approximately same amount of water for hydration is required but C_3S produces more $Ca(OH)_2$.
- Due to producing lesser amount of $Ca(OH)_2$ as well as heat of hydration, cement containing higher amount of C_2S is more suitable in acidic environment.
- Adhesive property of the cement paste is due to formation of calcium silicate hydrate ($C_3S_2H_3$).

* For C_3A :



* For C_4AF :



- The reaction of C_3A with water is more rapid and would lead to the flash set so gypsum is added for prevention.
- The calcium hydroxide, $Ca(OH)_2$ liberated during the reaction of silicate phase crystallizes in the available free space. However, $Ca(OH)_2$ is not a desirable product

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in concrete mass as it is soluble in water and gets leached out making the concrete porous.

- The only one advantage of $\text{Ca}(\text{OH})_2$ is its alkaline nature maintaining a pH value around 13 in the concrete which passivates reinforcing steel against corrosion.
- On hydration of C_3A ; C_3AH_6 (calcium aluminate hydrate) is formed which is stable product.
- On hydration of C_4AF ; C_3FH_6 (hydrated calcium ferrite) along with C_3AH_6 are formed. C_3FH_6 is comparatively more stable.

Heat of hydration

- The hydration of cement compound is exothermic and the quantity of heat per gram of unhydrated cement liberated upon complete hydration at a given temperature is called the heat of hydration.
- For the usual range of portland cements; about one-half of the total heat is liberated between 1 and 3 days, about 75% in 7 days and nearly 90% in 6 months.
- Heat of hydration depends on the chemical composition of the cement and is approximately equal to the sum of the heat of hydration of individual's pure compounds when their respective proportions by mass hydrated separately.
- It is clear that by reducing C_3A and C_4S ; the heat of hydration and its rate of cement can be reduced.
- Fineness of cement also affects the rate of heat liberation but not the total amount of heat which can be controlled by only controlling the quantity of cement in concrete mix.

Properties of Cement:

a) Chemical Composition:

→ the ratio of percentage of lime to percentage of silica, alumina and iron oxide, called as Lime saturation factor, defined by

$$LSF = \frac{CaO - 0.4SiO_3}{2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3}$$

→ It should not be less than 0.66 and should not be greater than 1.02.

→ The typical value in modern cements is 0.92 to 0.98.

→ the ratio of alumina to iron oxide, called as Alumina ratio is given by

$$\text{Alumina ratio, AR} = \frac{Al_2O_3}{Fe_2O_3}$$

→ usually value between 1 to 4.

→ the ratio of silica to alumina & iron oxide, called as Silica ratio is given by

$$\text{Silica ratio, SR} = \frac{SiO_2}{(Al_2O_3 + Fe_2O_3)}$$

→ typical values between 2 to 3.

⇒ weight of insoluble residue should not be more than 2%.

⇒ weight of magnesia should not exceed 5%.

⇒ sulphur content should not exceed 2.45%.

⇒ Total loss on ignition should not be more than 4%.

b) Fineness of cement:

- Finer the cement, more surface area will be available for reaction and gain strength in short time.
- either measured in specific surface (surface area per kg.) or number of particles per kg of cement.
- Fineness of cement affects:
— Hydration rate
— Setting time
— durability etc.

c) Soundness of cement:

- ability of hardened paste to maintain its volume.
- Unsoundness is caused due to free lime (CaO) and magnesia (MgO) present in cement.
- Test is carried out by Le Chatelier's apparatus.
↳ increase in distance between the pointers should not be more than 5 mm for cement that has been aerated for 7 days in humidity 50-80% before testing or more than 10 mm for cement that has been kept in an air tight container.

d) Consistency of cement:

- It can be defined as the amount of water per unit amount of cement to produce a plastic paste of cement.
- Consistency is determined by the Vicat apparatus which measures the depth of penetration of a 10 mm diameter plunger under its own weight.
- ~~Standard penetration of 50 mm~~
→ the ratio of amount of water and cement to penetrate the Vicat plunger to a depth of 5-7 mm from the bottom of the Vicat mould or 33-35 mm from top of the Vicat mould is standard consistency.

→ the standard or normal consistency for ordinary (10) Portland cement (OPC) varies between 26 to 33%.

e) Setting Time of Cement:

→ Setting of cement refers to change of cement paste from plastic to solid state. and the time to reach this stage is termed as setting time.

→ The setting time is divided into two parts, namely, the initial setting time and the final setting time.

i) Initial setting time:

→ the time from water added to cement to cement paste loses its plasticity.

→ plastic cement changes into solid mass.

→ It is also determined by Vicat apparatus, which measures the depth of penetration of 1mm diameter needle under a standard weight.

→ the time from water added to time when the needle penetrate to a depth of 5 ± 0.5 mm from the bottom of the mould i.e. 35 ± 0.5 mm from top of the mould.

→ A minimum time of 30 min. is prescribed for OPC. as initial setting time.

ii) Final setting time:

→ the time from water added to cement to the cement paste becomes a hard mass.

→ the cement paste hardened and gained strength.

→ It is also measured by Vicat apparatus.

→ It is also determined by Vicat apparatus, which measures the instant when 1mm dia. needle leave marks on cement paste and 5mm dia. cutting edge does not leave any mark.

→ The cutting edge of 5mm dia. is set 0.5mm behind the tip of the needle.

→ The final setting time should not be more than 600 min. for OPC.

f.) Strength:

⇒ Compressive strength

→ test on cube of cement-sand (1:3)

⇒ Tensile strength

→ test on briquette with thickness of 25.4 mm
and minimum area of cross-section 645 mm^2
at front.

→ Cement-sand mortar (1:3) is used.

g.) Heat of Hydration:

→ heat produced during reaction with water.

h.) False set & Flash set:

⇒ False set:

→ plasticity loss after mixing.

→ workability can be restored by additional mixing.

⇒ Flash set:

→ rapid & early loss of workability.

→ workability cannot be restored.

i.) Field tests of cement:

⇒ Colour → should be uniform.

⇒ Smooth → should be smooth, free from grit when touched with hand.

⇒ Should be free from lumps.



Chapter #1 (Lecture #4)

(1)

Introduction to special types of cement:

- Serve some specific functions such as hardening behaviour, producing different colours, giving superior workability without reducing strength, resisting penetration of water etc.

i.) Ordinary Portland Cement (OPC):

- Most common cement in use.
- has medium rate of strength ~~generation~~ development & heat generation.
- Suitable in general concrete construction, where there is no exposure to sulphates in soil or in the water.

ii.) Rapid Hardening Cement:

- higher early strength
- the strength develops rapidly due to higher percentage of C₃S and finer grinding.
- used in emergency works like road repairs, cold weather concrete etc.
- Not suitable for mass concrete.

iii.) Low Heat Cement:

- generates low heat of hydration.
- lower content of C₃A & C₃S & higher content of C₂S.
- low strength gain, but ultimate strength not affected.
- suitable in mass concrete where higher rate of heat generation is undesirable.

iv.) Sulphate Resisting Cement (SRC)

* Sulphate attack:

- when C_3A reacts with gypsum; Calcium sulpho-aluminate is formed which is expansive in nature causing crack and disintegration of concrete.
- should ~~contain~~ contain low amount of C_3A preferably below 5% to avoid sulphate attack.
- Recommended for use in marine environment and foundation structures if chemically aggressive soils. ~~contain~~

v.) Portland Pozzolana Cement (PPC)

- obtained by adding 10-25% of pozzolanic materials like fly ash, burnt clay, or other pozzolanas during grinding.
- contains silica and alumina materials.
- useful in mass concrete due to having great resistance to expansion.
- less heat of hydration.

vi.) Water proof cement.

- It is prepared by adding small amount of water repellent materials like sodium stearate, etc.
- used in basement, water retaining structures etc.

vii.) Coloured cement:

- obtained by adding 5-10% coloured pigment with OPC.

- used for decorative purposes.

viii.) white cement:

- also called as china clay.
- superior aesthetic value.

(8.)

ix.) Portland Blast furnace cement:

- Corrosion resisting cement
- Blast furnace slag should be 25-65%.
- lower heat generation.
- Resistant to weathering attack.
- useful in mass concrete due to lower heat of hydration

x.) Hydrophobic cement:

- Contains admixtures which form a thin film around cement grains and decrease the melting ability of cement grains.
- initially gain in strength is less but not affected after 28 days.

x.i.) High alumina cement

- Amount of alumina is high (about 35%).
- used for refractory concrete to resist high temperatures.
- resist action of sulphates
- useful in underwater construction.
- Not suitable for mass concrete.

x.ii.) Quick setting cement:

- obtained by adding Al_2SO_4 & CaCl_2 with OPC.
- Amount of gypsum is reduced.
- expensive.
- useful in under-water construction.

x.iii.) Anti-bacterial cement:

- obtained by adding anti-bacterial agents.
- used in ~~swim~~ swimming pool constructions etc.

x.iv.) Air-entraining cement:

- air entraining agents like vinyl resin, Danex etc. added.
- useful in masonry construction.

Use of water in concrete

- most important constituents.
- water for mixing
- " washing aggregate
- water curing
- hydration, workability.

water for mixing & washing aggregate

organic — maximum 0.02%.

inorganic — 3%.

Sulphate — 0.04%.

Chloride — 2%.

Suspended matter — 1% for PCC

2% for RCC

- Drinking water may not be suitable with high % of Sodium or Potassium
↓
danger of alkali ex-s.
- presence of algae → result loss in strength
- pH 6-8 better
- sea water - risk of corrosion
- water of sugar → retards setting time.

Water of curing:

→ mix of water is suitable for curing.

Admixtures:

→ material to modify some property of concrete either in plastic or hardened.

functions:

→ desirable.

→ impart strength

→ accelerate or retard rate of hydration

→ increase strength

→ increase workability & durability.

→ resistance to chemical attack.

→ resistance to freezing & thawing (frost action)

→ reduce shrinkage.

→ reduce permeability.

→ control alkali-aggregate reaction

→ improve wear resistance

→ reduce segregation & bleeding.

Types:

chemical:

i.) Accelerator

ii.) Retarder

iii.) Plasticizers (water reducing)
 Accelerating
 Retarding.

iv.) Super-plasticizer

- v.) Colouring admixture
 vi.) air entraining admixture.
 vii.) water proofing/ repellent

mineral admixture.

- i.) natural minerals.
 ii.) By products minerals.
 - surkhi.
 - Metakaolinize
 - Rice Husk ash.
 - Silica fume

use of mineral admixtures:

- used as replacement of cement (5-10%) without affecting strength.
- increase rate of strength gain.
- increase water tightness.
- retard setting time
- improve resistance to attack by sulphates & sea-water
- increase workability
- control heat evolution.
- resistance to frost action (freezing & thawing) etc.

Structure of Concrete:2.1) Concrete as three phase system:

→ Type, amount, size, shape and distribution of phases present in the solid stage is called as structure of concrete.

→ Basically, the concrete structure are described on two basis:

a) Macrostructure: Gross structure, visible to human being.
(size about $200\text{ }\mu\text{m}$)

→ Mix of paste, fine aggregates, coarse aggregates of different shape and sizes.

b) Microstructure: microscopically magnified part of macro-structure (size of particle $< 100\text{ }\mu\text{m}$)
→ It is complex structure.

→ Concrete is a heterogeneous material composed of three phases:

i.) Aggregate: It contains aggregate particles of different shape and size.

ii.) Binding medium phase:

→ consist of incoherent mass of hydrated cement paste.

iii.) Transition zone phase:

→ Interfacial region between the coarse aggregate particle and hydrated cement paste.

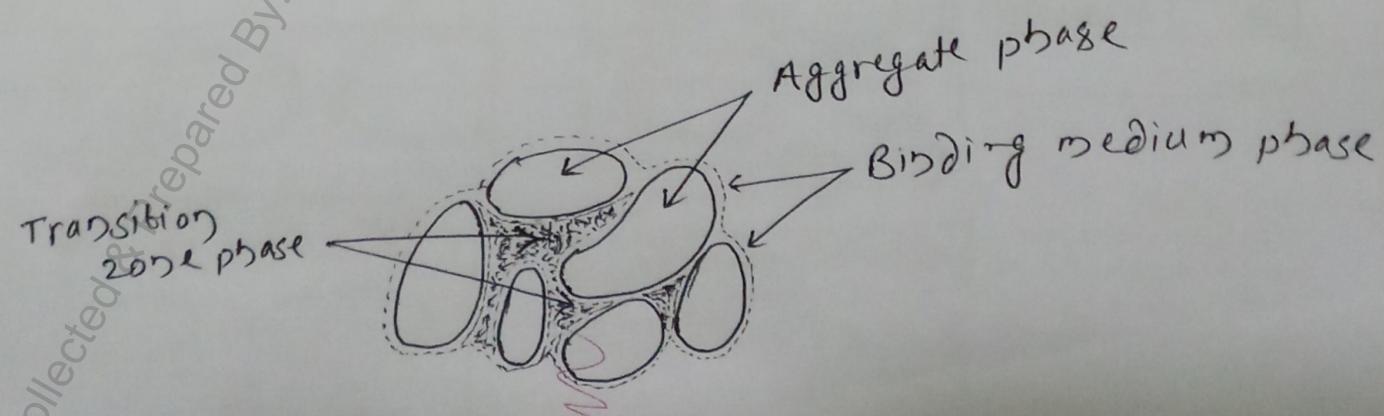


Fig. Phase of Concrete.

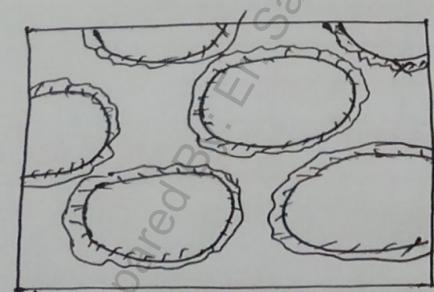
2) Structure of aggregate phase:

- 60-70% of the volume of solids is the most of the concrete & hence most important phase in comparison to other two phases.
- Responsible for unit weight, elastic modulus, soundness of concrete because these properties are based on physical characteristics.
- Size, shape, texture affect the strength of concrete.
- Larger the size of aggregate and higher the proportion of elongated & flaky particles; the greater the chances for water films to accumulate next to aggregate surface thus weakening cement paste aggregate in transition zone.

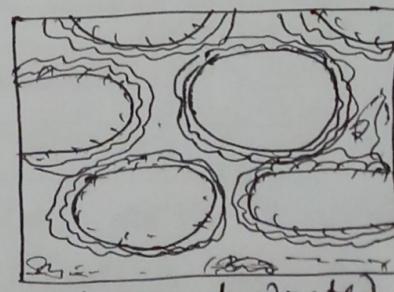
2.3) Structure of the hydrated cement paste (HCP) / Binding medium phase:

Hydration process of cement is not instantaneous. Reaction starts just after adding water to cement and it continues till long time with decreasing rate.

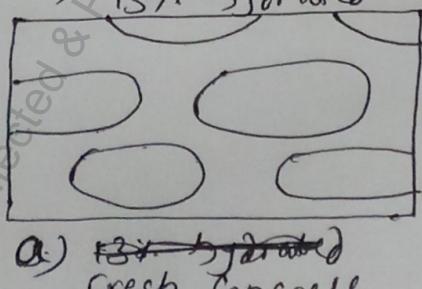
- A cement gains strength due to C_3S .
- C_3S may get hydrated whereas C_2S which lies in interior part may not get hydrated.
- The hydrated product adheres firmly to unhydrated core.



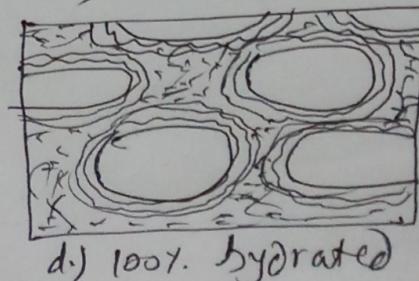
b) ~~fresh concrete~~
0% hydrated



c) 67% hydrated



a) ~~fresh concrete~~
0% hydrated



d) 100% hydrated

a) Solids in HCP:

(3)

The various solids that are present in HCP are:

i.) calcium silicate hydrate phase (C-S-H phase)

- Most important in determining the properties of the paste.
- It consists of 50-60% volume of HCP.
- This is not a well-defined compound or exact structure is not known.
- It has very high surface area ($100-700 \text{ m}^2/\text{gm.}$)
- This imparts the van der wall force, which will influence the strength of HCP.
- The size of gel pores is almost 18 \AA .

ii.) calcium hydroxides

- This is also called as portlandite.
- It consists of 20-25% volume of HCP.
- Tends to form large crystals with ~~distinctive~~ distinctive hexagonal form.
- It has lower surface area, so less van der wall force than C-S-H phase.
- This is not a desirable product from hydration.
- This is alkaline in nature and maintains the pH value of concrete around 13.
- This product is soluble in water and gets leached out making concrete porous.
- higher percentage has adverse effect on chemical durability to acidic solution due to high solubility than C-S-H phase.

Calcium-sulphoaluminate hydrate:

(4)

- It consists of nearly 15-20% volume of HCP.
- The presence of this product will result in making the concrete vulnerable to sulphate attack, which produces ~~which produces~~ These are needle shaped prismatic crystals called as ettringite.
- In paste of OPC, ettringite eventually transforms to the monosulphate hydrate which forms hexagonal plate crystals.

Unhydrated clinker grains:

- depends on the particle size of cement and degree of hydration.
- size of particle vary from 1μm to 50 μm.
- smaller sized particles hydrates first and larger become smaller due to hydration.
- At later stage, due to lack of available space, formation of very dense hydration product occur.

Voids in HCP:

i) Interlayer spacing of C-S-H:

- Size of 18 \AA .
- porosity of 28%.
- size are too small to have adverse effect on strength and permeability of HCP.
- water in these voids are held by hydration bonding. removal of water under certain conditions lead to drying shrinkage.

void $> 50 \text{ nm} \rightarrow$ macropores (strength & permeability.)

void $< 50 \text{ nm} \rightarrow$ micropores (drying shrinkage.)

- (8)
- i) Capillary voids:
- spaces not filled by solid component of HCP.
 - irregular in shape and size has adverse effects on strength and permeability.
 - water-cement ratio and degree of hydration is responsible for size and amount of these capillary voids.

iii) Air voids:

- voids are formed when air gets trapped in the concrete during the early stage.
- these voids are larger in size and have adverse effect on strength of concrete.

* Entrained air voids:

- produced due to addition of air entraining admixtures.
- Effect strength.
- spherical in shape, size varies from 50-100-200 μm.

* Entrapped air voids:

- produced due to improper mixing of concrete.
- larger than entrained air.
- irregular in shape.

c) water in HCP:

i) Capillary water:

- water present in voids larger than 2.5 nm.
- In voids $> 50 \text{ nm} \rightarrow$ effects on strength.
- In voids $< 50 \text{ nm} \rightarrow$ effects on shrinkage.

ii) Adsorbed water:

- phenomenon due to which water gets held to surface of the solids due to attractive force.
- physically held by hydrogen bonding upto six molecular layers of water.

- Bond energy decreases with distances from solid surface.
- Major portion loss by drying HCP to 30% RH (relative humidity).
- Less responsible for drying shrinkage of HCP on drying.

iii) Interlayer water:

- Associated with C-S-H structure.
- Monomolecular water layer between C-S-H layers is strongly held by hydrogen bonding.
- Lost on strong drying.

iv) C-S-H structure shrinks under water lost.

v) Chemically combined water:

- Integral part of structure.
- Not lost on drying.

d) Strength of HCP:

- Principle source of strength is van der wall force.
- Degree of adhesion depends upon surface involved.
- Strength is inversely proportional to porosity.
- Small crystals of C-S-H (calcium-sulphoaluminate hydrate) and hexagonal calcium-aluminates hydrate possess enormous surface area and adhesion property.
- Voids in HCP → function of amount mixed and degree of hydration.

e) Stability of HCP:

- It is not stable dimensionally.
- held by weak van der wall force.

f) Durability of HCP:

- As HCP is alkaline, so exposure to acidic environment cause deterioration.
- Permeability is the primary factor for durability.
- Porosities represented by C-S-H interlayer space and small capillaries do not contributes to permeability of HCP.

2.4.) Transition zone in concrete!

(7)

i.) Significance of transition zone:

- Concrete is brittle in tension and relatively tough in compression.
- Compressive strength of concrete is greater than tensile strength by an order of magnitude.
- At given cement content and water-cement ratio, age of hydration, strength of concrete decreases as the coarse aggregate size increases.
- The permeability of a concrete containing even a very dense aggregate will be higher by an order of magnitude than the permeability of the corresponding cement paste.

ii.) Structure of transition zone

- Experimentally difficult to obtain structure of transition zone.
- Higher water-cement ratio around larger aggregate particles.
- More porous structure in vicinity of coarse aggregates.

iii.) Strength of transition zone:

- Adhesion force is due to van der wall force.
- In early stage age, volume and size of voids in transition zone are larger, so less strength in transition zone.
- However, with increase in age, strength of transition zone may become greater than the initial strength or early strength.
- Larger the aggregate size, thicker the water film around aggregate and develop crack under tension.
- Micro cracks are developed due to shrinkage and temperature variation.

Chapter 3 :

Mix Design of Concrete and Property of Green Concrete:

* Workability and its test:

- Workability of concrete can be defined as "the ease with which the concrete can be mixed, transported, placed, ~~and compacted~~, and finished."
- Should have the minimum possible workability consistent with satisfactory placing and compaction of concrete.
- Insufficient workability or more workable concrete results in incomplete concrete compaction which may severely affect the strength, durability and surface finish of concrete.
- The workability of concrete can also be defined as the "amount of useful internal work necessary to provide full compaction". This work i.e. in compaction, energy is required to
 - overcome the internal friction between individual particles in concrete.
 - overcome the surface friction between concrete and formwork or reinforcement.
- Workability is important;
 - * if the concrete is not workable i.e. mix is too dry; it will be difficult to handle and place in position.
 - * to overcome the internal friction between individual particles in concrete to make it workable.
 - * to overcome the surface friction between concrete and formwork or reinforcement.
 - * If the concrete is more workable i.e. too wet; the coarse aggregate may settle at bottom of mass and because non-uniform composition, called segregation, water comes on surface called bleeding. Segregation & bleeding should be avoided.

* Factors affecting workability of concrete:

(2)

i) Water content

→ increasing water content increase workability and vice-versa.

ii) Size of aggregate: for given quantity of water and paste, bigger size of aggregate will give higher workability.

iii) Shape of aggregate: Angular, elongated or flaky aggregates results low workability whereas rounded shape provides high workability.

iv) Grading of aggregate:

→ densely graded aggregate gives low workability & open graded aggregate gives higher workability whereas well-graded aggregate is suitable for appropriate workability.

v) Mix proportions:

→ Higher aggregate/cement ratio → low workability
lower aggregate/cement ratio → high workability.

vi) Mixing time:

Mixing time increase → workability decreases
and vice versa.

vii) Mixing temperature:

higher temperature → lower workability
and vice versa.

viii) Surface texture of aggregate:

Rough textured aggregates provides poor workability whereas smooth or glassy textured aggregates give better workability.

ix) Use of Admixture:

→ use of air entraining agents and super-plasticizers can improve workability without affecting strength, durability and surface finish.

Test of Workability / Measurement of Workability:

There are different tests that are available to check/measure workability [consistency]. These are.

[Consistency: the relative mobility or ability of a freshly mixed concrete to flow. It can be measured by slump test for concrete, flow for mortar or grout and penetration resistance for neat cement paste]

- i.) Slump test
- ii.) Compaction factor test
- iii.) Vee-Bee Consistency test
- iv.) Flow test
- v.) Kelly ball test.

Among these, the slump test and compaction factor test is commonly used due to easiness in field and laboratory.

1.) Slump test:

- Most common method
- Not suitable for very wet and very dry concrete
- Used conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch
- The apparatus required for conducting slump test consists of a metallic mould in the form of frustum of cone having following dimensions:

Base diameter = 200 mm

Top diameter = 100 mm

Height = 300 mm

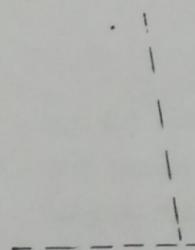
Thickness of mould + 1.6 mm

* Tamping rod of 16 mm diameter with length of 600 mm.

* Procedure:

- The mould is placed on a smooth, flat, rigid and non-absorbent surface. Inner surface of mould should be ~~not~~ thoroughly cleaned and free from adherence of any old set concrete.
- fill the mould with fresh concrete in 3 equal height layers.
- Each layers are tamped with tamping rod 25 times. After the top layer has been tamped, the concrete is struck off level with trowel.
- Mould is removed immediately, ensuring its movement is vertical direction allowing the concrete ~~to set~~ for settlement.
- The subsidence is referred as slump of concrete (in mm). or, the decrease in the height of the centre of the slumped concrete is called slump.

* Type of Slump:



Water - Cement ratio in Concrete:

- Can be expressed either in terms of volume or weight (mass.)
- In terms of volume, water is litre per bag of cement
- In terms of weight, quantity of water per unit weight of cement.
- if 500 gm of water is used per kg of cement, then $w/c = 0.5$ (by weight)

if 25 litre of water is used per bag of cement

$$\text{then } w/c = \frac{25}{\cancel{35}} = 0.71 \text{ (by volume.)}$$

(1 bag cement = ~~35~~ litres.)

- The minimum w/c ratio is 0.38 required for concrete : for complete reaction (hydration) with gel pores.
[$0.38 = 0.23$ for hydration + 0.15 to fill gel pores.]
- w/c ratio can be reduced by using plasticizers and superplasticizers.
- Significant influence on workability of concrete.
→ higher the w/c ratio → higher will be the fluidity & hence increase workability.
- On the other hand; on increasing w/c ratio strength decreases.
- * Abram's law:
Strength of concrete is ~~only~~ dependent upon w/c ration provided that other ingredients as fixed proportion.

$$S = \frac{A}{B^x} \text{ MPa.}$$

$S \rightarrow$ strength

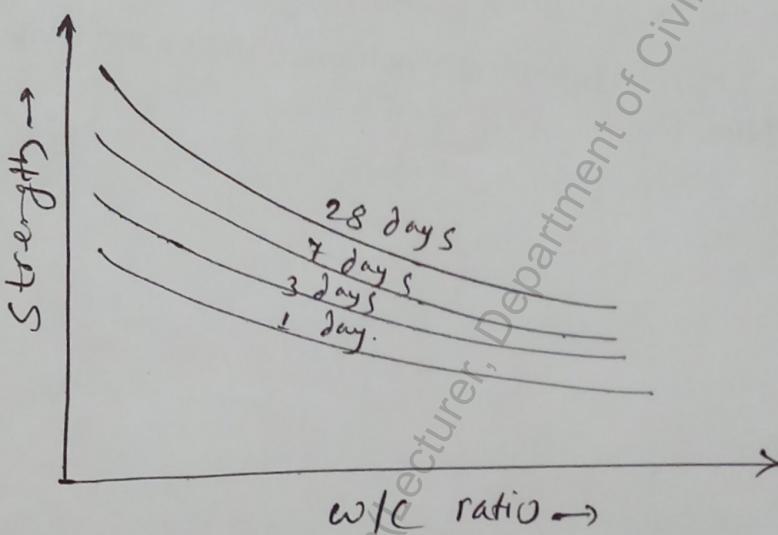
$A \rightarrow$ constant = 984 MPa.

$B \rightarrow$ constant depending on cement properties
& age of concrete

= 4 for 28 days

= 7 for 7 days

$x =$ ~~water~~ w/c ratio by volume.



Segregation & bleeding.

* Segregation → refers to the separation of the components of fresh concrete resulting in a non-uniform mix.

→ Two forms of segregation:

a) the coarser particles tend to separate out if they travel along a slope or settle more than finer particles. This type of segregation occurs if mix is too dry.

b) Separation of grout (cement + water) from the mix. This type of segregation occurs if mix is too wet.

* Causes of segregation / factors affecting segregation:

- High quantity of large sized particles / grading.
- Excessive water content.
- Insufficiently mixed concrete.
- Low fine fraction in sand.
- Low cement content.
- Unfavorable shape of aggregates (flaky & elongated particles).
- too dry or too wet concrete.

* Effects:

- Doesn't give homogeneous mass
- decrease strength
- Rack pockets, sand streaks, and porous layers in concrete.
- Excess mortar goes to top surface causing plastic shrinkage cracks.

* Prevention:

- Correct proportioning.
- Proper handling, transporting, placing, compacting & finishing.
- If segregation observed → remix will be beneficial.
- Use of workability agents (plasticizers)

* Bleeding:

- A form of segregation in which some water in the mix comes out to the surface of concrete.
- This is caused by inability of mix to hold all water when solid constituents settle downwards.
- As a result of bleeding, the top layer of concrete placed becomes wet, porous and weak and not durable concrete will result.

→ In some cases, bleeding may create capillary channels which increase the permeability of concrete.

* Causes of bleeding:

- Excessive water content
- Lack of fines in mix.
- poorly graded aggregates.
- ~~high Blende~~

* Effects

- loss in homogeneity
- reduces bond betw. aggregate → hence reduces strength.
- make permeable concrete.
- sometimes, cement paste along with water also comes to the surface known as "laitance" which reduces wearing quality.
- plastic shrinkage cracks ~~would~~ would develop.

* Prevention of bleeding:

- ~~use~~ use of higher fineness cement
- use of high cement content.
- addition of pozzolana.
- decrease in water content
- use of air entrainment.
- increasing fines & their fineness.
- use of admixtures.
- proper proportioning & mixing.

Quality control in site:

(mixing, handling, placing, compaction & curing)

- Concrete is generally produced in batches at the site with locally available material of variable characteristics. It is therefore likely to vary from one batch to another. The variation depends upon several factors such as
 - variation in quality of constituents.
 - variation in mix proportions.
 - variation in mixing.
 - quality of overall workmanship & supervision.
- The consistency of concrete batching, mixing, placing, curing testing etc. all affects the strength of concrete.
- The aim of quality control is to reduce the different variations and produce uniform material providing the characteristic desirable for the job.
- It is necessary to define the quality of concrete in terms of desired performance, characteristic, economics, safety and other factors.

* Advantages of quality control:

- Quality control is the rational use of available resources after testing their characteristics resulting in the reduction of material cost.
- Quality control reduces maintenance cost.
- In absence of quality control at site; designer is attempt to over design; so as to minimize the risk. These adds to the overall cost.

* Mixing:

- The mixing operation consists essentially of rotation or stirring; the objective being to coat the surface of all the aggregate particles with cement paste, and to blend all the ingredients of concrete into a uniform mass, the uniformity must not be disturbed by the process of discharging from the mixer.
- Mixing may be done
 - manually
 - mechanical mixers.
- The various types of mechanical mixers:
 - a.) Batch mixers
 - Tilting type mixer.
 - Non-tilting type mixer.
 - Pan mixer.
 - transit mixer.
 - b.) Continuous mixer etc.
- minimum time should be at least 2 minutes
- Mixing should be done until uniform mixtures.

* Handling:

- After mixing; concrete should be transported to site immediately without any segregation, drying etc. and should remain cohesive.
- The choice of handling/transportation methods obviously depend upon resource available & economic considerations as well as with requirements. following methods adopted:
 - Pan method
 - wheel barrow

- buckets
- conveyor belts,
- chute
- truck etc.

→ Bad handling method that promote segregation must be avoided

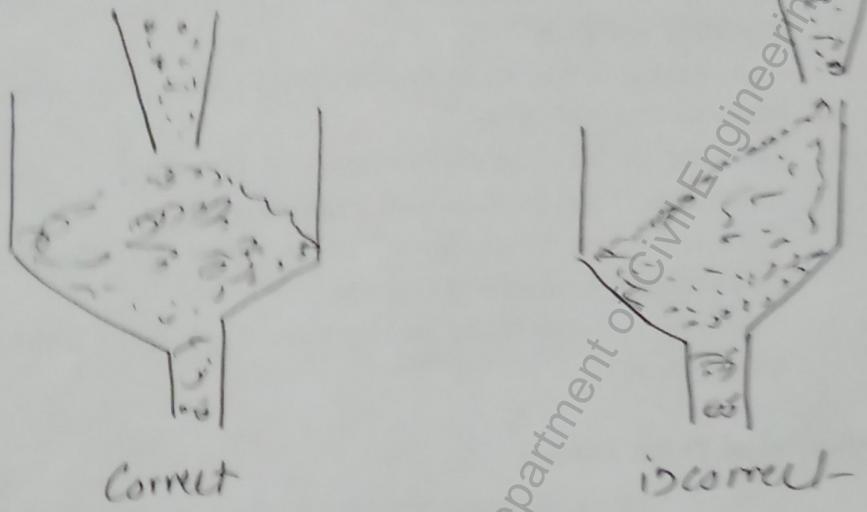
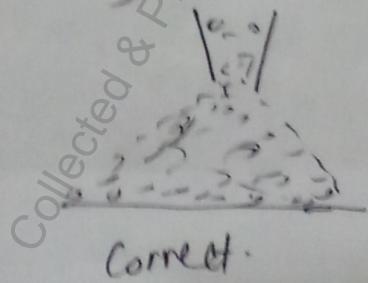


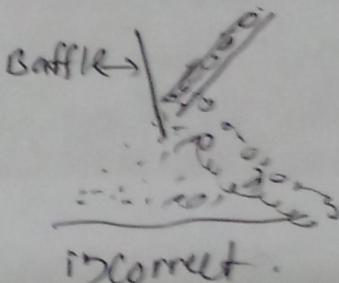
Fig. Control of segregation on filling concrete buckets

ii) placing:

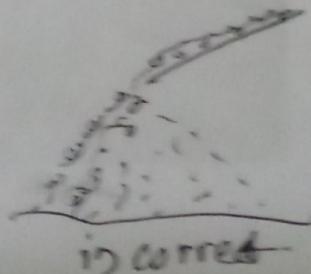
- concrete should be poured as ready as practicable in its final position to avoid re-handling
- should be placed and compacted before initial setting times of concrete and should not be subsequently disturbed.
- the main objective of pouring to final position so that segregation is avoided and concrete can be fully compacted.



Correct.



incorrect.



incorrect

Compaction

(8)

- placing & compaction are independent and carried out almost simultaneously.
- should be thoroughly compacted and fully worked around rebars, around embedded fixtures and into corners of framework.
- should be compacted using mechanical vibrators
- over-vibration & undervibration should be avoided.

Curing:

- process of preventing the loss of moisture from the concrete and maintain favourable temperature so that the hydration of cement may continue till desired properties are achieved.

* objectives:

- Keep concrete saturated.
- reduce shrinkage.
- preserve properties of concrete.
- prevent loss of water by evaporation and maintain hydration
- control temperature.

* methods:

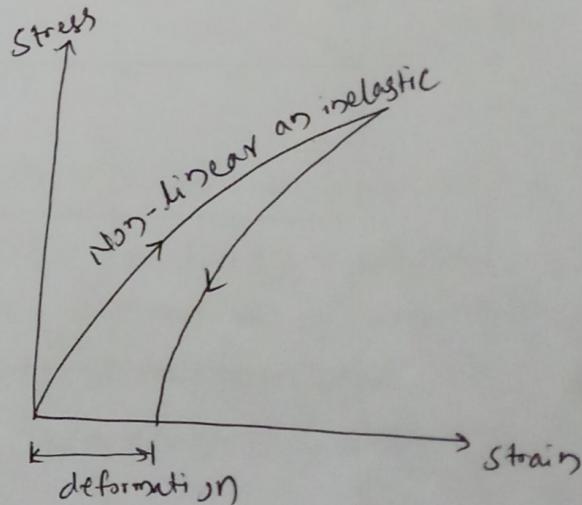
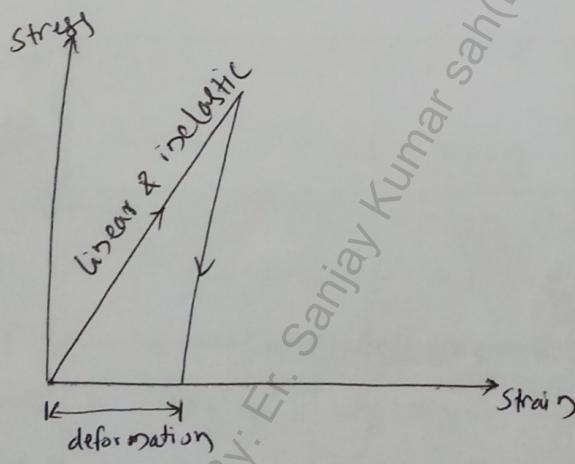
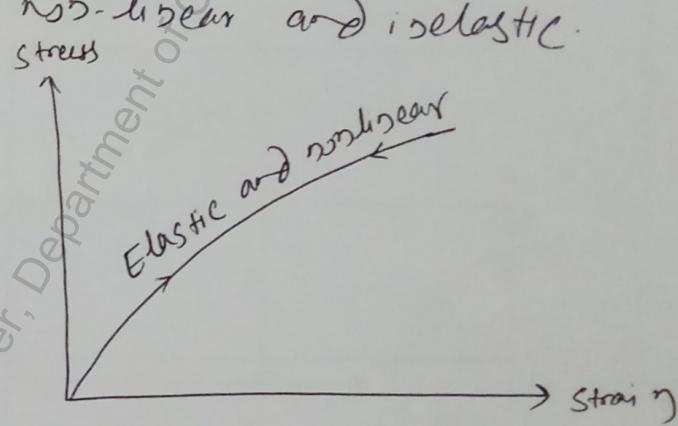
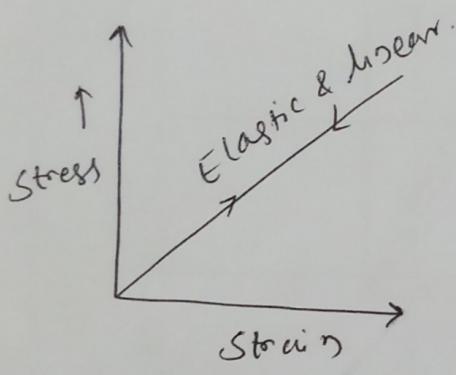
- sprinkling water.
- steam curing
- Pounding on concrete.
- membrane curing.
- shading of concrete work etc.

Chapter #4

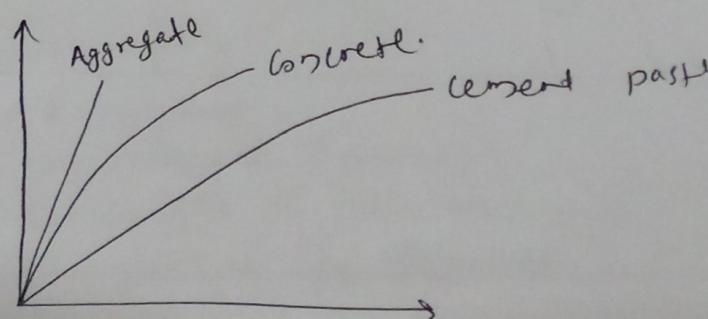
Properties of Hardened Concrete:

* Deformation of hardened concrete: Moduli of elasticity:

- Concrete behaves almost elastic when load applied initially.
- But under sustained loading, the strain increases with time under constant stress.
- At very low stress, the behaviour of concrete is not very pronounced ~~but~~ but at moderate & ~~high~~ high stress, the behaviour of concrete is non-linear and inelastic.

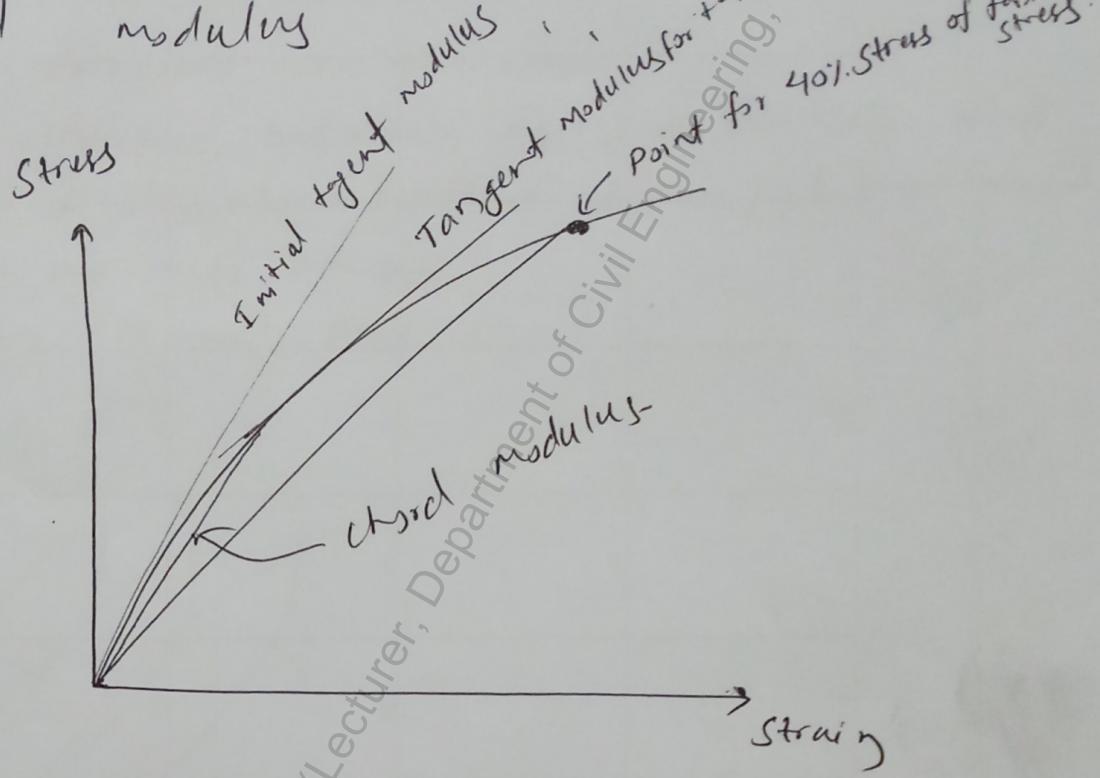


* Strain-Stress curve for concrete



1.) static modulus of elasticity:

- i) initial tangent modulus of elasticity
- ii) Tangent modulus of elasticity.
- iii) Secant modulus ..
- iv) chord modulus



2.) Dynamic modulus of elasticity

- Since the stress-strain relationship of concrete is a complex phenomenon, the static elasticity modulus does not truly represent the ~~the~~ elastic behaviour of concrete.
- The stress-strain curve exhibits small curvature, this slope is called dynamic modulus of elasticity.
- determined by subjecting the concrete member to longitudinal vibrations at their natural frequency.

$$E_d = K \nu^2 L^2 \cdot s$$

o K - Constant

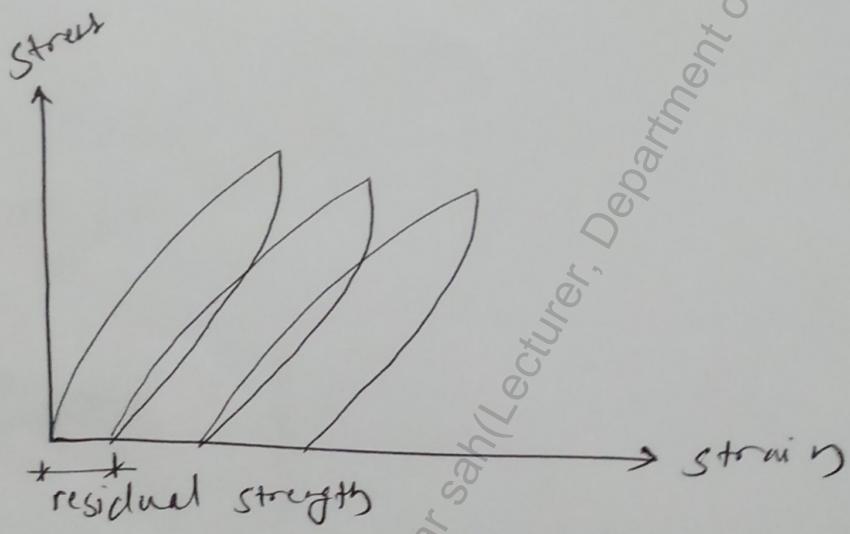
ν - resonant frequency

L - length of specimen

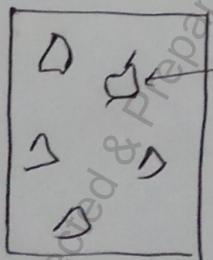
s - density of concrete.

Flexural Modulus of elasticity:

- The stress-strain curve of concrete lies between that of aggregate and cement paste
- over the most of range this relationship is non-linear.
- The reason for non-linear behaviour in the stress-strain relationship is the formation of micro-cracks.
- The micro-cracks are formed
 - at interface between aggregate particles and cement paste, as a result of differential movement between the two phases.
 - within cement paste itself.

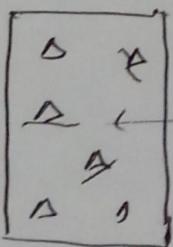


Due to phenomenon of creep and micro-cracking, the concrete does not return to its original length during unloading. Hence, there will be a residual strain at zero loads. This process is called hysteresis loop.



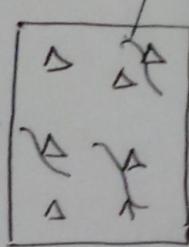
i) when 30% of ultimate stress.

micro-cracks

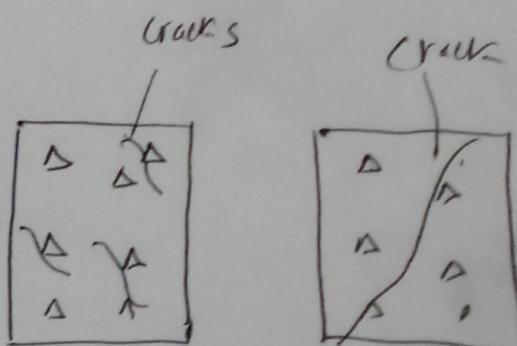


ii) when 50% of ultimate stress

cracks



iii) 75% of ultimate



iv) failure stress.

- i.) At about 25-30% of ultimate stress
→ random cracks - transition zone around large aggregate.
- ii.) About 50%
→ grow from transition zone to paste.
- iii.) 75%: → paste cracks - bond crack - start.
- iv.) At ultimate → failure occurs.

Chapter 4

(1)

Shrinkage & Creep:

* Shrinkage: Change in volume by the loss of moisture through evaporation/hydration.

* Type 8:

a) Plastic shrinkage:

- occurs due to loss of water by evaporation from freshly prepared concrete while cement paste is in plastic stage.
- For higher cement content of mix, plastic shrinkage is higher.
- Its magnitude is of order of 1% of the absolute volume of dry cement.
- The contraction in volume induces tensile stress at the surface layers due to the restraint caused by non-shrinking inner concrete. → hence, we can say that, the plastic shrinkage takes place at surface.
- Plastic shrinkage is directly proportional to loss of water.

b) Drying shrinkage:

- The reduction of volume (strain) after setting and hardening of concrete, due to loss of water by evaporation, with respect to time.
- ~~The amount of shrinkage~~
- The concrete subjected to drying shrinkage, when placed in water or high humidity, swells due to absorption of water by the cement paste getting partial recovery from the shrinkage.

→ The amount of shrinkage recovered while placing is water or ^{at} higher humidity is called reversible shrinkage ~~while~~ whereas the unrecovered shrinkage is called residual or irreversible shrinkage (2)

$$\therefore \text{Drying shrinkage} = \text{Reversible shrinkage} + \text{irreversible / residual shrinkage}$$

Reversible shrinkage = 40 to 70% of drying shrinkage.

- If concrete are cured properly; reversible shrinkage forms a larger proportion of drying shrinkage, so that it is fully hydrated before exposed to drying.
- If concrete is not fully hydrated before being exposed to drying or drying is accompanied by extensive carbonation or both; irreversible / residual shrinkage forms larger proportion of drying shrinkage.

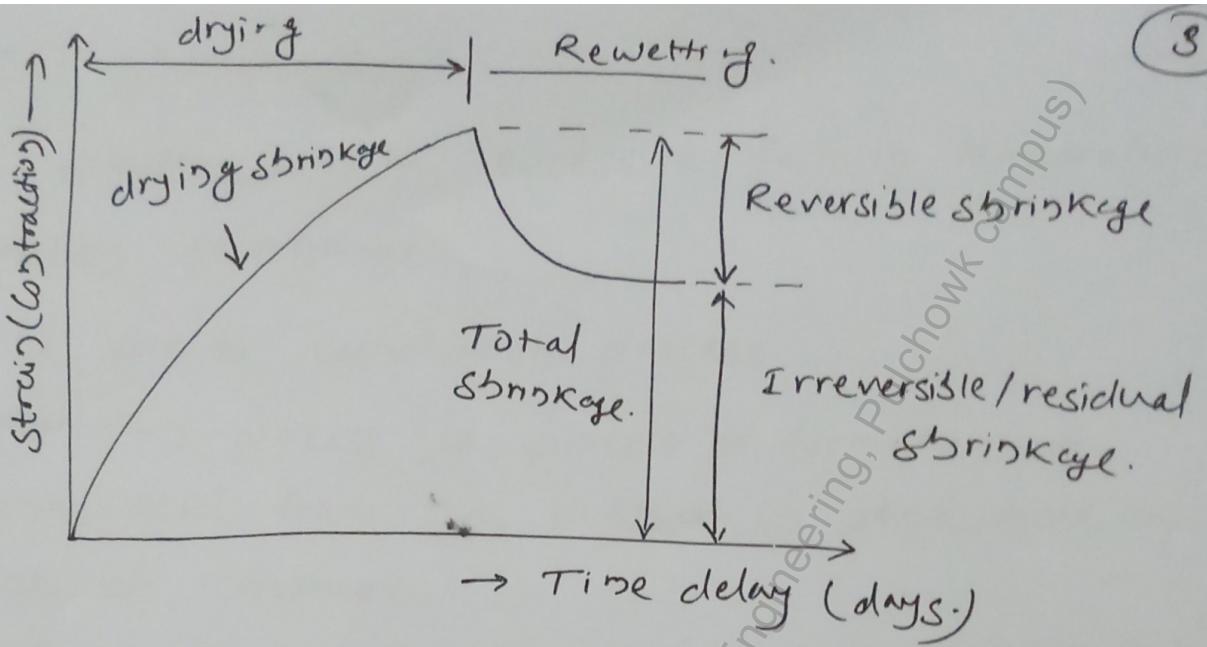


Fig. Moisture movement in concrete.

* Cracking due to drying shrinkage.

- When the induced shrinkage tensile stress exceeds the tensile strength of the concrete, cracking will occur.
- Cracking due to drying shrinkage usually occurs at the early age of concrete when the strength of the concrete is relatively low.

C.) Autogenous shrinkage:

- If no movement of water to or from the set paste of concrete is allowed; then the shrinkage occurred is known as autogenous shrinkage.
- This shrinkage is caused by the loss of water consumed by or used up in the hydration of cement.
- Theoretically; this phenomenon occurs in concrete with low water-cement ratio (less than 0.42).
- The magnitude of this shrinkage is very small of the order of 50×10^{-6} to 100×10^{-6} → hence it has no more significance.

(4) d) Thermal shrinkage:

→ It occurs due to excessive fall in temperature.

e) Carbonation shrinkage:

→ occurs due to carbonation process.

→ Carbonation process is process of formation of carbonic acid from CO_2 present in atmosphere in presence of moisture.

→ The carbonic acid reacts with $\text{Ca}(\text{OH})_2$ of hydrated cement and form $\text{CaCO}_3 \rightarrow$ results the contraction of concrete → called carbonation shrinkage.

→ It depends upon the carbonating rate, permeability of concrete, moisture content, CO_2 content and relative humidity of the atmosphere.

→ Carbonation shrinkage is found to be in addition to the drying shrinkage and adds to the total shrinkage.

Factors affecting shrinkage:

i) Cement paste and aggregate content

→ induced by cement paste and restrained by aggregate.

ii) Effect of water-cement ratio

→ higher w/c ratio → ~~bigger~~ larger the shrinkage

iii) type of aggregate:

→ heavy wt. aggregate - low shrinkage.

→ light wt. .. → high ..

iv) Effect of relative humidity:

higher at lower RH.

v) Effect of time (age)

→ shrinkage takes place over long periods. However, large fraction of total shrinkage takes place at early times (mainly drying shrinkage) and small portion over long periods (mainly carbonation shrinkage).

vi) Effect of size and shape of concrete member:

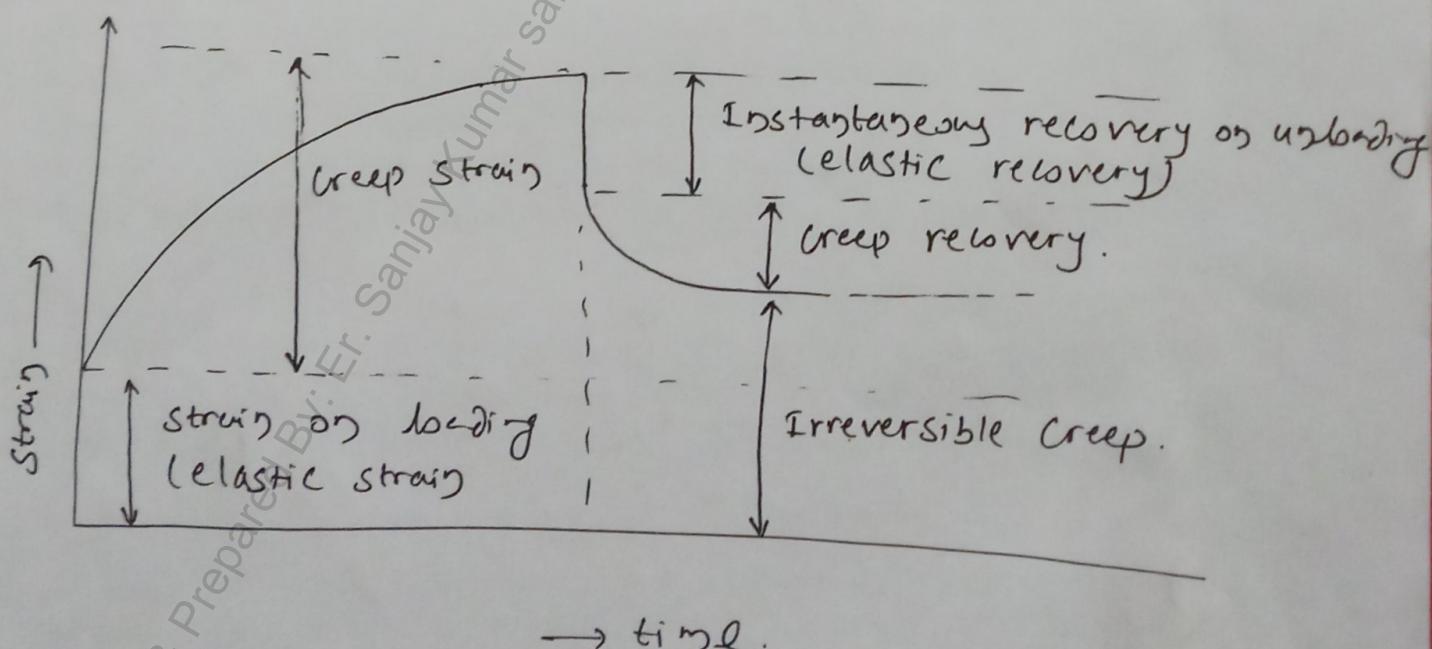
→ related to exposed surface.

→ high at higher exposed surface.

Creep: increase in strain under sustained loading.

→ time dependent.

→ not related/associated with shrinkage, swelling and thermal deformations.



→ 15% of creep is estimated to be recoverable.

Factors: already explained in previous class.)

Creep :

- time dependent behaviour under sustained loading.
- when concrete is subjected to sustained loading, its deformation keeps increasing with time, even if the load is not altered. This time dependent component of strain is termed as creep.
- factors influencing creep in concrete.
 - Cement content ↑ - ↑
 - water-cement ratio ↑ - ↑
 - aggregate content ↓ - ↑
 - air entrainment ↑ - ↑
 - relative humidity ↓ - ↑
 - temperature ↑ - ↑
 - thickness of member ↓ - ↑
 - ~~load occurs on ear~~
- age of concrete ↓ - ↑
(early age)
 - loading period ↑ - ↑

Fatigue, Impact and Dynamic loading:

* Fatigue strength:

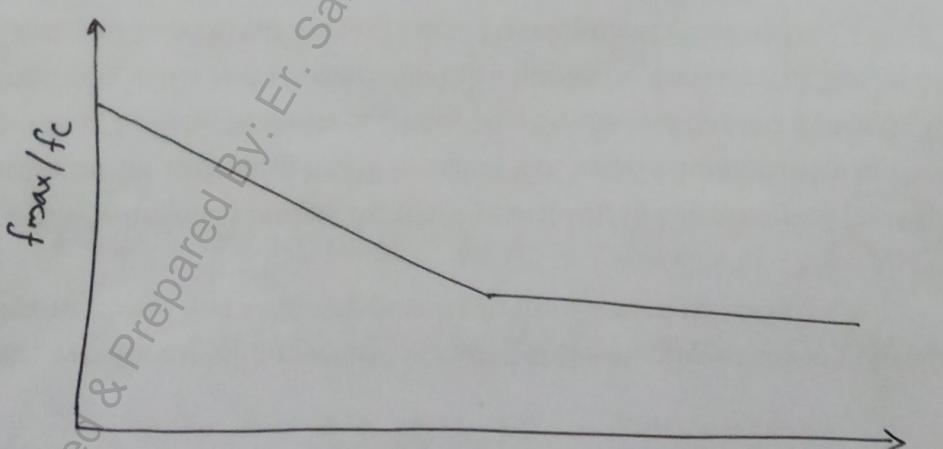
- When a material fails under a number of repeated loads, each load being smaller than the static compressive strength of concrete, then failure takes place is called fatigue failure of concrete.
- The application of repeated load on a material develops fatigue in it.
- There are two types of fatigue failure:

a) Static fatigue failure:

- Failure occurs under a sustained load (or. a slowly increasing load) near or below the strength under an increasing load, called as static fatigue failure. or, creep rupture failure.

b) Fatigue / Simple fatigue failure:

- Failure occurs under cyclic or repeated loading.
- The case of repeated loading can be seen in structures like road pavements, airport pavements, marine structures etc.
- The relationship between stress level and number of cycles of failure can be represented as below:



f_{max} = maximum stress in a cycle. $\log N$

f_c = strength of concrete under static loading.

N = Number of cycles.

→ There are various relationship to reflect above graph. (2)

→ According to Aas-Jacobsen, the relationship based on 50% confidence level is as follows:

$$\log N = \frac{\left\{ 1 - \frac{f_{\max}}{f_c} \right\}}{\beta \left\{ 1 - \frac{f_{\min}}{f_{\max}} \right\}}$$

verified

where $\beta = 0.064$

f_{\min} = minimum stress in a cycle of loading.

→ John Hudson gives the following relationships for 95% confidence level, for the constant range of alternating stress, as below:

$$\log N = \frac{\left\{ 1 - \frac{f_{\max}}{f_c} \right\}}{\beta \left\{ 1 - \frac{f_{\min}}{f_{\max}} \right\}} - 1.9 \quad (\text{to check})$$

where $\beta = 0.085$

→ According to Kakuta and others;

~~$\log N = \frac{1}{\beta} \left[1 - \frac{f_{\max}}{f_c} \right]$~~

$$\log N = 17 \left\{ 1 - \frac{(f_{\max} - f_{\min})/f_c}{\left(1 - \frac{f_{\min}}{f_c} \right)} \right\} \quad (\text{verified})$$

[Ref. Manual for Numerical Methods in
Concrete Modelling and Applications.
→ by M.Y. H. Bangash]

Impact or dynamic loading:

- If the breaking of the structure or specimens takes place under a very short time of loading (i.e. fraction of the number of cycles), strength under dynamic load is observed.
- This is basically the interaction of f_{max}/f_c versus logN curve with the f_{max}/f_c axis. This can be termed as strength under impact load. This is a complicated experiment to be carried out.
- The CEB-FIP model code (1990) recommends that the increase in compressive strength due to impact, with rate of loading less than 10^6 MPa/sec , can be computed using the relationship:

$$\frac{f_{c,\text{imp}}}{f_c} = \left(\frac{\sigma}{\sigma_0} \right)^{\alpha_s}$$

where,

$f_{c,\text{imp}}$ = impact compressive strength

f_c = compressive strength under static loading

σ = impact strength rate

$\sigma_0 = 1 \text{ MPa/sec.}$

$$\alpha_s = \frac{1}{5 + \frac{f_c}{f_{c0}}} ; f_{c0} = 10 \text{ MPa.}$$

- The ultimate strength of concrete is also affected by the rate of loading. Due to progressive micro-cracking at sustained loads, a concrete will fail at a lower stress than that induced by instantaneous

(4)

or short - time loading normally used in the laboratory. A relationship between the short-term and long term loading strength of concrete has been illustrated in fig. below:

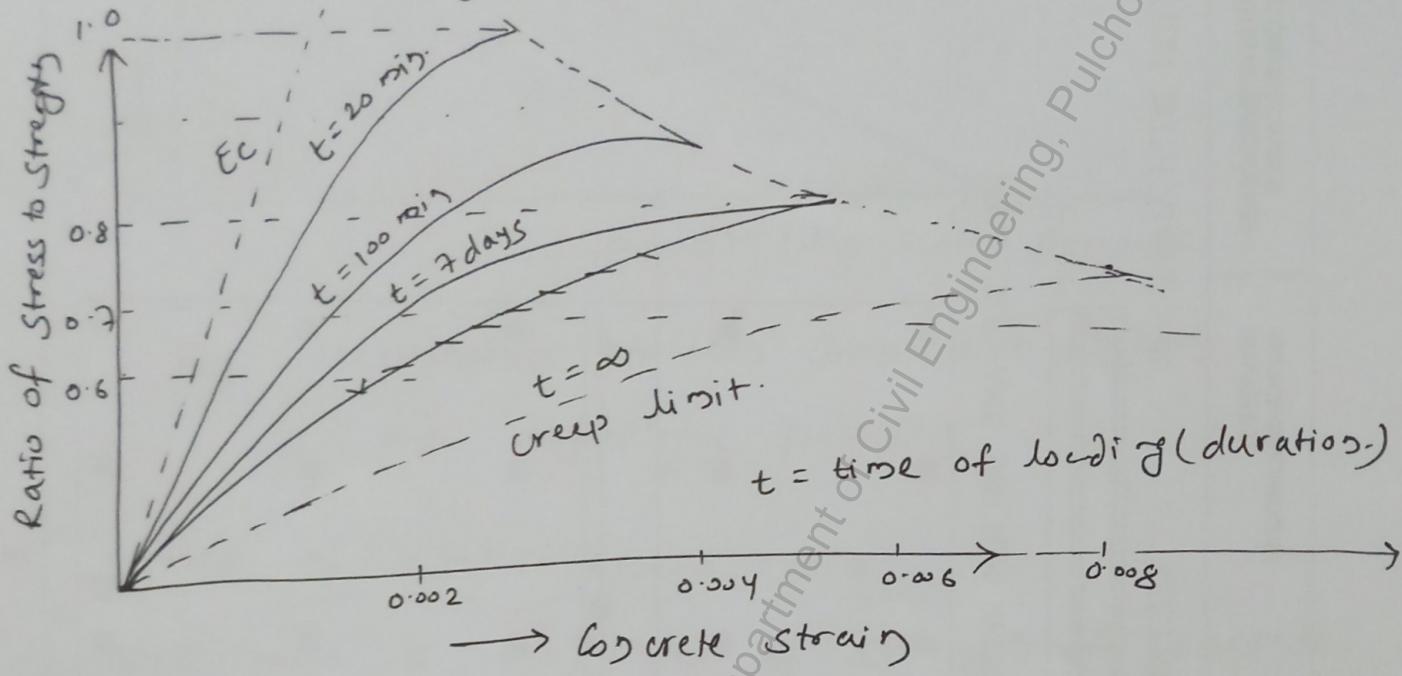


Fig. Relationship between the short-term and long-term loading strengths of concrete.

Effect of porosity, water-cement ratio and aggregate size:

* Effect of porosity: [Neville book; page 101]

- primary factor that governs strength of concrete.
- w/c ratio is major influencing factor for porosity
- depends on the degree of hydration and w/c ratio.
- decrease in porosity with increase in the degree of hydration.
- The magnitude of porosity is such that, for the usual range of w/c ratios, the cement paste is only about 'half solid'. For instance, at w/c ratio of 0.6, the total volume of pores is between 47 to 60% of the total volume of the cement paste, depending on the degree of hydration.

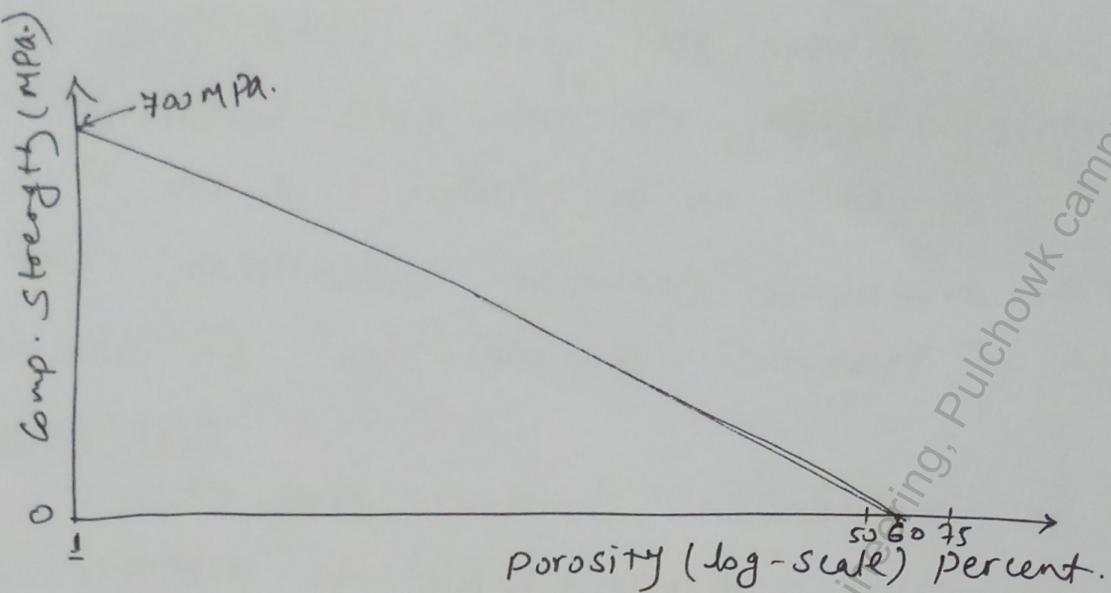
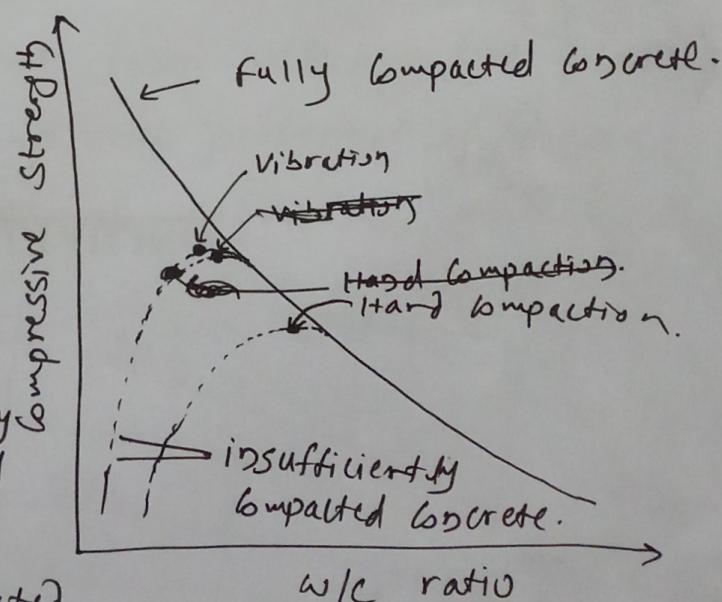


Fig. relationship between compressive strength and logarithmic porosity.

Effect of water-cement ratio:

- w/c ratio is an index of strength of concrete.
- The strength of cement-paste increases with increasing cement content and decrease with water content and air content.
- For the fully compacted concrete at a given age and temperature, its strength is inversely proportional to w/c ratio.
- In the figure, strength vs w/c ratio shows that at lower w/c ratio could be used when the concrete is vibrated to get higher strength whereas comparatively higher w/c ratio is required when concrete is hand compacted or manually compacted.



- In both cases, when w/c ratio is below the practical limit, the strength of concrete fall rapidly due to introducing of air voids.
- The relationship between compressive strength of concrete and w/c ratio is introduced by Abram's law.

Abram's Law:

With given materials and condition of test, the quantity of mixing water to the quantity of cement also determines the strength of concrete and is independent of aggregate cement ratio, so long as the mix is of workable plasticity. Mathematically,

$$C = \frac{A}{B^\alpha}$$

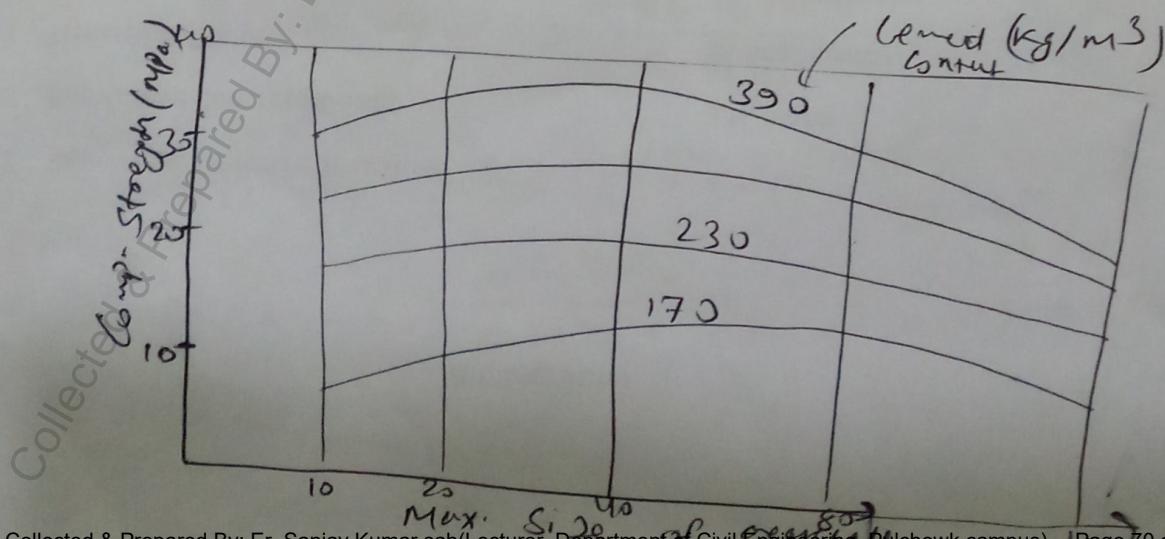
C - Compressive strength of concrete.

A, B - Empirical constants.

α - w/c ratio

Effect of aggregate size (on strength of concrete)

- Aggregate is an important factor affecting the concrete strength. The most important properties of concrete are shape, texture and size of aggregate.



Effect of gel/space ratio:

(7)

- defined as the ratio of volume of the cement gel to the sum of the volumes of cement gel and capillary pores.
- An alternative parameter to porosity.
- higher gel/space ratio reduces the porosity and therefore increases the strength of concrete
- A higher w/c ratio decreases the gel/space ratio increasing the porosity and decreasing the strength of concrete.

If C be the mass of cement

V_c be the specific volume of cement

ω_0 be the volume of mixing water

α be the degree (fraction) of hydration. (%)

* Power's ^{experiment} assumption:

$$1 \text{ cm}^3 \text{ (volume of cement)} \equiv \frac{2.06}{C} \text{ cm}^3 \text{ volume of cement (after } \underline{\text{hydration}}\text{)}$$

$$\begin{aligned} \therefore \text{Gel space ratio } (\gamma) &= \frac{\text{volume of hydrated cement gel}}{\cancel{\text{volumes}} \text{ space available}} \\ &= \frac{\text{volume of hydrated cement gel}}{\text{volume of cement} + \text{volume of water}} \\ \gamma &= \frac{2.06 \times C \cdot V_c \cdot \alpha}{C \cdot V_c \cdot \alpha + \omega_0} \quad \dots \dots (i) \end{aligned}$$

Using $V_c = 0.319 \text{ ml/gm}$ = specific volume of cement

$$\gamma = \frac{0.657 \alpha}{0.319 \alpha + \frac{\omega_0}{C}} = \frac{0.657 C \alpha}{0.319 C \alpha + \omega_0} \quad \dots \dots (ii)$$

$$\text{Porosity } (P) = \frac{V_v}{V}$$

$$\text{or, } 1-P = 1 - \frac{V_v}{V} = \frac{V-V_v}{V}$$

$$\text{or, } 1-P = \frac{V_s}{V} = \gamma$$

$$\therefore [1-P = \gamma] \quad \dots \dots \text{(iii)}$$

P = porosity

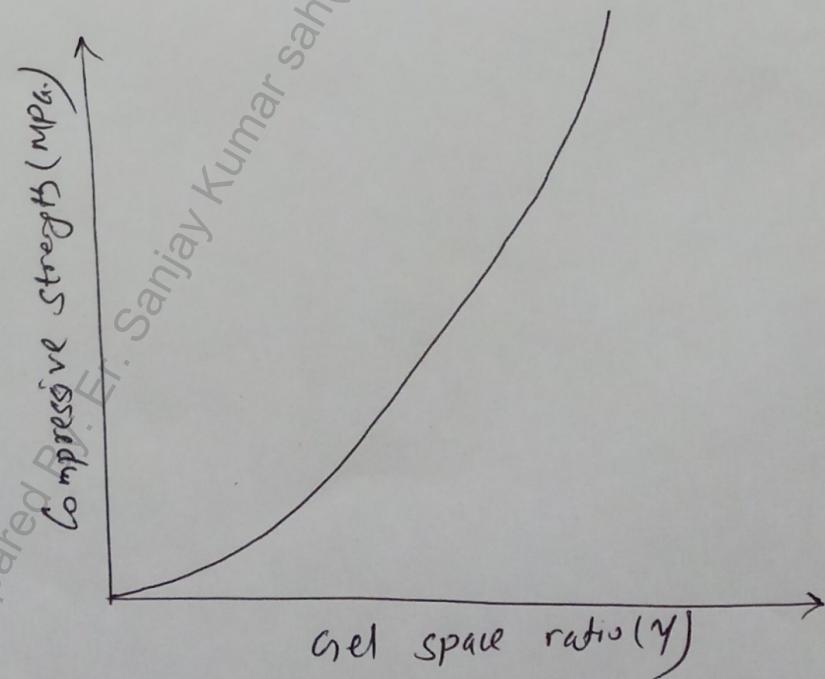
γ = gel/space ratio.

Also,

$$\text{Compressive strength} = 240 \gamma^3 \text{ (in MPa.)}$$

(Some literatures used 234 also)

→ 240 represent intrinsic or maximum strength of the gel when $\gamma=1$.



Chapter 15

4 Testing of Concrete & Quality Control

Compressive strength!

→ in order to determine compressive strength.

cube Test

150 x 150 x 150 (standard size)

$$100 \times 100 \times 10 =$$

Tests on age of 1, 3, 7, 14, 28, 90 & 365
days.

generally 7 days & 28 days.

* Cylinder Test :

According to British Standard.

$$\text{fey} \quad \frac{4}{5} \quad \text{fcu}$$

(cylinder) cube.)

~~Standard~~ Site 150m dia → 300m depth

$$\left(\frac{5}{d} = 2\right)$$

100 mm x 200 mm.

→ L. Her wife suggested that

$$f_{cu} = 0.46 + 0.2 \log_{10}\left(\frac{f_u}{2840}\right)$$

(2)

Correction factor for other ratios of $\frac{h}{d}$

$\frac{h}{d}$ ratio	Correction factors	
	American standard	British Standard
2.00	1.00	1.03
1.75	0.98	0.98
1.50	0.96	0.96
1.25	0.93	0.94
1.00	0.87	0.92

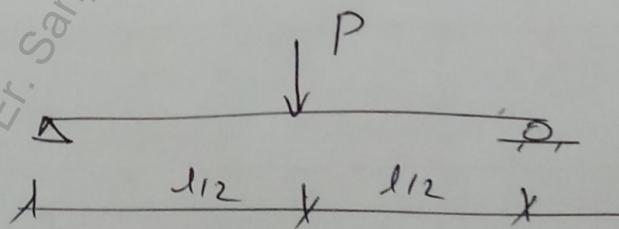
Tensile strength test.

a.) Direct tension

→ difficult to test (rarely tested)

$$f_{ct} = 0.35 \sqrt{f_{ck}}$$

b.) Flexure test (modulus of rupture).

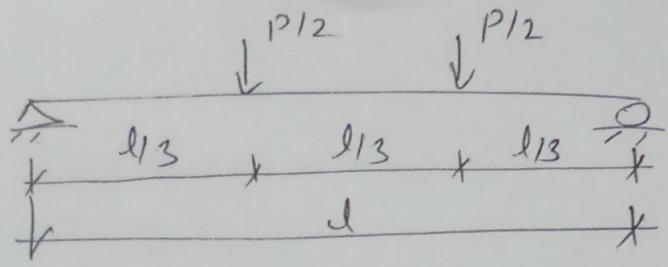


Centre point loading

$$\frac{M}{I} = \frac{f_{ur}}{y}$$

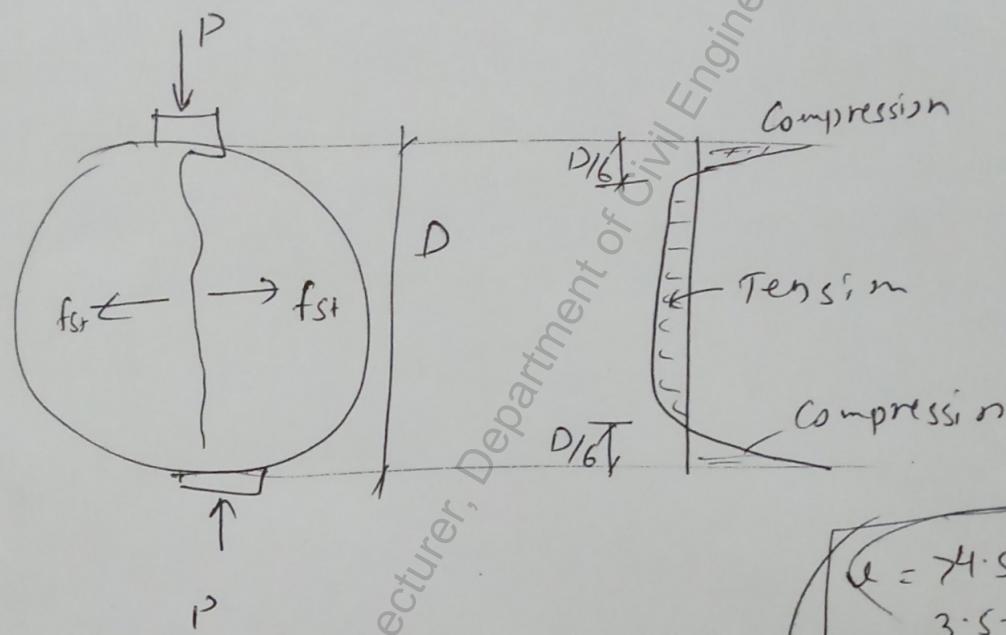
$$\Rightarrow f_{ur} = \frac{M}{I} \times y = \frac{P l}{4} \times \frac{12}{bd^3} \times \frac{d}{2} = \frac{3}{2} \frac{P l}{bd^2}$$

(3)



$$f_{cr} = \frac{P_1}{bd^2}$$

c.) splitting test



horizontal tensile strength

$$(f_{st}) = \frac{2\sigma}{\pi D}$$

$\epsilon = 74.5 \rightarrow$	Excellent
3.5 - 4.5 →	good
3 - 3.5 →	medium
2 - 3 →	doubtful
1.2 →	very poor

Non-destructive Tests:

Schmidt rebound hammer.

(in situ compressive strength.)

Ultrasonic pulse velocity method:

based on pulse velocity of

ultrasonic wave through concrete.

$$v = F \left(\frac{\rho E}{P} \right)^{1/2} \quad \left. \begin{array}{l} \{ E - \text{modulus of elasticity} \\ \rho - \text{density} \end{array} \right.$$

5.4) Variability of concrete strength and Acceptance criteria:

- Since, the concrete strength is a variable quantity, when designing a concrete mix, we must aim at minimum strength higher than the required minimum strength from the structural point of view so that we can expect every part of the structure to be made of a concrete of adequate strength.
- Let us assume the mean strength (\bar{x}) = 30 MPa.
standard deviation (σ) = 5 MPa.

Then, for 90% confidence interval;
(i.e. 95% results above minimum strength)

$$\text{minimum strength} = \bar{x} - K\sigma$$

(also known as characteristic strength)

$$= 30 - 1.65 \times 5 \\ = 21.75 \text{ MPa.}$$

$$\text{maximum strength} = 30 + 1.65 \times 5 \\ = 38.25 \text{ MPa.}$$

(*) 95% confidence interval
i.e. only ~~20~~ 97.5% results above minimum; $K = 1.96$

* Acceptance Criteria: [IS 456: 2000; cl. 16.1, 16.2, 16.3]

1.) Compressive strength (cl. 16.1)

* For M15

$$f_{\text{mean}} \geq f_{ck} + 0.825 \times \text{established standard deviation}$$

or

$$f_{ck} + 3 \text{ MPa}; \text{ whichever is greater}$$

* ~~f > 15000 N/mm²~~:

$$f_{\text{individual}} \geq (f_{ck} - 3) \text{ MPa.}$$

* For M20 & above:

$$f_{\text{mean}} \geq f_{ck} + 0.825 \times \text{established standard deviation}$$

$$\text{or } f_{ck} + 4 \text{ MPa; whichever is greater}$$

$$f_{\text{individual}} \geq (f_{ck} - 4) \text{ MPa.}$$

2.) Flexural strength (cl. 16.2) [$f_{cr} = 0.7 \sqrt{f_{ck}}$ - flexural tension]
 $f_{ct} = 0.35 \sqrt{f_{ck}}$ - direct tension]

$$f_{\text{mean}} \geq (f_{cr} + 0.3) \text{ MPa}$$

$$f_{\text{individual}} \geq (f_{cr} - 0.3) \text{ MPa.}$$

Chapter #6

Concrete Durability:

(6) Effects of water and permeability

~~Concrete durability:~~

- Durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.
- A durable concrete is one that performs satisfactorily under anticipated exposure (working) conditions during its service life span.
- One of the main characteristics influencing the durability of concrete is its permeability to ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances.
- Most of the durability problems in the concrete can be attributed to the volume change in concrete caused by many factors like internal volume change due to hydration, the effect of heat of hydration, the pozzolanic action, sulphate attack, carbonation, moisture movement, ^{frost action}, all types of shrinkages, effect of chlorides, corrosion of steel reinforcement etc.
- The volume change in concrete results in the cracks, but it is the crack that promotes permeability and thus it becomes a part of cyclic action causing deterioration of concrete.

* Factors influencing durability:

- environment
- cover to steel.
- type and quality of constituents materials .
- cement content and w/c ratio .
- compaction of concrete.
- shape and size of concrete.

1.) Effect of water and permeability on concrete durability:

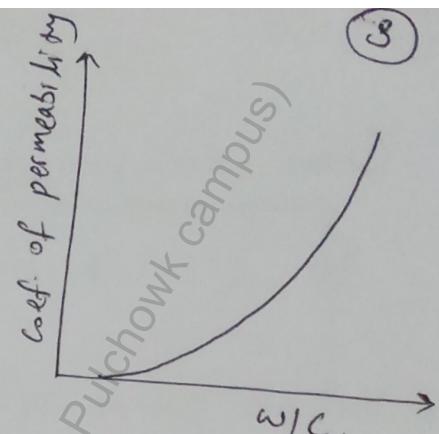
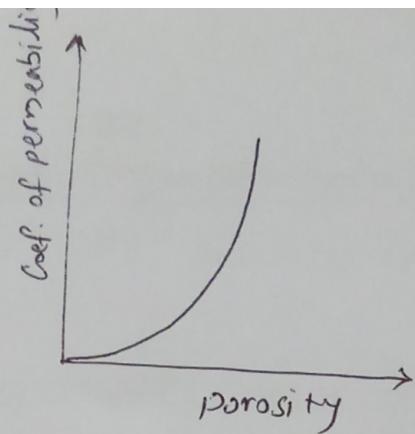
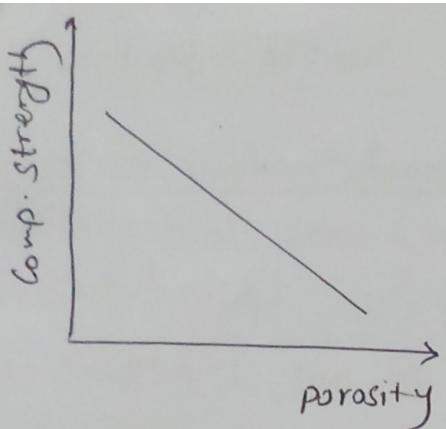
→ The study of permeability of concrete is important for the following reasons:

- The penetration of some aggressive solution may adversely affect the durability of concrete, example leaching out of $\text{Ca}(\text{OH})_2$, aggressive liquid attack on concrete etc.
- In case of reinforced cement concrete (RCC), ingress of moisture and air will result in corrosion of steel leading to an increase in the volume of steel, consequently causing cracking and spalling of concrete cover.
- The penetration of moisture in concrete, if saturated, it will be more liable to frost-action (freeze-thaw).
- In some structural members; permeability itself is of importance such as in water retaining structures, dams etc.

→ The permeability of concrete is controlled by capillary pores/voids or porosity. It depends on -

- w/c ratio
- age/degree of hydration
- gradation of aggregate.
- Compaction of concrete
- Segregation/bleeding etc.

→ In general, the higher the strength of cement paste, the lower will be the ~~permeability~~ permeability and hence, higher the durability.



6.2.) physical and chemical causes of concrete deterioration:

* physical causes of concrete deterioration

a) Surface wear → Abrasion
Erosion
Cavitation

b.) cracking → Volume change due to ~~expansion~~
- temp. & humidity gradient
- crystallization pressure of salts in pores
structural loading - overloading & impact
- cyclic loading.
Exposure to extreme temp.r - freeze-thaw
- fire

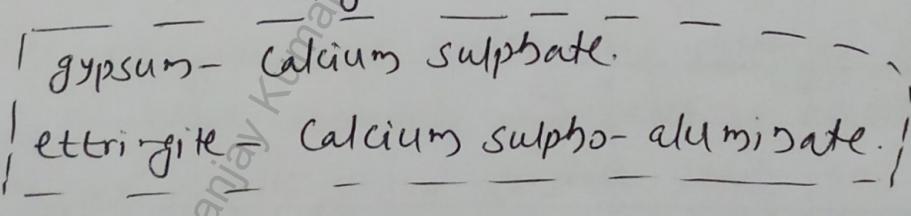
chemical causes of concrete deterioration:

- Sulphate attack.
- Attack by sea-water.
- Alkali-aggregate reaction
- Acid attack ~~etc.~~
- Chloride ion penetration ~~etc.~~
- Carbonation etc.

a) Sulphate attack:

(4)

- Sulphates are generally found in ground water and sub-soil. Sea-water also contains large quantity of sulphates.
- Sulphates can be naturally occurring or could be as a consequence of industrial waste disposal.
- Calcium, sodium, magnesium and ammonium sulphates are harmful to concrete as they can lead to increase in the concrete volume and consequent cracking.
- Calcium Sulphate reacts with calcium aluminate present in cement hydrates forming an expansive ~~etc~~ ettringite.
- Sodium sulphate reacts with calcium hydroxide and forms expansive gypsum and in presence of alumina may lead to formation of ettringite.
- Magnesium sulphate reacts with cement compounds decomposing the cement itself and subsequently producing gypsum and ettringite.



Attack by Sea-Water:

- Sea water contains sulphates and hence attacks the concrete in similar way as sulphate attack but does not generally cause expansion of concrete. This is because chlorides are also present in sea water which dissolves gypsum and ettringite. So, there is no destruction but only a slow decrease in strength due to the corrosion of reinforcement.
 - Expansion can take place as a result of the pressure exerted by the crystallization of salts in the pores of the concrete.
 - Concrete subjected to fluctuations of sea-water level is severely attacked while permanently immersed concrete is least attacked.

C) Alkali - aggregate Reaction / Alkali - Silica Reaction:
(AAR) (ASR)

- Alkaline hydroxide derived free alkali in cement reacts with silicious material in aggregate, as a result alkali-silicate gel is formed around the aggregate particles. This gel swells by absorbing water and internal pressure is created and hence expansion and cracking occurs.
 - Expansion and cracking of concrete leads to the loss of strength and elastic modulus.

d.) Acid attack:

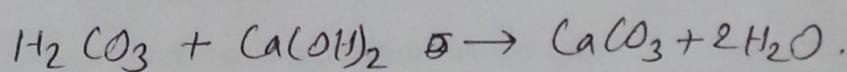
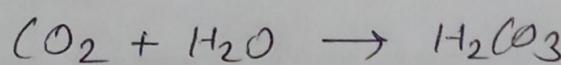
- In industrial plants, concrete floors come in contact with liquids which damage floors.
 - In damp/moist conditions SO_2 & CO_2 and other acid fumes present in the atmosphere affect the concrete by dissolving and removing part of the set cement mass.
 - Degree of attack increases as acidity increases. Acid attack occurs at pH below 6.5. A pH less than 4.5 leads to severe attack.

Chloride-ion Penetration:

- Chloride ions present in the concrete can have harmful effect on concrete as well as on the reinforcement.
- ~~It~~ It results in concrete swelling of 2 to 2.5 times, which results reduction of concrete strength.
- Presence of chloride ions near the reinforcement steel makes it vulnerable to corrosion.
- As per IS 456:2000, the amount of chloride permitted in concrete is limited to acid-soluble chloride contents of 0.4 and 0.6 kg/m³ of concrete is ~~for~~ pre-stressed and reinforced concretes respectively.
- Some of the chloride present in the concrete can be chemically fixed by reactions with C₃A compound of cement forming calcium chloro-aluminate hydrate.
- This explains the good performance of cement containing high amount of C₃A.

Carbonation:

- The reaction of carbon-dioxide with calcium-hydroxide forming calcium carbonate is called as carbonation.
- In presence of moisture CO₂ forms H₂CO₃ which further reacts with Ca(OH)₂ of hydrated cement forming CaCO₃ which results reduction in strength as well as small shrinkage in concrete too.



- The rate of carbonation is mainly influenced by the permeability & ~~calcium content~~ of concrete and amount of CO₂ & moisture present in ambient atmosphere.

carbonation is more rapid in hot climate than in moderate climate.

- once, carbonation starts; due to shrinkage, concrete being porous or cracking → again chance of penetration of CO_2 & moisture and hence process triggered.
- The main disadvantage of carbonation is that due to shrinkage, concrete get cracked. and become more porous.
- The pH value of pure water is hardened concrete is generally is between 12.5 to 13.5 which prevents the reinforcing steel from action of oxygen & water (i.e. corrosion) but due to carbonation, it reduces alkalinity of the pore water which results the corrosion of steel in acidic environment.
- The corrosion/rusting of steel increases its volume resulting cracking /spalling of concrete cover.
- * Factors affecting rate of carbonation:
 - level of pore water i.e. relative humidity.
 - Grade of concrete - slower in strong concrete.
 - permeability of concrete.
 - protection of concrete → higher in unprotected concrete.
 - Age of concrete.
 - presence of CO_2 in environment.

Corrosion/rusting of steel in concrete:

- The strongly alkaline nature of $\text{Ca}(\text{OH})_2$ in concrete (pH above 12.5) prevents the corrosion of steel reinforcement by the formation of a thin protective film of iron oxide on the metal surface; this protection is known as passivity.
- However, if concrete is permeable to the extent that carbonation reaches the concrete in contact with steel or soluble chlorides can penetrate to the reinforcement and if water and oxygen are present, then corrosion of reinforcement will take place.
- The passivity of iron oxide layer is destroyed when pH falls below about 11. The formation of rust results in an increase in volume of steel resulting cracking and spalling of the concrete cover.
- The process of corrosion of steel can be explained as below:

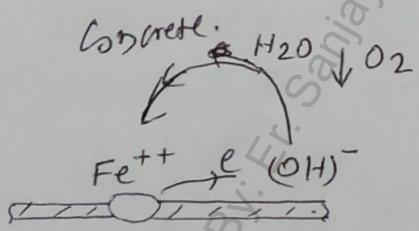


fig. Electrochemical process of corrosion

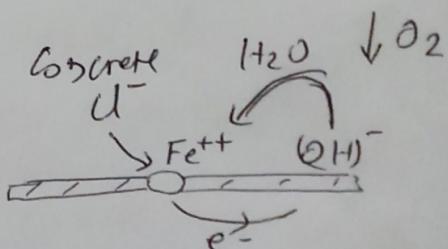
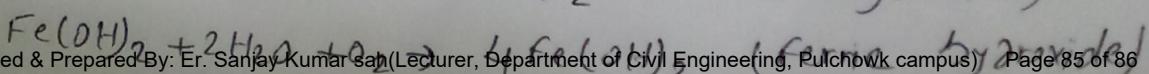
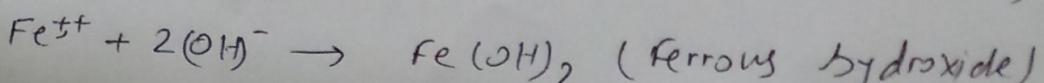
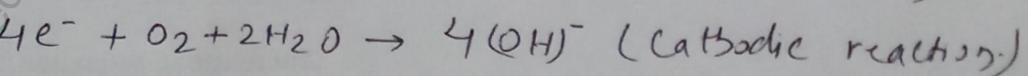
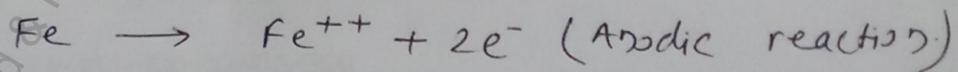


fig. electrochemical process of corrosion in presence of chloride.



* Effect of Corrosion:

- The corrosion products are more voluminous than parent metal and their formation and deposition on the surface of reinforcing bars leads to excessive pressure on surrounding concrete resulting cracking & spalling of concrete over time.
- Once crack formed; it allows passage to water, air, chloride etc. through concrete and the corrosion process triggered.
- Reinforced concrete members may suffer damage due to loss of bond between concrete & steel.
- Loss of sectional area of rebar may lead to structural failure.

* Preventive measures against corrosion:

- Most important precaution is to provide dense concrete.
- Provide adequate cover to reinforcing bars.
- Galvanization or protective coating on reinforcement can also be used.
- Sea water shouldn't be used for mixing or curing.
- Use of Slag or Pozzolana cement.
- Controlling permissible crack width during design of RC member.