LECTURE NOTES

On

CONCRETE TECHNOLOGY

III B. Tech I semester (IARE-R16)

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UNIT-1

Concrete Technology

Definition:

Cement is defined in many ways as follows,

- Cement, any material that hardens and becomes strongly adhesive after application.

- Manufactured substance consisting of gypsum plaster, or Portland cement.

- Portland cement hardens and adheres after being mixed with water.

History of Cement:

- The term “Portland cement” was first used in 1824 by Joseph Aspdin, a British cement-maker, because of the resemblance between concrete made from his cement and Portland stone, which was commonly used in buildings in Britain.

- At that time cements were usually made in upright kilns where the raw materials were spread between layers of coke, which was then burnt.

- The first rotary kilns were introduced about 1880. Portland cement is now almost universally used for structural concrete.

Manufacturing Process:

- Main ingredients used in the manufacture of cement are:
- Limestone
  - Calcium
- Clay, shale
  - Silica/Alumina
- Quarrying

  - local resources necessary: no market

- Limestone ($CaCO_3$) and Clay are two main raw materials used for manufacturing Portland cement clinker.

- Clays have various amount of SiO_2 and Al_2O_3.
- In the manufacturing process of Portland cement, clinker consist essentially of grinding the raw materials, mixing them in appropriate proportion, burning the raw material in a kiln at a temperature of 1400-1500^oC until material partially fuses into balls known as Clinker and grinding cooled clinker together with a small amount of gypsum rock.

- The mixture of raw material is burned in a rotary kiln.

THE KILN

The heart of the cement plant

- Largest moving part of any machine.

- Inclined, rotates up to 50m long and 5m diam.

- Heated by fire jet.

- The rotary kiln is along steel cylinder lined with refractory brick (length /diameter ~30). Modern kilns may reach 6m in diameter and over 180m in height with a production capacity exceeding 1000 tonnes a day.

- The kiln is inclined a few degrees from the horizontal (about 4 cm\m) and is rotated about its axis at a speed of about 60 to 150 revolution\hour).

- Pulverized coal or gas is used as the source of heat. The heat is supplied from the lower end of the kiln. The max. temperature near the lower end of the kiln is generally about 1400-1500 ^OC.

- The upper end of the kiln the temperature is around 150 ^OC.

- The mixture of the raw material is fed from the upper end of the kiln.This material move toward the lower end by effect of inclanation and rotation of the kiln. Thus the materials are subjected to high temperature at lower end of the kiln.

- The materials that are introduced into the rotary kiln are subjected to several distinct process as they move downward.

- When the raw materials are fed into the kiln, drying of the material takes place, and any free water in the raw material is evaporated.

- Clay losses its water about 150 to 350 ^{O}C.

- Clay decompose at a range of 350 to 650 ^{O}C.

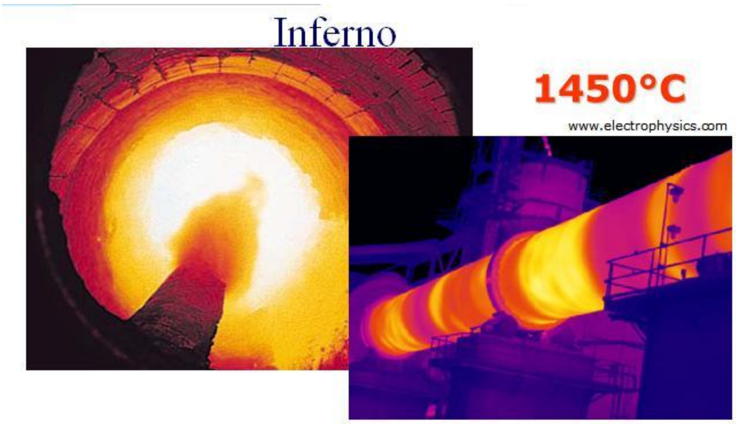
- Magnesite in raw material loss about 600 ^{O}C.

- The limestone losses its CO_2 at about 900 ^{O}C.

- At 1250 to 1280 ^{O}C some liquid formation begins and compound formation start to takes place.

- Clinkering begins at about 1280^{O}C. The liquid that forms during the burning process causes the charge to agglomerate into nodules of various size, usually 1 - 25 mm in diameter known as **Portland cement clinker**.

- All exhaust gases produced during the burning process of the materials leave the kiln through the stack.



COOLING & GRINDING

- Rapid cool – glassy

- Grinding– Starts at golf ball size– ends about 2-80 microns, 300 m^2/kg

- depend on application

- Typical plant: 1 MT/y

- Portland cement is manufactured by inter grinding the portland cement clinker with some (3 to 6 %) **Gypsum rock**.

QUANTITIES

- Worldwide: ~2 GT/y
  - China: 860 MT/y US: 100 MT/y
  - India: 200 MT/y UK: 12 MT/y
- CONCRETE: ~15 GT/y
  - cf. steel ~1 GT/y, wheat ~0.6 GT/y, rice ~0.4 GT/y
  - 2.5 T for each of us!
  - 2mm Earth surface

ECONOMIC IMPORTANCE

- Availability & price crucial to national development
  - Cement: 1-2% of total construction costs
  - Construction: 5-10% of GDP
  - Demand for cement is key economic indicator

APPLICATIONS

- Structural
  - Reinforced concrete
- Structuro-functional
  - bone/dental cements
- Functional
  - waste immobilisation, land remediation
- Sculptural

- Improbable

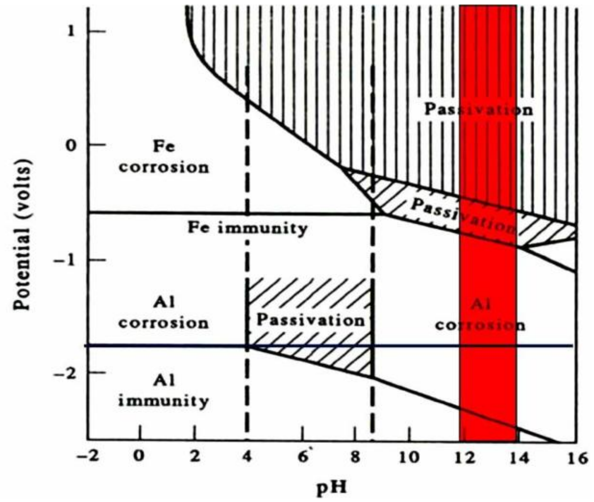
CONCRETE

Concrete is a mixture of Cement paste and aggregate

- Compression: up to 120 MPa
  - Comparable to Al
- Tension: <10 MPa
- Tension reinforcement
  - steel bars

THE RC COINCIDENCES: 1

- Reason why RC bonds together is coefficient of thermal expansion
  - Steel: 12μ/°C
  - Concrete: 7-12μ/°C
  - else RC would fall apart after a day



THE RC COINCIDENCES: 2

- Fe Passivation
  - alkaline environment (pH 11-14)
  - oxide layer 5nm

  - prevents rusting
  - corrosion only when disturbed

WASTE IMMOBILISATION

- e.g. Nuclear waste
  - solidifies waste
  - nanostructure holds certain ions in place: less leaching
  - cement chemistry tailored to particular waste

DENTAL CEMENT

- Glass -ionomer cements
  - Al_2O_3/SiO_2 glass + phosphoric acid
- Replacing traditional mercury amalgam

CPC BONE CEMENTS

- Calcium phosphates
  - Hydrate to form hydroxyapatite
  - $Ca_{10}(PO_4)_6(OH)_2$
  - natural bone (and tooth) mineral
  - bond & bioactivity
  - Add water.

LAND REMEDIATION

- Stabilisation/solidification
  - reaction between cement and soil immobilises contaminants
  - also adds structural strength

SCULPTURE

- Achievement of forms not possible in other media

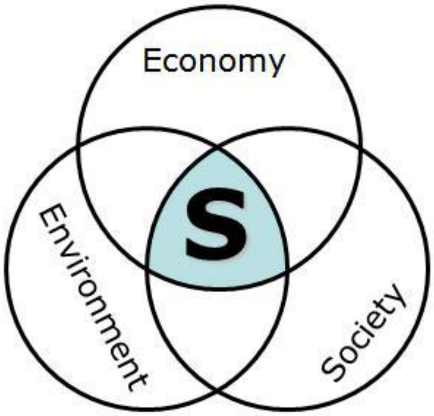
IMPROBABLE

Improbable, but true

- Foamed concrete
  - void filling
  - Fire fighting (cement foams based on ettringite)
- Weather control
  - “bombrainy clouds with cement”

SUSTAINABILITY

- Wealth creation, environmental protection and social justice going hand in hand”
- “development which meets the needs of the present without compromising the ability of future generations”



NEGATIVE

- 5% of global CO_2 emissions
  - ~1 w/w CO_2/cement
  - limestone: $CaCO_3$ @ 600°C ⇒ $CaO + CO_2$
  - fuel: 100 kg oil & 100 kWh per tonne
- Quarrying
  - resource use: 1.6 t/t
  - landscaping

POSITIVE

- Waste as fuel
  - tyres; solvents; biomass
- Thermal mass
  - bare concrete absorbs in day and radiates at night
  - reduced heating & air-con
  - 50% less energy over building life
- Waste as additives
  - ggbs; pfa; csf

CEMENT

(Chemical Composition and Hydration)

Oxide Composition of Portlant Cement

- Portland cement is composed of four major oxides: lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron (Fe_2O_3).

- Also Portland cement contains small amount of magnesia (MgO), alkalies (Na_2O and K_2O), and sulfuric anhydrite (SO_3).

Approximate Composition Limits of Oxides in Portland Cement

Oxide	**Common Name**	**Content, %**
CaO	Lime	60-67
SiO_2	Silica	17-25
Al_2O_3	Alumina	3-8
Fe_2O_3	Iron	0,5-6
MgO	Magnesia	0,1-4
Na_2O and K_2O	Alkalies	0,2-1,3
SO_3	Sulfuric anhydride	1-3

Mass Percentage			
Oxide	Cement 1	Cement 2	Cement 3
CaO	66	63	66
SiO_2	20	22	20
Al_2O_3	7	7.7	5.5
Fe_2O_3	3	3.3	4.5
Others	4	4	4

Major Compounds of Portland Cement (Bogue's Compound Composition)

Name		Chemical formula	Abbreviation
1.	Tricalcium silicate	$3CaO.SiO_2$	C_3S
2.	Dicalcium silicate	$2CaO.SiO_2$	C_2S
3.	Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A
4.	Tetracalcium alumino ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

.

Bogue's Compound Composition

- C_3S=4.07(CaO)-7.6(SiO_2)- 6.72(Al_2O_3)-1.43(Fe_2O_3) – 2.85(SO_3)

- C_2S= 2.87 (SiO_2) - 0.75(3Cao. SiO_2)

- C_3A= 2.65(Al_2O_3) – 1.69 (Fe_2O_3)

- C_4AF = 3.04 (Fe_2O_3)

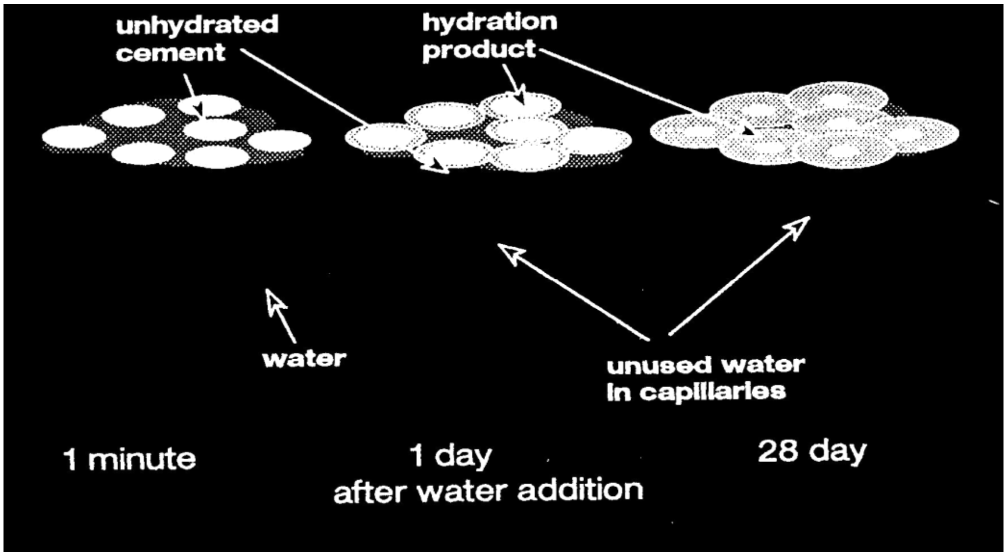
Significance of Compound Composition

Mass Percentage			
Compound	**Cement 1**	**Cement 2**	**Cement 3**
C_3S	65	33	73
C_2S	8	38	2
C_3A	14	15	7
C_4AF	4	10	14

Hydration of cement

- When Portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. This chemical reaction with water is called "hydration". Each one of these reactions occurs at a different time and rate. Together, the results of these reactions determine how Portland cement hardens and gains strength.

OPC hydration



- Hydration starts as soon as the cement and water are mixed.

- The rate of hydration and the heat liberated by the reaction of each compound is different.

- Each compound produces different products when it hydrates.

- Tricalcium silicate (C_3S). Hydrates and hardens rapidly and is largely responsible for initial set and early strength. Portland cements with higher percentages of C_3S will exhibit higher early strength.

- Tricalcium aluminate (C_3A). Hydrates and hardens the quickest. Liberates a large amount of heat almost immediately and contributes somewhat to early strength. Gypsum is added to Portland cement to retard C_3A hydration. Without gypsum, C_3A hydration would cause Portland cement to set almost immediately after adding water.
- Dicalcium silicate (C_2S). Hydrates and hardens slowly and is largely responsible for strength increases beyond one week.

- Tetracalcium aluminoferrite (C_4AF). Hydrates rapidly but contributes very little to strength. Its use allows lower kiln temperatures in Portland cement manufacturing. Most Portland cement color effects are due to C_4AF.

Characteristics of Hydration of the Cement Compounds

Compounds	Reaction Rate	Amount of Liberated	Strength	Heat Liberation
C_3S	Moderate	Moderate	High	High
C_2S	Slow	Low	Low initially, high later	Low
C_3A	Fast	Very high	Low	Very high
C_4AF	Moderate	Moderate	Low	Moderate

- **Reactions of Hydration**

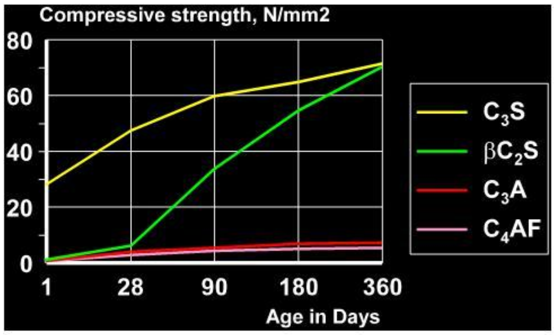
$2C_3S + 6H = C_3S_2H_3 + 3Ca(OH)_2$
(100 + 24 = 75 + 49)

$2\,C_2S + 4H = C_3S_2H_3 + Ca(OH)_2$
(100 + 21 = 99 + 22)

$C_3A + 6H = C_3AH_6$
$[C_3A + CaSO_4 . 2H_2O = 3Cao. Al_2O_3. 3CaSO_4. 31H_2O]$

Calcium Sulfoaluminate

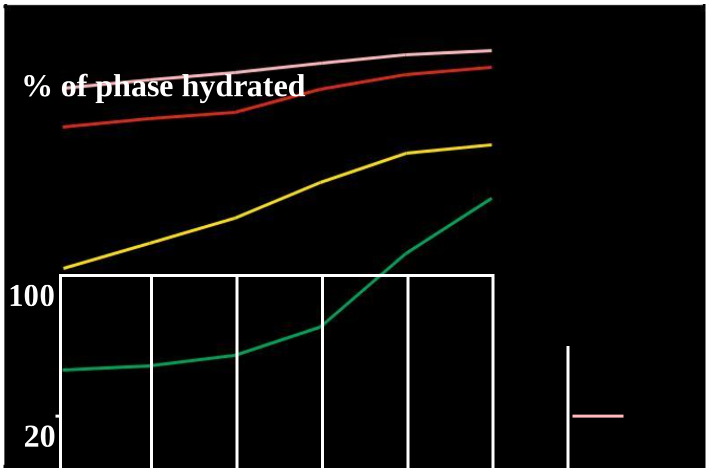
- **Strength gain of cement phases**



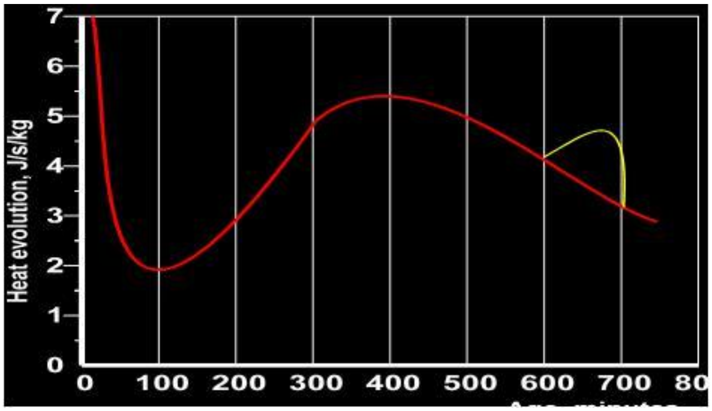
Heat of Hydration

- The heat of hydration is the heat generated when water and Portland cement react. Heat of hydration is most influenced by the proportion of C_3S and C_3A in the cement, but is also influenced by water-cement ratio, fineness and curing temperature. As each one of these factors is increased, heat of hydration increases.
- For usual range of Portland cements, about one-half of the total heat is liberated between 1 and 3 days, about three-quarters in 7 days, and nearly 90 percent in 6 months.
- The heat of hydration depends on the chemical composition of cement.

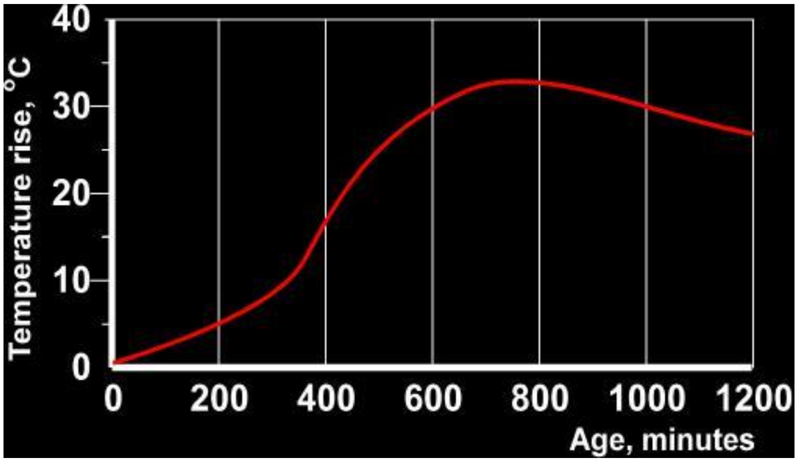
Hydration rate of cement phases



Hydration curve from conduction calorimetry

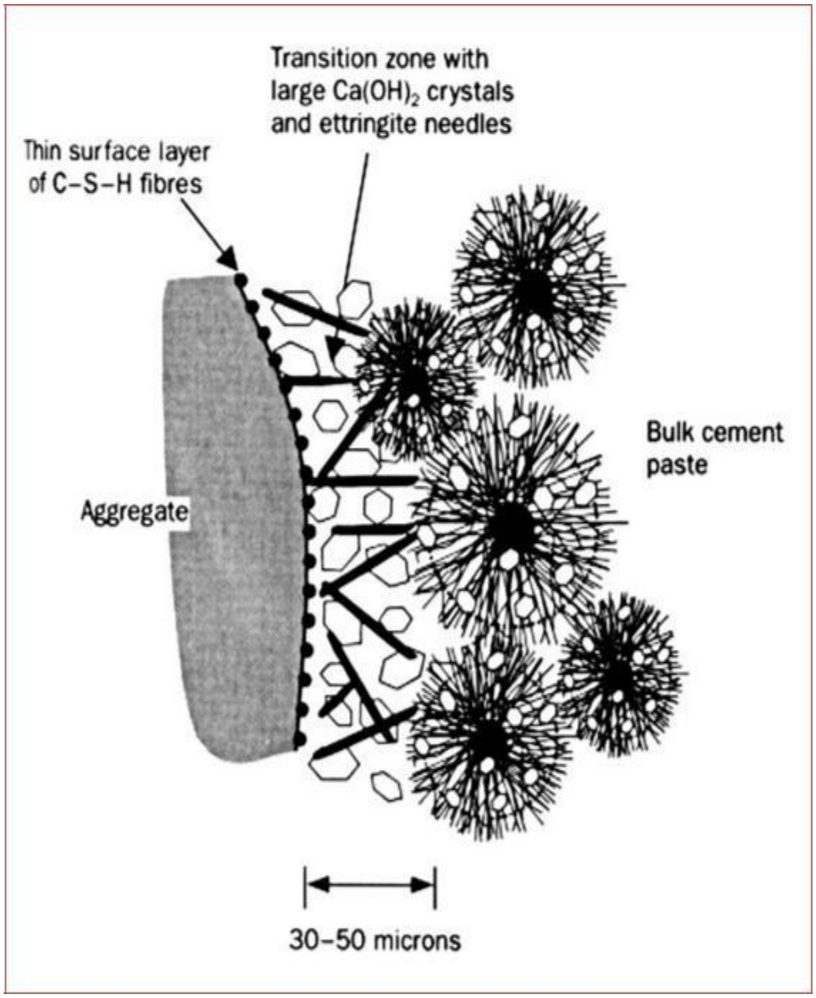


Temperature rise curve in practice



Microstructure of cement paste

Phases in Microstructure

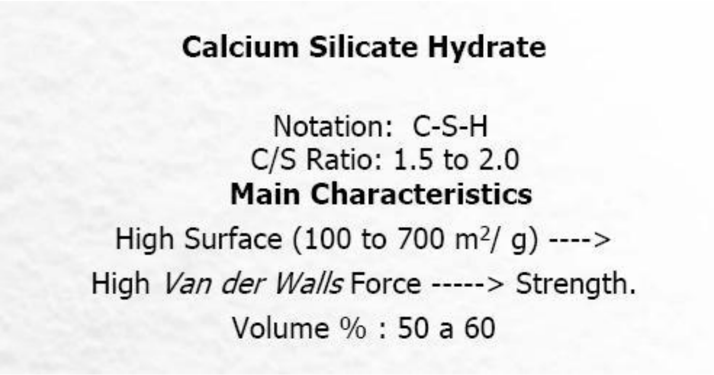


Socket where a sand grain has been pulled away from cement paste in 1-day old mortar. The sand grain was originally at the top of the picture. Note the open structure and the presence of crystals of calcium hydroxide in this region.

“In Portland cement mortars, the microstructure of the interfacial zone, extending to about 20 to 50 µm from the sand grain surface, is significantly different from that of the bulk paste matrix away from the sand grain. It is characterized by a massive CH layer engulfing the sand grain and by some channel type gaps.”

“The formation of this zone may be the result of the presence of some water-filled gaps around the sand grains in the fresh mortar. These gaps may be the result of bleeding and inefficient filling with cement particles of the 20-µm space around the grain surface.”

Solids in the Cement Paste



Calcium Silicate Hydrate

Notation: C-S-H
C/S Ratio: 1.5 to 2.0
Main Characteristics
High Surface (100 to 700 m^2/ g) ---->
High *Van der Walls* Force -----> Strength.
Volume % : 50 a 60

Cement : Physical Properties and Types of Cement

Physical Properties

- Portland cements are commonly characterized by their physical properties for quality control purposes. Their physical properties can be used to classify and compare Portland cements. The challenge in physical property characterization is to develop physical tests that can satisfactorily characterize key parameters.

The physical properties of cement

- Setting Time

- Soundness
- Fineness
- Strength

Setting Time

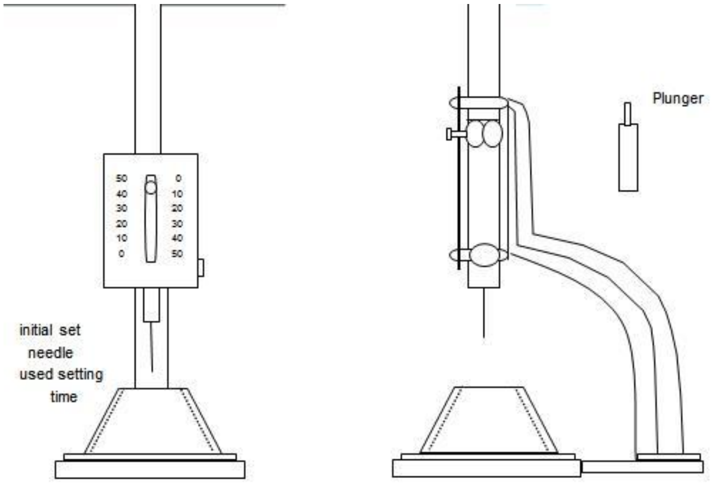
- Cement paste setting time is affected by a number of items including: cement fineness, water-cement ratio, chemical content (especially gypsum content) and admixtures. Setting tests are used to characterize how a particular cement paste sets.

- For construction purposes, the initial set must not be too soon and the final set must not be too late. Normally, two setting times are defined:
- Initial set. Occurs when the paste begins to stiffen considerably.
- Final set. Occurs when the cement has hardened to the point at which it can sustain some load.
- Setting is mainly caused by C_3A and C_3S and results in temperature rise in the cement paste.
- False set :No heat is evolved in a false set and the concrete can be re-mixed without adding water
- Occures due to the conversion of unhydreous/semihydrous gypsum to hydrous gypsum($CaSO_4.2H_2O$)
- Flash Set: is due to absence of Gypsum. Specifically used for under water repair.

Tests:

Consistency

- The consistency is measured by the Vicat apparatus using a 10mm diameter plunger.
- A trial paste of cement and water is mixed and placed in the mould having an inside diameter of 70mm at the base and 60mm at the top, and a height of 40mm.
- The plunger is then brought into contact with the top surface of the paste and released. Under the action of its weight the plunger will penetrate the paste. The depth depending on the consistency.
- When the plunger penetrates the paste to a point 5 to 7mm from the bottom of the mould. The paste is considered to be at “normal consistency”.
- The water content of the paste is expressed as a percentage by weight of dry cement. The usual range of values being between 26% and 33%.



• Vicat Apparatus: front and side views

Setting time

- The setting time test is conducted by using the sameVicat apparatus, except that a 1mm diameter needle is used for penetration.
- The test is started about 15 minutes after placing the cement paste (which has normal consistency) into the mold. Trials for penetration of the needle are made.
- The final setting time is defined as the length of time between the penetration of the paste and the time when the needle(with annular ring) no longer sinks visibly into the paste.
- The initial setting time is defined as the length of time between the penetration of the paste and the time when the needle penetrates 25mm into the cement paste.

Soundness

- When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed expansion. This expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). Most Portland cement specifications limit magnesia content and expansion.
- The cement paste should not undergo large changes in volume after it has set. However, when excessive amounts of free CaO or MgO are present in the cement, these oxides can slowly hydrate and cause expansion of the hardened cement paste.
- Soundness is defined as the volume stability of the cement paste.

Test For Soundness

- IS prescribe a Soundness Test conducted by using the Le Chatelier apparatus. The apparatus consists of a small brass cylinder split along its generatrix. Two indicators with pointed ends are attached to the cylinder on either side of the split.
- The cylinder (which is open on both ends) is placed on a glass plate filled with cement paste of normal consistency, and covered with another glass plate.
- The whole assembly is then immersed in water at 20 ± 1^{o}C for 24 hours. At the end of that period the distance between the indicator points is measured. The mould is then immersed in water again and brought to a boil. After boiling for one hour the mould is removed from the water, after cooling, the distance between the indicator points is measured again. This increase represents the expansion of the cement paste for Portland cements, expansion is limited to 10mm.

Fineness

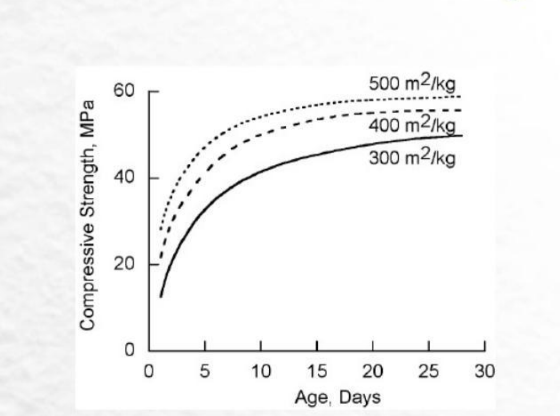
- Fineness, or particle size of Portland cement affects Hydration rate and thus the rate of strength gain. The smaller the particle size, the greater the surface area-to-volume ratio, and thus, the more area available for water-cement interaction per unit volume. The effects of greater fineness on strength are generally seen during the first seven days.
- When the cement particles are coarser, hydration starts on the surface of the particles. So the coarser particles may not be completely hydrated. This causes low strength and low durability.
- For a rapid development of strength a high fineness is necessary.

Test for Fineness

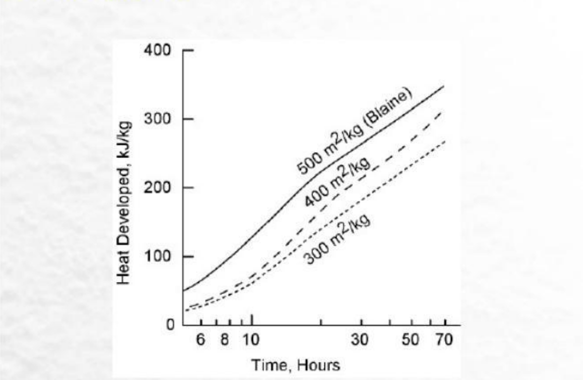
- There are various methods for determining the fineness of cement particles. The Blaine air-permeability method is the most commonly used method.
- In the Blaine air-permeability method, given volume of air is passed through a prepared sample of definite density. The number and size of the pores in a sample of given density is a function of the particles and their size distribution anddetermines the rate

of air flow through the sample. Calculations are made and the fineness is expressed in terms of cm^2/g or m^2/kg.

Influence of cement fineness on strength



Influence of fineness on heat development in cement pastes



Strength

- Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water-cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, curing conditions, size and shape of specimen, loading conditions and age.

Duration of Testing

Typically, Durations of testing are:

- 1 day (for high early strength cement)
- 3 days, 7 days, 28 days and 90 days (for monitoring strength progress)
- 28 days strength is recognised as a basis for control in most codes.
- When considering cement paste strength tests, there are two items to consider:
- Cement mortar strength is not directly related to concrete strength. Strength tests are done on cement mortars (cement + water + sand) and not on cement pastes.

Compressive Strength

- Compressive strength of Portland cement is determined by the BIS method.
- The cement paste (consisting of 1 part cement+3 parts standard sand+ water, by weight) is placed in 7cm molds. And the specimens are water cured for various ages for testing.

- The mortar specimens taken out of the molds are subjected to compression to determine the strength.
- The compressive strength test is conducted on mortar cubes.. After finding the breaking load in compression, P_{max} , Compressive Strength is calculated by the relation $\sigma_c = P_{max} / A$, where $A=50cm^2$.
- The average of the results found by testing six specimen is the compressive strength of the mortar cubes.

Types of Cement

- **Types of Portland Cement**

  The rapid increase in sophistication of design and construction techniques and the greater attention to variations in regional and job conditions have created demand for modifications of certain properties of concrete. This has resulted in the development of several "types" of Portland cement and a greater use of concrete admixtures.

  The production of a different type of Portland cement involves certain adjustments in the manufacturing process; mainly the selection of raw materials, chemical proportions, special additives, and degree of grinding.

IS 456-2000 recognises several types of cement for RCC construction.

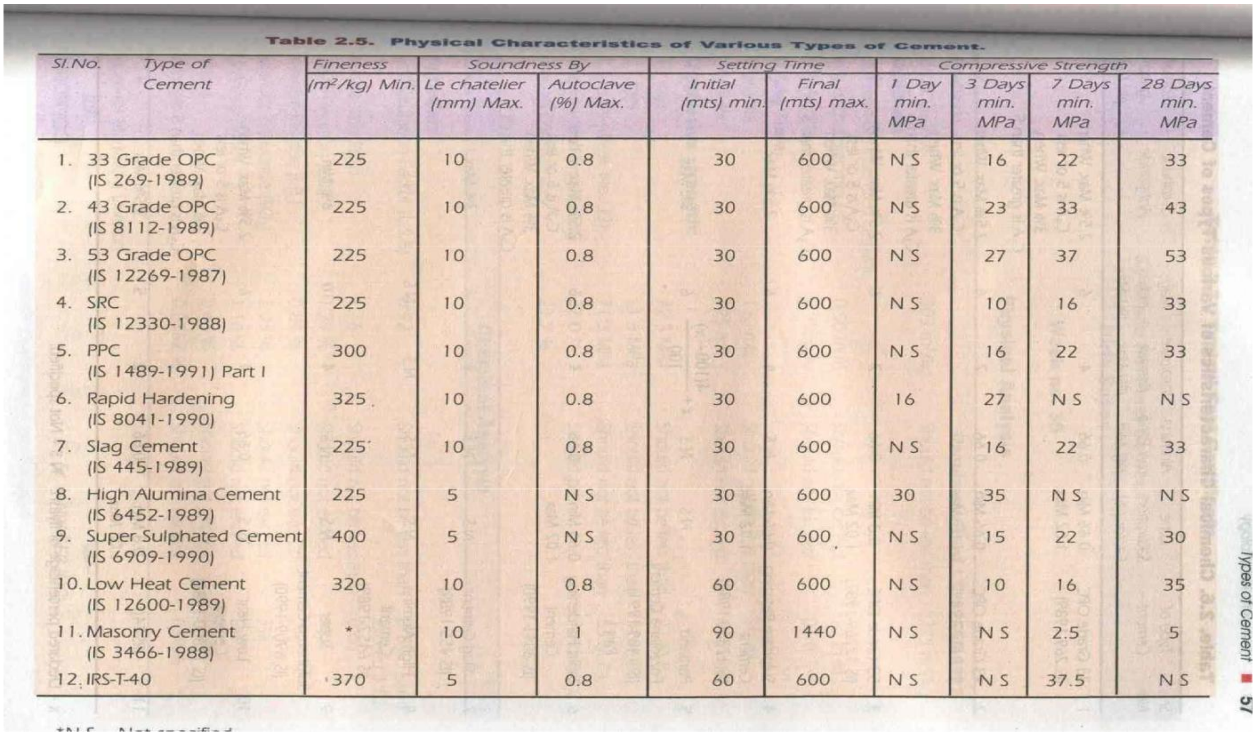


Table 2.5. Physical Characteristics of Various Types of Cement.

Sl.No.	Type of Cement	Fineness (m^2/kg) Min.	Soundness By		Setting Time		Compressive Strength			
			Le chatelier (mm) Max.	Autoclave (%) Max.	Initial (mts) min.	Final (mts) max.	1 Day min. MPa	3 Days min. MPa	7 Days min. MPa	28 Days min. MPa
1.	33 Grade OPC (IS 269-1989)	225	10	0.8	30	600	N S	16	22	33
2.	43 Grade OPC (IS 8112-1989)	225	10	0.8	30	600	N S	23	33	43
3.	53 Grade OPC (IS 12269-1987)	225	10	0.8	30	600	N S	27	37	53
4.	SRC (IS 12330-1988)	225	10	0.8	30	600	N S	10	16	33
5.	PPC (IS 1489-1991) Part I	300	10	0.8	30	600	N S	16	22	33
6.	Rapid Hardening (IS 8041-1990)	325	10	0.8	30	600	16	27	N S	N S
7.	Slag Cement (IS 445-1989)	225	10	0.8	30	600	N S	16	22	33
8.	High Alumina Cement (IS 6452-1989)	225	5	N S	30	600	30	35	N S	N S
9.	Super Sulphated Cement (IS 6909-1990)	400	5	N S	30	600	N S	15	22	30
10.	Low Heat Cement (IS 12600-1989)	320	10	0.8	60	600	N S	10	16	35
11.	Masonry Cement (IS 3466-1988)	*	10	1	90	1440	N S	N S	2.5	5
12.	IRS-T-40	370	5	0.8	60	600	N S	N S	37.5	N S

AGGREGATES USED FOR CONCRETE MAKING

Concrete The Extensively used material after water because of the following reasons

Versatile Pliable when mixed Strong & Durable Does not Rust or Rot Does Not Need a Coating Resists Fire Almost Suitable for any Environmental Exposure Conditions

Concrete is a Rocklike Material

Ingredients

- Portland Cement
- Coarse Aggregate
- Fine Aggregate
- Water

Admixtures (optional)

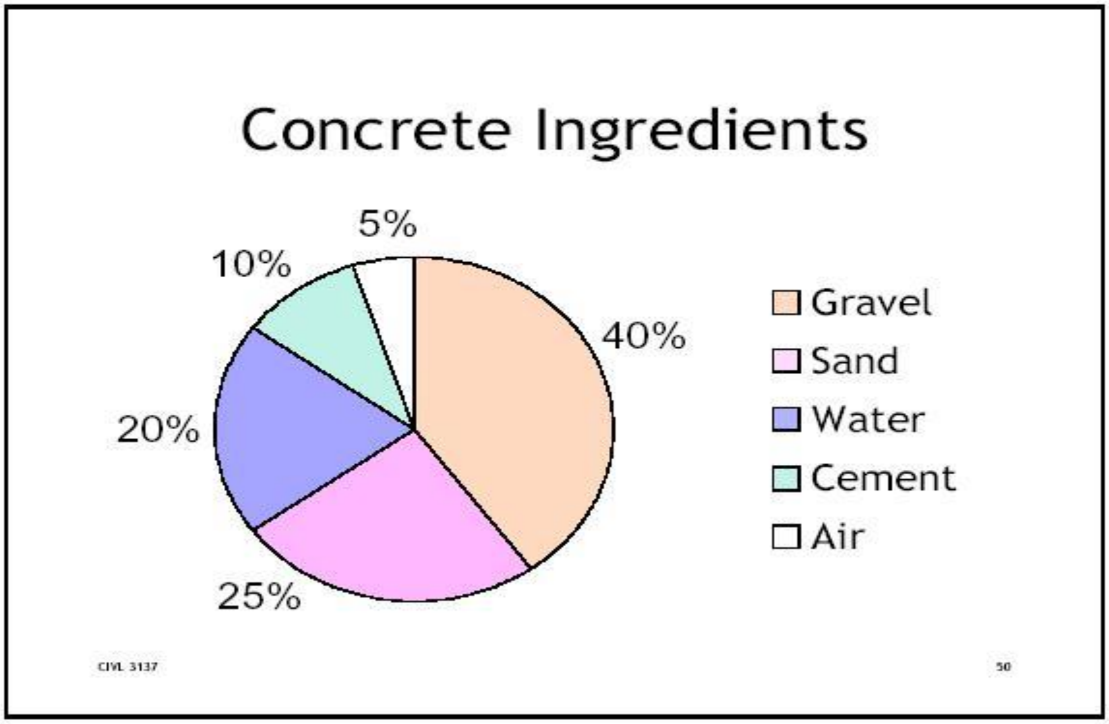
Aggregates generally occupy 65- 80% of a concrete's volume. Aggregates are inert fillers floating in the cement paste matrix for concretes of low strength. The strength of aggregates do not contribute to the strength of concrete for low strength concrete.The characteristics of aggregates impact performance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

Why use aggregate

- Reduce the cost of the concrete
  - 1/4 - 1/8 of the cement price
- Reduce thermal cracking
  - 100 kg of OPC produces about 12^{o}C temperature rise
- Reduces shrinkage
  - 10% reduction in aggregate volume can double shrinkage
- High aggregate : cement ratio (A/C) desirable
- A/C mainly influenced by cement content
- Imparts unit weight to concrete

Table Showing the diverse nature of the ingredients of the concrete

Ingredient	**Size**	**Shape**	**Specific Gravity**	**Texture**
Cement	50 microns Average Particle size	Nearly Spherical	3.00 to 3.20	Smooth
Coarse Aggregtes	80mm - 4.75mm	Round, Angular, cuboidal, rounded, flaky, elongated	2.6-2.8	Glassy, Smooth, Granular, Crystalline, Honeycombed and porous
Fine Aggregates	4.75mm-150µ	Angular or rounded	2.5-2.6	Smooth, Granular
Water	-	-	1.0	-
Mineral Admixtures	<40 microns Average Size	Nearly Spherical	Varies	Glassy, smooth



WHY USE AGGREGATE

- Reduce the cost of the concrete
  - 1/4 - 1/8 of the cement price

- Reduce thermal cracking
  - 100 kg of OPC produces about 12^{o}C temperature rise

- Reduces shrinkage
  - 10% reduction in aggregate volume can double shrinkage

- High aggregate : cement ratio (A/C) desirable

- A/C mainly influenced by cement content

- Imparts unit weight to concrete

AGGREGATE CLASSIFICATION

Aggregates are classified as below:

Based on

- **size:-** F.A & C.A.
- **Specific Gravity:-** Light Weight, Normal Weight and Heavy Weight Aggregates.
- **Availability:-** Natural Gravel and Crushed Aggregates.
- **Shape:-** Round, Cubical, Angular, Elongated and Flaky Aggregates.
- **Texture:-** Smooth, Granular, Crystalline, honeycombed and Porous.

There are two types of Aggregates used in concrete making based on their size:

- Coarse Aggregates.
- Fine Aggregates.

Fine Aggregate

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

Coarse Aggregate

- Gravel and crushed stone.
- ≥ 4.75 mm.
- typically between 9.5 and 37.5 mm.

ROCK AND MINERAL CONSTITUENTS IN AGGREGATES

1. **Minerals**

- Silica Quartz, Opal
- Silicates Feldspar, Clay
- Carbonate
- Calcite, DolomiteSulfate
- Sulfate
- Gypsum, Anhydrite
- Iron sulfide
- Pyrite, Marcasite
- Iron oxide
- Magnetite, Hematite

2. **Igneous rocks**

- Granite
- Syenite
- Diorite
- Gabbro
- Peridotite
- Pegmatite
- Volcanic glass
- Felsite
- Basalt

3. **Sedimentary rocks**

- Conglomerate
- Sandstone
- Claystone, siltstone, argillite, and shale
- Carbonates
- Chert

4. **Metamorphic rocks**

- Marble
- Metaquartzite
- Slate
- Phyllite
- Schist

NORMAL-WEIGHT AGGREGATE

Most common aggregates

- Sand
- Gravel
- Crushed stone

Produce normal-weight concrete 2200 to 2400 kg/m^3

LIGHTWEIGHT AGGREGATE

Expanded

- Shale
- Clay
- Slate
- Slag
  - Pumice Scoria Perlite
  - Vermiculite Diatomite

Produce lightweight insulating concrete— 250 to 1450 kg/m^3

HEAVYWEIGHT AGGREGATE

- Barite
- Limonite
- Magnetite
- Ilmenite
- Hematite
- Iron
- Steel punchings or shot

Produce high-density concrete up to 6400 kg/m^3 Used for Radiation Shielding

AGGREGATE CHARACTERISTICS

GRADING OF AGGREGATES

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

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

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

Gradation (grain size analysis)

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

Ensure maximum density and strength using a maximum density curve

GOOD GRADATION

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

Concrete with good gradation will have fewer voids for water to permeate (durability)

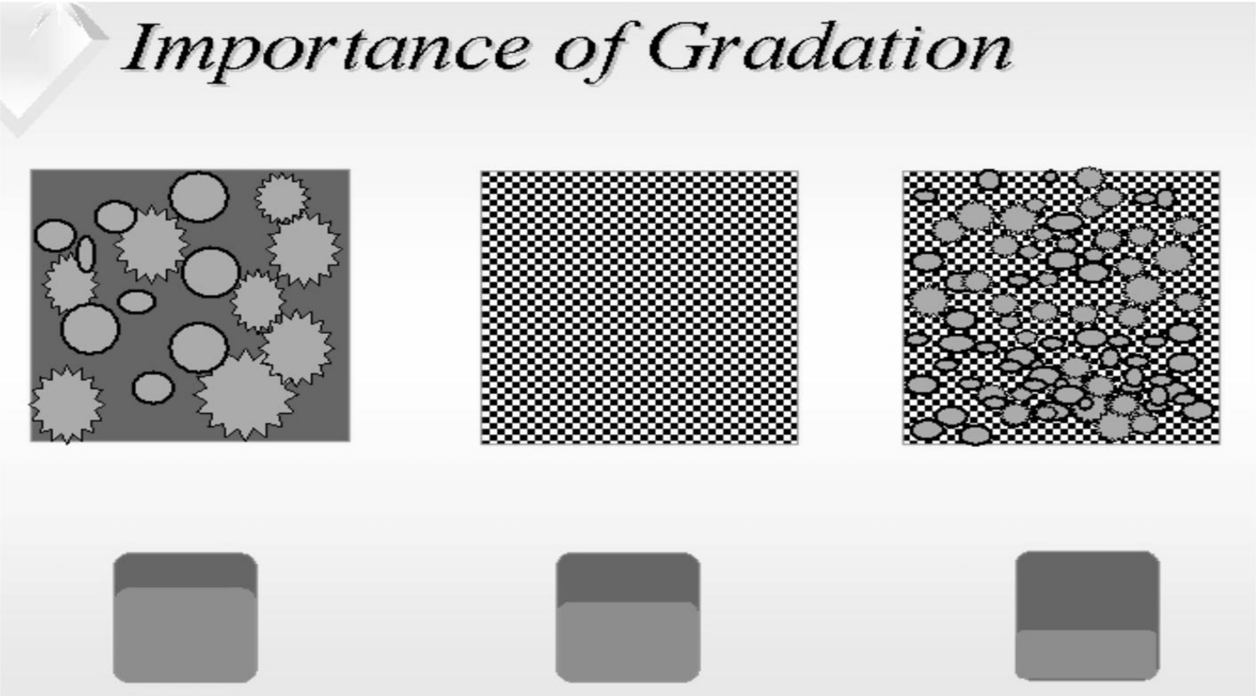
Particle size distribution affects:

Workability

Mix proportioning

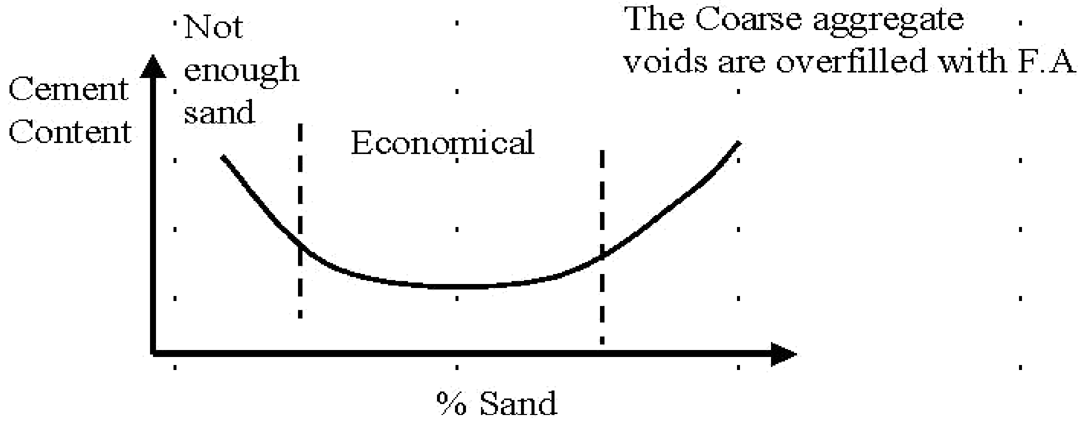
Freeze-thaw resistance (durability)

Range of Particle Sizes



Importance of Gradation

Significance of Grading



Fine-Aggregate Grading Limits IS -383

IS Sieve Designation	**Percentage passing by weight Grading**			
	Zone-I (Coarse Sand)	**Zone-II Most Suitable/Desirable**	**Zone-III**	**Zone-IV (Fine Sand)**
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600µm	15-34	35-59	60-79	80-100
300µm	5-20	8-30	12-40	15-50
150µm	0-10	0-10	0-10	0-15
Fineness Modulus	**4.0-2.71**	**3.37-2.10**	**2.78-1.71**	**2.25-1.35**

The percentage passing **600µm** sieve will decide the zone of the sand.

Zone-I	Coarse Sand
Zone-II	
Zone-III	
Zone-IV	Fine Sand

Grading Limits Can also be represented through a graph of sieve size on the x-axis and % passing on the Y-axis (Semi log sheet).

FINENESS MODULUS (FM)

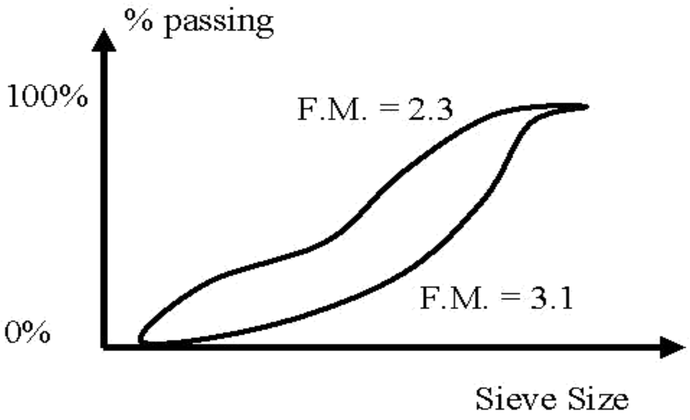
The results of aggregate sieve analysis is expressed by a number called Fineness Modulus. Obtained by adding the sum of the cumulative percentages by mass of a sample aggregate retained on each of a specified series of sieves and dividing the sum by 100. The specified sieves are: 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm , 19.0 mm , 37.5 mm , 75 mm , and 150 mm.

Results of Sieve Analysis and calculation of FM of Sand

Sieve size	Percentage of individual fraction retained, by mass	Percentage passing, by mass	Cumulative percentage retained, by mass
10 mm	0	100	0
4.75 mm	2	98	2
2.36 mm	13	85	15
1.18 mm	20	65	35
600 µm	20	45	55
300 µm	24	21	79
150 µm	18	3	97
Pan	3	0	
Total	100		283

Fineness modulus = 283 ÷ 100 = 2.83

- Index of fineness of an aggregate.
- The fineness modulus of the fine aggregate is required for mix design since sand gradation has the largest effect on workability. A fine sand (low FM) has much higher effect paste requirements for good workability.
- The FM of the coarse aggregate is not required for mix design purposes.
- It is computed by adding the cumulative percentages of aggregate retained on each of the specified series of sieves, and dividing the sum by 100 [smallest size sieve: No. 100 (150 µm)].



For concrete sand, FM range is 2.3 to 3.1

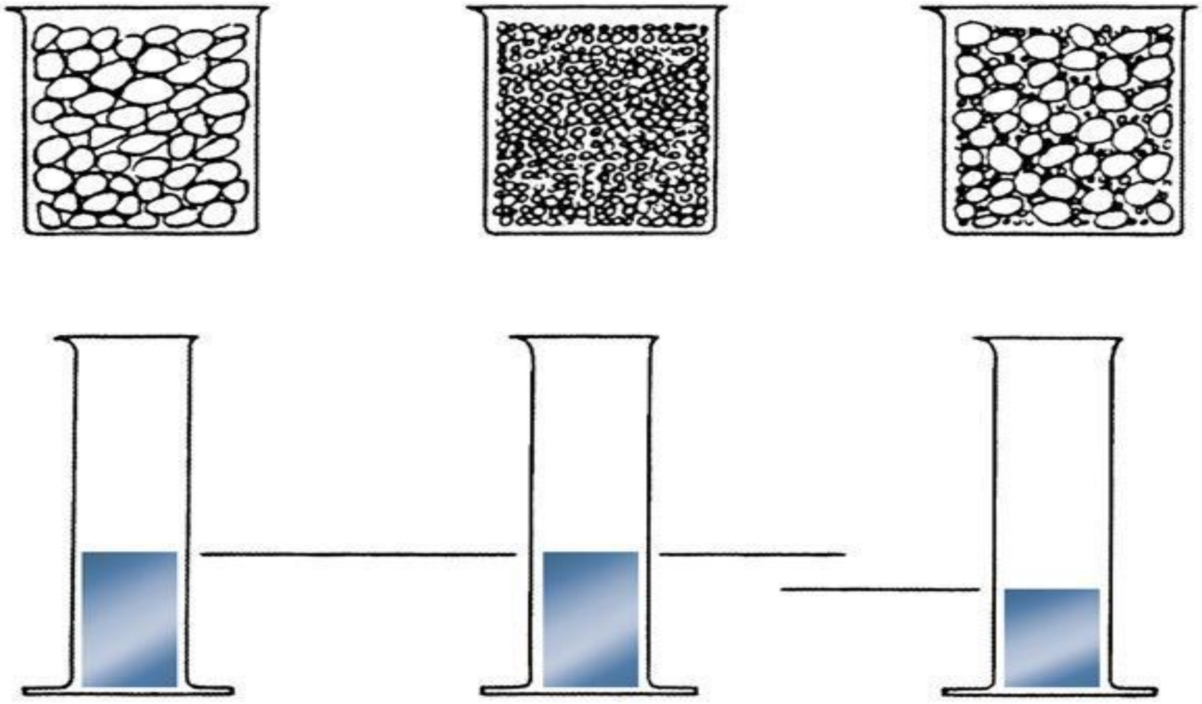
- Note: The higher the FM, the coarser the aggregate.
- It is important to note that the fineness modulus is just one number which only characterizes the average size of the aggregate, and different grading may have the same fineness modulus.

FINE AGGREGATE EFFECT ON CONCRETE

- Over sanded (More than required sand)
  - Over cohesive mix.
  - Water reducers may be less effective.
  - Air entrainment may be more effective.
- Under sanded (deficit of sand)
  - Prone to bleed and segregation.
  - May get high levels of water reduction.
  - Air entrainers may be less effective.
- Sand grading
  - gap graded or single sized may enhance bleed and segregation. Air entrainment may help fill the gaps.
- Coarse aggregate
  - Poor grading may give a harsh mix at low workabilities and segregation at high workabilities.
  - Effect on admixtures is small.

– Elongated or flaky aggregates may cause workability difficulties.

Reduction of Voids



If uniform size aggregates are there there will be more voids as can be seen from the first two figures.If properly graded aggregates are used which contain suitable percentage of all size then the voids will be minimum.

MAXIMUM SIZE VS. NOMINAL MAXIMUM SIZE OF AGGREGATE

Maximum size — is the smallest sieve that all of a particular aggregate must pass through.

Nominal maximum size — is the standard sieve opening immediately smaller than the smallest through which all of the aggregate must pass.

The nominal maximum-size sieve may retain 5% to 15%.

Nominal Maximum Size of Aggregate

Size should not exceed 1/5 of the narrowest dimension between sides of forms. 3/4 clear spacing between rebars and between rebars and the form. 1/3 depth of slabs. Higher maximum aggregate size lowers paste requirements, increases strength and reduces w/c ratio. Excessively large aggregates reduce strength due to reduced surface area for bonding. It affects the paste requirements, optimum grading depends on MSA and nominal max. size. The higher MSA, the lower the paste requirements for the mix. Aggregate size affects the following concrete properties: water demand, cement content, microcracking (strength).

Effect of aggregate size on the surface area

Size	% of particles	Volume	Surface area
1"	1	1 cubic inch	6 square inches
.5"	8	1 cubic inch	12 square inches
0.25	64	1 cubic inch	24 square inches
0.125	512	1 cubic inch	48 square inches

Larger particles, less surface area, thicker coating, easy sliding of particles. Smaller particles, more surface area, thinner coating, interlocking of particles

Maximum Aggregate Size and Water Requirement

Effect on water demand

<table>
<tr><th>Max size of Aggregate</th><th colspan="2">Slump 30 - 60 mm</th><th>Slump 60 - 180 mm</th></tr>
<tr><td>10 mm</td><td colspan="2">230 kg/m^3</td><td>250 kg/m^3</td></tr>
<tr><td>20 mm</td><td colspan="2">210 kg/m^3</td><td>225 kg/m^3</td></tr>
<tr><td>40 mm</td><td colspan="2">190 kg/m^3</td><td>205 kg/m</td></tr>
<tr><th colspan="3">Effect on cement content at constant w/c of 0.60</th><td></td></tr>
<tr><th>Max size of aggregate</th><th>Water content</th><th>Cement content</th><th>A:C ratio</th></tr>
<tr><td>10 mm</td><td>230 kg/m^3</td><td>380 kg/m^3</td><td>4.7</td></tr>
<tr><td>20 mm</td><td>210 kg/m^3</td><td>350 kg/m^3</td><td>5.3</td></tr>
<tr><td>40 mm</td><td>190 kg/m^3</td><td>315 kg/m^3</td><td>6.0</td></tr>
</table>

In general the grading and maximum size of aggregate affect the following:

- Relative aggregate proportions (i.e. FA/CA and FA/TA ratios)
- Cement and water requirements
- Workability and pumpability of fresh concrete: very coarse sands and coarse aggregate can produce harsh, unworkable mixes
- Uniformity of concrete from batch to batch
- Porosity, shrinkage, and durability of hardened concrete
- Economy in concrete production: very fine sands are often uneconomical

Moisture In Aggregates

Aggregates have two types of moisture:

- Absorbed moisture – retained in pores
- Surface moisture – water attached to surface Aggregates have four moisture states:

Oven dry: all moisture removed

Air dry: internal pores partially full & surface dry

Saturated-surface dry: pores full & surface moisture removed

Wet: pores full and surface film

SSD aggregate does not add or subtract water

Not easily obtained in the field

Moisture Absorption

We must determine how much water dry aggregate will consume into its voids

This takes water away from the mix and reduces workability & W/C ratio

We adjust mix proportions for absorption

We want to: provide aggregates water for absorption maintain workability of the mix

SHAPE AND SURFACE TEXTURE OF AGGREGATES

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

- Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for road and pavements. The total surface area of rough textured angular aggregate is more than smooth rounded aggregates for the given volume. By having greater surface area, the angular aggregates may show higher bond strength than rounded aggregates.The shape of the aggregates becomes all the more important in case of high strength and high performance concrete where very low water/cement ratio is required to be used . In such cases cubical aggregates are required for better workability.

- Surface texture is the property, the measure of which depends upon the relative degree to which particle surface are polished or dull, smooth or rough. Surface texture depends upon hardness, grain size, pore structure, structure of the rock and the degree to which the forces acting on it have smoothened the surface or roughened. Experience and laboratory experiments have shown that the adhesion between cement paste and the aggregate is influenced by several complex factors in addition to the physical and mechanical properties. As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume. A smooth particle , however, will require a thinner layer of paste to lubricate its movements with respect to another aggregate particle. It will therefore permit denser packing because of enhanced workability.

Aggregate:Shape and Surface Texture

Ideal aggregates:

– spherical or cubical

– round shape, fine porous surface

– reduced particle interaction (friction)

– results in good workability and good surface area for bonding natural sands are good examples of this

Non Ideal aggregates:

– angular

– elongated

– flaky or rough

– high particle interaction

– requires more cement paste to achieve workability results in increased cost.

Rounded: Good workability, low water demand, poor bond

Irregular: Fair workability, low water demand

Angular: Increased water demand, good bond

Elongated: May lack cohesion and require increased fines

Flaky: Aggregate stacks give workability problems

Coarse Aggregate Texture

- Glassy.
- Smooth.
- Granular.
- Crystalline
- Honeycombed and porous.

- Depends on: rock hardness, grain size, porosity, previous exposure.
- Aggregate shape and texture affect the workability of fresh concrete through their influence on cement paste requirements.
- Sufficient paste is required to coat the aggregates and to provide lubrication to decrease interactions between aggregate particles during mixing.
- Ideal particle is one close to spherical in shape (well rounded and compact) with a relatively smooth surfaces (natural sands and gravels come close to this ideal).
- More angular shapes - rough surfaces – interfere with the movement of adjacent particles (less workable) –They also have a higher surface –to –volume ratio – more paste.
- Flat or elongated aggregates should be avoided.
- Rough surface requires more lubrication for movement (crushed stone).
- Shape can influence strength by increasing surface area available for bonding with the paste. Rough surfaces –improve mechanical bond.
- Irregular aggregates (angulars) –higher internal stress concentrations –easier bond failure.

Flaky Aggregates

Aggregate characteristics like Shape, Size and Textues Influence the following

Fresh concrete

- Mix proportions
- Workability / water demand
- Cohesion / pumpability
- Air content / entrainment Hardened concrete
- Strength
- Density
- Shrinkage
- Skid & abrasion resistance
- Elastic modulus
- Durability
- Color.

For tests on aggregates please refer text books and concrete testing manuals.

UNIT 2

FRESH CONCRETE

Workability of concrete

The behavior of green or fresh concrete from mixing up to compaction depends mainly on the property called "**workability of concrete**". Workability of concrete is a term which consists of the following four partial properties of concrete namely, Mixability, Transportability, Mouldability and Compactibility.

In general terms, workability represents the amount of work which is to be done to compact the compact the concrete in a given mould. The desired workability for a particular mix depends upon the type of compaction adopted and the complicated nature of reinforcement used in reinforced concrete. A workable mix should not segregate. The partial properties of workability are discussed below:

- **Mixability:** It is the ability of the mix to produce a homogeneous green concrete from the constituent materials of the batch, under the action of the mixing forces. A less mixable concrete mix requires more time of mixing to produce a homogeneous and uniform mix.

- **Transportability:** Transportability is the capacity of the concrete mix to keep the homogeneous concrete mix to keep the homogeneous concrete mix from segregating during a limited time period of transportation of concrete, when forces due to handling operations of limited nature act. Any segregation that is caused during the remaining operations that follow.

In most of the countries, general recommendations for practice exist for transporting the concrete, which fact highlights the importance of this property.

- **Mouldability:** It is the ability of the fresh concrete mix to fill completely the forms or moulds without losing continuity or homogeneity under the available techniques of placing the concrete at a particular job/ this property is complex, since the behavior of concrete is to be considered under dynamic conditions.

- **Compactibility:** Compactibility is the ability of concrete mix to be compacted into a dense, compact concrete, with minimum voids, under the existing means of compaction at the site. The best mix from the point of view of compactibility should close the voids to an extent of 99% of the original voids present, when the concrete was placed in the moulds.

Factors affecting workability:

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming.

The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

- Water content
- Surface texture of aggregate
- Use of admixtures
- Mix proportions
- Shape of aggregates
- Grading of aggregates
- Size of aggregates

- **Water content:** Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability. At the work site, supervisors who are not well versed with the practice of making good concrete resort to adding more water for increasing workability. This practice is often resorted to because this is one of the easiest corrective measures that can be taken at the site. It should be noted that from the desirability point of view, increase of water content is the last recourse to be taken for improving the workability even in the case of uncontrolled concrete. For controlled concrete one cannot arbitrarily increase the water content. In case all other steps to improve workability fail, only as last recourse the addition of more water can be considered. More water can be added, provided a correspondingly higher quantity of cement is also added to keep the water/cement ratio constant, so that the strength remains the same.

- **Mix proportions:** Aggregate/ cement ratio is an important factor influencing workability. The higher the aggregate/cement ratio, the leaner is the concrete. In lean concrete, less quantity of paste is available for providing lubrication, per unit surface area of aggregate and hence the mobility of aggregate is restrained. On the other hand, in case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

- **Size of aggregate:** The bigger the size of the aggregate, the less the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste, bigger size of aggregates will give higher workability. The above of course will be true within certain limits.

- **Shape of aggregates:** The shape of the aggregate influences the workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability to rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate. Not only that, being round in shape, the frictional resistance is also greatly reduced. This explains the reason why river sand and gravel provide greater workability to concrete than crushed sand and aggregate.

The importance of shape of the aggregate will be of great significance in the case of present day high strength and high performance concrete when we use very low w/c in the order of about 0.25. We have already talked about that in years to come natural sand will be exhausted or costly. One has to go for manufactured sand. Shape of crushed sand as available today is unsuitable but the modern crushers are designed to yield well shaped and well graded aggregates.

- **Surface texture:** The influence of surface texture on workability is again due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume. From the earlier discussions it can be inferred that rough textured aggregate will show poor workability and smooth or glassy textured aggregate will give better workability. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.

- **Grading of aggregates:** This is one of the factors which will have maximum influence on workability. A well graded aggregate is the one which has least amount of voids in a given volume. Other factors being constant, when the total voids are less, excess paste is available to give better lubricating effect. With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles. Aggregate particles will slide past each other with the least amount of compacting efforts. The better the grading, the less is the void content and higher the workability. The above is true for the given amount of paste volume.

- **Use of admixtures:** Of all the factors mentioned above, the most important factor which affects the workability is the use of admixtures. It is to be noted that initial slump of concrete mix or what is called slump of reference mix should be about 2 – 3 cm to enhance the slump many fold at a minimum doze. Without initial slump of 2-3 cm, the workability can be increased to higher level but it requires higher dosage – hence uneconomical.

MEASUREMENT OF WORKABILITY: Slump Test

Objective: To determine the consistency of concrete mix of given proportions.

Scope and Significance

Unsupported fresh concrete flows to the sides and a sinking in height takes place. This vertical settlement is known as slump. In this test fresh concrete is filled into a mould of specified shape and dimensions, and the settlement or slump is measured when supporting mould is removed. Slump increases as *water-content* is increased. For different works different slump values have been recommended.

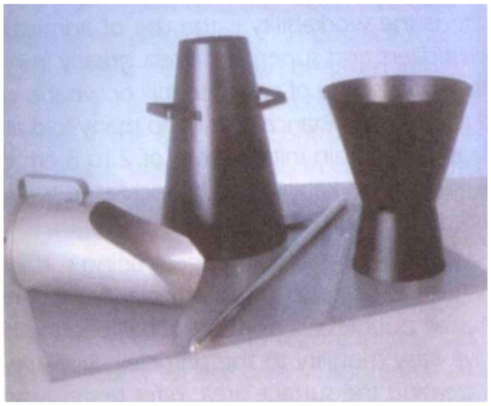
The slump is a measure indicating the *consistency or workability* of cement concrete. It gives an idea of water content needed for concrete to be used for different works. A concrete is said to be workable if it can be easily mixed, placed, compacted and finished. A workable concrete should not shown any segregation or bleeding. Segregation is said to occur when coarse aggregate tries to separate out from the finer material and a concentration of coarse aggregate at one place occurs. This results in large voids, less durability and strength. Bleeding of concrete is said to occur when excess water comes up at the surface of concrete. This causes small pores through the mass of concrete and is undesirable.

By this test we can determine the water content to give specified slump value. In this test water content is varied and in each case slump value is measured till we arrive at water content giving the required slump value.

This test is not a true guide to workability.

Apparatus

Iron pan to mix concrete, slump cone, spatula, trowels, tamping rod and graduated cylinder.



Slump test apparatus

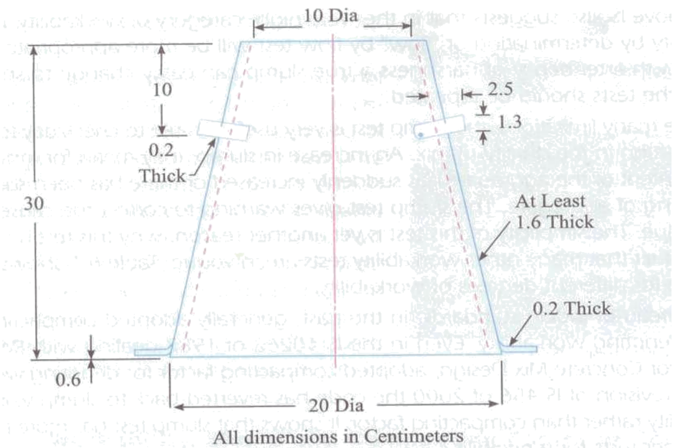
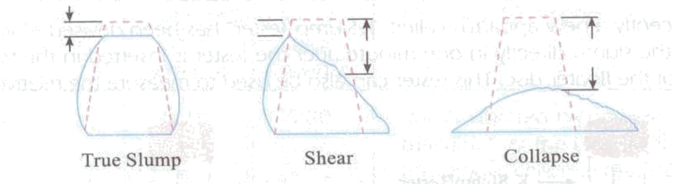


Fig. 6.1. Typical mould for Slump test.



Slump: true, shear and collapse

Procedure

Four mixes are to be prepared with water-cement ratio (by mass) of 0.50, 0.60, 0.70 and 0.80, respectively, and for each mix take 10 kg of coarse aggregates, 5kg of sand and 2.5kg of cement with each mix proceed as follows:

- Mix the dry constituents thoroughly to get a uniform colour and then add water

- Place the mixed concrete in the cleaned slump cone mould in 4 layers, each approximately ¼ of the height of the mould. Tamp each layer 25 times with tamping rod distributing the strokes in a uniform manner over the cross-section of the mould. For the second and subsequent layers the tamping rod should penetrate in to the underlying layer.

- Strike off the top with a trowel or tamping rod so that the mould is exactly filled.

- Remove the cone immediately, raising it slowly and carefully in the vertical direction.

- As soon as the concrete settlement comes to a stop, measure the subsidence of concrete in mm which will give the slump.

Note: Slump test is adopted in the laboratory or during the progress of work in the field for determining consistency of concrete where nominal maximum size of aggregate does not exceed 40mm.

Any slump specimen which collapses or shears off laterally gives incorrect results and if this occurs the test is repeated, only the true slump should be measured.

Observations & Calculations

Water Cement Ratio	Slump in mm

Standard Values

SL.NO.	NAME OF WORKS	SLUMP, MM	WATER-CEMENT RATIO
1	Concrete for roads and mass concrete	25 to 50	0.70
2	Concrete for R.C.C. beams and slabs	50 to 100	0.55
3	Columns and retaining walls	75 to 125	0.45
4	Mass concrete in foundation	25 to 50	0.70

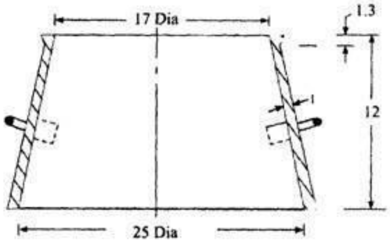
.

Flow tests

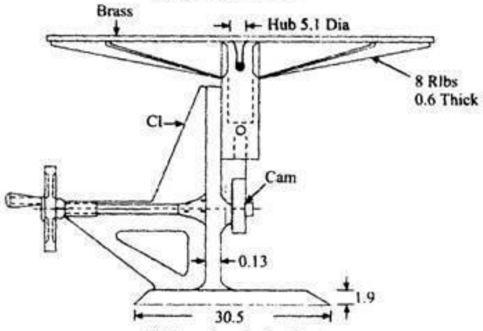
Flow Test

This is a laboratory test, which gives an indication of the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation. In this test, a standard mass of concrete is subjected to jolting. The spread or the flow of the concrete is measured and this flow is related to workability.

Figure shows the details of apparatus used. It can be seen that the apparatus consists of flow table, about 76 cm. in diameter over which concentric circles are marked. A mould made from smooth metal casting in the form of a frustum of a cone is used with the following internal dimensions. The base is 25 cm. in diameter upper surface 17 cm. in diameter and height of the cone is 12 cm.



Mould For Flow Test



All dimensions in Centimetres

Flow Table Apparatus

The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould

Spread diameter in cm - 25 x 100

Flow percent : 25

The value could range anything from 0 to 150 per cent.

A close look at the pattern of spread of concrete can also give a good indication of the characteristics of concrete such as tendency for segregation.

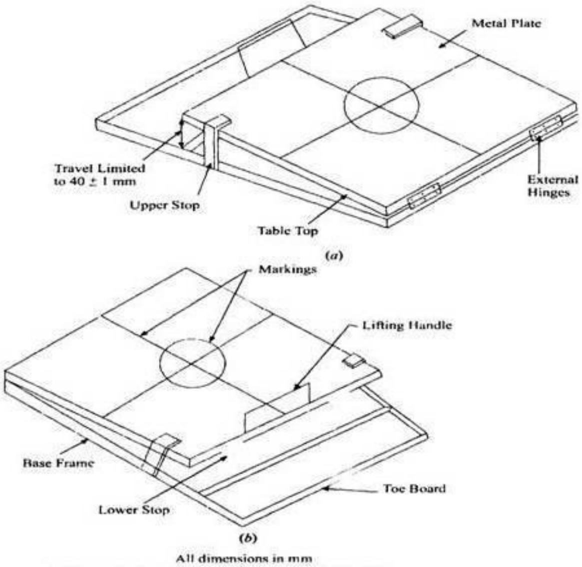
Flow Table Apparatus

The BIS has recently introduced another new equipment for measuring flow value of concrete. This new flow table test is in the line with BS 188 I part 105 of 1984 and DIN 1048 part I. The apparatus and method of testing is described below.

The flow table apparatus is to be constructed in accordance with Figure (a) and (b) Flow table top is constructed from a flat metal of minimum thickness 1.5 mm. The top is in plan 700 mm x 700 mm. The centre of the table is marked with a cross, the lines which run paralled to and out to the edges of the plate, and with a central circle 200 mm in diameter. The front of the flow table top is provided with a lifting handle as shown in Fig (b) The total mass of the flow table top is about 16 ± 1 kg.

The flow table top is hinged to a base frame using externally mounted hinges in such a way that no aggregate can become trapped easily between the hinges or hinged surfaces. The front of the base frame shall extend a minimum 120 mm beyond the flow table top in order to provide a top board. An upper stop similar to that shown in Fig (a) is provided on each side of the table so that the lower front edge of the table can only be lifted 40 ± I mm.

The lower front edge of the flow table top is provided with two hard rigid stops which transfer the load to the base frame. The base frame is so constructed that this load is then transferred directly to the surface on which the flow table is placed so that there is minimal tendency for the flow table top to bounce when allowed to fall.



Flow table apparatus (as per IS 9103 of 1999)

Compaction Factor Test

Objective: To determine the workability of concrete mix of given proportions by the compaction factor test.

Scope and Significance

Compaction factor test is adopted to determine the workability of concrete, where nominal size of aggregate does not exceed 40mm, and is primarily used in laboratory. It is based upon the definition, that workability is that property of the concrete which determines the amount of work required to produce *full compaction*. The test consists essentially of applying a standard amount of work to standard quantity of concrete and measuring the resulting compaction. To find the workability of freshly prepared concrete, the test is carried out as per specification of IS: 1199-1959. Workability gives an idea of the capability of being worked, i.e., idea to control the quantity of water in cement concrete mix to get uniform strength.

It is more sensitive and precise than slump test and is particularly useful for concrete mixes of low workability. The compaction factor (C.F.) test is able to indicate small variations in workability over a wide range.

Apparatus

Compaction factor apparatus, trowels, Graduated cylinder, balance, tamping rod and iron buckets

Procedure

- Keep the compaction factor apparatus on a level ground and apply grease on the inner surface of the hoppers and cylinder.
- Fasten the flap doors.
- Weigh the empty cylinder accurately and note down the mass as W_1 kg.
- Fix the cylinder on the base with fly nuts and bolts in such a way that the central points of hoppers and cylinder lie on one vertical line. Cover the cylinder with a plate.
- Four mixes are to be prepared with water-cement ratio (by mass) 0.50, 0.60, 0.70, and 0.80, respectively. For each mix take 9 kg of aggregate, 4.5 kg sand 2.25 kg of cement. With each mix proceed as follows:
- Mix sand and cement day, until a mixture of uniform colour is obtained. Now mix the coarse aggregate and cement-sand mixture until coarse aggregate is uniformly distributed throughout the batch.

- Add the required amount of water to the above mixture and mix it thoroughly until concrete appears to be homogeneous.
- Fill the freshly mixed concrete in upper hopper gently and crefully with hand·scoop without compacting.
- After two minutes, release the trap door so that the concrete may fall into the lower hopper brining the concrete into standard compaction.
- Immediately after the concrete has come to rest, open the trap door of lower hopper and allow the concrete to fall into the cylinder bringing the concrete into standard compaction.
- Remove the excess concrete above the top of the cylinder by a pair of trowels, one in each hand will blades horizontal slide them from the opposite edges of the mould inward to the centre with a sawing motion.
- Clean the cylinder from all sides properly. Find the mass of partially compacted concrete thus filled in the cylinder, say W_2 kg.
- Refill the cylinder with the same sample of concrete in approximately 50mm layers, vibrating each layer heavily so as to expel all the air and obtain full compaction of the concrete.
- Struck off level the concrete and weigh and cylinder filled with fully compacted concrete. Let the mass be W_3 kg.

Workability By Vee-Bee Consistometer

Objective

To determine the workability of freshly mixed concrete by the use of Vee - Bee consistometer.

Scope and Significance

The workability of fresh concrete is a composite property, which includes the diverse requirements of stability, mobility, compactability, placeability and finishability. There are different methods for measuring the workability. Each of them measures only a particular aspect of it and there is really no unique test, which measures workability of concrete in its totality. This test gives an indication of the mobility and to some extent of the compactibility of freshly mixed concrete.

The test measures the relative effort required to change a mass of concrete from one definite shape to another (i.e., from conical to cylindrical) by means of vibration. The amount of effort called remoulding effort is taken as the time in seconds required to complete the change. The results of this test are of value in studying the mobility of the masses of concrete made with varying amounts of water, cement and with various types of gradings of aggregate.

The time required for complete remoulding in seconds is considered as a measure of workability and is expressed as the number of Vee-Bee seconds. The method is suitable for dry concrete. For concrete of slump in excess of 50mm, the remoulding is so quick that the time cannot measured.

Apparatus

Cylindrical container, Vee-Bee apparatus (consisting of vibrating table, slump cone) standard iron rod, weighing balance and trowels.

Procedure

1 Place the slump cone in the cylindrical container of the consistometer. Fill the cone in four layers, each approximately one quarter of the height of the cone. Tamp each layer with twenty-five strokes of the rounded end of the tamping rod. The strokes are distributed in a uniform manner over the cross-section of the cone and for the second and subsequent layers the tamping bar should penetrate into the underlying layer. After the top layer has been rodded, struck off level the concrete with a trowel so that the cone is exactly filled.

2 Move the glass disc attached to the swivel arm and place it just on the top of the slump cone in the cylindrical container. Adjust the glass disc so as to touch the top of the concrete cone, and note the initial reading on the graduated rod.

3 Remove the cone from the concrete immediately by raising it slowly and carefully in the vertical direction. Lower the transparent disc on the top of concrete. Note down the reading on the graduated rod.

4 Determine the slump by taking the difference between the readings on the graduated rod recorded in the steps (2) and (3) above.

5 Switch on the electrical vibrations and start the stopwatch. Allow the concrete to remould by spreading out in the cylindrical container. The vibrations are continued until the concrete is completely remoulded, i.e, the surfaces becomes horizontal and the whole concrete surface adheres uniformly to the transparent disc.

6 Record the time required for complete remoulding seconds which measures the workability expressed as number of Vee-Bee seconds.

Standard Values

Workability description	Vee-Bee Time, Seconds
Extremely dry	32-18
Very stiff	18-10
Stiff	10-5
Stiff plastic	5-3
Plastic	3-0
Flowing	----

Segregation:

Segregation is defined as the separation of the constituents of a homogeneous mixture of concrete. It is caused by the differences in sizes and weights of the constituent particles. Segregation can be controlled by properly choosing the grading of aggregates and by carefully handling wet mixes. In relatively lean and dry mixes, segregation can be caused by the coarser particles separating out because they travel farther along the slope or settle to a greater extent than finer particles. The second form of segregation occurs in very wet mixes in which the cement – water paste separates from the mix.

Segregation can also be caused by poor handling, such as dropping wet concrete from a considerable height, passing long chutes along a slope, and discharging concrete carelessly against some firm obstruction. It may also be caused by the vibration of concrete. Though vibration provides a useful means of compaction, over – vibration leads to segregation. This can happen when vibration is allowed to continue for too long. It leads to the separation of coarse aggregates from the mix. These aggregates settle at the bottom, and the cement – water paste moves to the top in the form of laitance (scum). This laitance is different from bleed water.

Segregation is difficult to measure. However, its occurrence is easily detected. The flow test can indicate the susceptibility of a mix that is likely to segregate. In dry mixes, heavier particles move away and occupy the edges of the flow table. In wet mixes, the cement paste trends to move away from the middle and the centre of the flow table is left only with coarser particles.

Bleeding:

Bleeding is also known as 'water gain'. It is the accumulation of water at the surface, which accompanies the sedimentation of freshly mixed concrete. This happens due to the inability of the solid constituents of the mix to hold all the mixing water and they settle downwards due to gravity and the water moves upwards.

Bleeding is expressed quantitatively as the total settlement per unit height of concrete or as the percentage of mixing water. In extreme cases, this can be nearly 20%. Bleeding is a function of (a) air velocity, (b) temperature, and (c) humidity. If the rate of bleeding is roughly equal to the rate of evaporation, then bleeding will not cause any problem. If the rate of bleeding is less than the rate of evaporation, then the surface becomes dry, because of which cracks appear on it. The restraint at the bottom encourages such cracks. The evaporation of water from the surface of concrete depends on (a) the relative humidity of the surrounding air, (b) the ambient temperature, and (c) the velocity of wind.

Process of Manufacture of Concrete:

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. It is interesting to note that the ingredients of good concrete and bad concrete are the same. If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality. With the same material if intense care is taken to exercise control at every stage, it will result in good concrete. Therefore, it is necessary for us to know what are the good rules to be followed in each stage of manufacture of concrete for producing good quality concrete. The various stages of manufacture of concrete are:

- Batching
- Mixing
- Transporting
- Placing
- Compacting
- Curing
- Finishing.

Batching:

The measurement of materials for making concrete is known as batching. There are two methods of batching:

a. Volume batching b. Weigh batching

Volume batching:

Volume batching is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume. Volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand. The amount of solid granular material in a cubic metre is an indefinite quantity. Because of this, for quality concrete material has to be measured by weight only. However, for unimportant concrete or for any small job, concrete may be batched by volume.

Cement is always measured by weight. It is never measured in volume. Generally, for each batch mix, one bag of cement is used. The volume of one bag of cement is taken as thirty five (35) litres. Gauge boxes are used for measuring the fine and coarse aggregates.

Water is measured either in kg or litres as may be convenient. The quantity of water required is a product of water/cement ratio and the weight of cement; for example, if the water/cement ratio of 0.5 is specified, the quantity of mixing water required per bag of cement is 0.5 x 50.0025 kg or 25 litres. The quantity is, of coarse, inclusive of any surface moisture sent in the aggregate.

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- **Weigh Batching:**

Strictly speaking, weigh batching is the correct method of measuring the materials. For important concrete, invariably, weigh batching system should be adopted. Use of weight system in batching, facilitates accuracy, flexibility and simplicity. Different types of weigh batchers are available, the particular type to be used, depends upon the nature of job. Large weigh batching plants have automatic weighing equipment. The use of this automatic equipment for batching is one of sophistication and requires qualified and experienced engineers. In this, further complication will come to adjust water content to cater for the moisture content in the aggregate. In smaller works, the weighing arrangement consists of two weighing buckets, each connected through a system of levers to spring-loaded dials which indicate the load. The weighing buckets are mounted on a central spindle about which they rotate. Thus one can be loaded while the other is being discharged into the mixer skip. A simple spring balance or the common platform weighing machines also can be used for small jobs.

On large work sites, the weigh bucket type of weighing equipments is used. This fed from a large overhead storage hopper and it discharges by gravity, straight into the mixer. The weighing is done through a lever-arm system and two interlinked beams and jockey weights. The required quantity of say, coarse aggregate is weighed, having only the lower beam in after balancing, by turning the smaller lever, to the left of the beam, the two beams are interlinked and the fine aggregate is added until they both balance. The final balance is indicated by the pointer on the scale to the right of the beams. Discharge is through the swivel gate at the bottom.

Automatic batching plants are available in small or large capacity. In this, the operator press one or two buttons to put into motion the weighing of all the different materials, the flow of each being cut off when the correct weight is reached. In their most advanced forms, automatic plants are electrically operated on a punched card system. This type of plant is particularly only suitable for the production of ready-mixed concrete in which very frequent changes in mix proportion have to be made to meet the varying requirements of different customers.

In some of the recent automatic weigh batching equipments, recorders are fitted which record graphically the weight of each material, delivered to each batch. They are meant to record, and check the actual and designed proportions.

Aggregate weighing machines require regular attention if they are to maintain their accuracy. Check calibrations should always be made by adding weights in the hopper equal to the full weight of the aggregate in the batch. The error found is adjusted from time to time.

In small jobs, cement is often not weighed; it is added in bags assuming the weight of the bag as 50 kg. In reality, though the cement bag is made of 50 kg. At the factory, due to transportation, handling at a number of places, it loses some cement, particularly when jute bags are used. In fact, the weight of a cement bag at the site is considerably less. Sometimes, the loss of weight becomes more than 5 kg. This is one of the sources of error in volume batching and also in weigh batching, when the cement is not actually weighed. But in important major concreting jobs, cement is also actually weighed and the exact proportion as designed is maintained.

Weigh batcher

Measurement of Water:

When weigh batching is adopted, the measurement of water must be done accurately. Addition of water by graduated bucket in terms of litres will not be accurate enough for the reason of spillage of water etc. It is usual to have the water measured in a horizontal tank or vertical tank fitted to the mixer. These tanks are filled up after every batch. The filling is so designed to have a control to admit any desired quantity of water. Sometimes, water- meters are fitted in the main water supply to the mixer from which the exact quantity of water can be let into the mixer.

In modern batching plants sophisticated automatic microprocessor controlled weigh batching arrangements, not only accurately measures the constituent materials, but also the moisture content of aggregates.

Moisture content is automatically measured by sensor probes and corrective action is taken to deduct that much quantity of water contained in sand from the total quantity of water. A number of such sophisticated batching plants are working in our country, for the last 4-5 years.

Mixing:

Thorough mixing of the materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency. There are two methods adopted for mixing concrete.

A Hand Mixing. B. Machine mixing

Hand Mixing: Hand mixing is practised for small scale unimportant concrete works. As the mixing cannot be thorough and efficient, it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method.

Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement. Spread out the measured quantity of coarse aggregate and fine aggregate in alternate layers. Pour the cement on the top of it, and mix them dry by shovel, turning the mixture over and over again until uniformity of colour is achieved. This uniform mixture is spread out in thickness of about 20 cm. Water is taken in a water-can fitted with a rose-head and sprinkled over the mixture and simultaneously turned over. This operation is continued till such time a good uniform, homogeneous concrete is obtained. It is of particular importance to see that the water is not poured but it is only sprinkled. Water in small quantity should be added towards the end of the mixing to get the just required consistency. At that stage, even a small quantity of water makes difference.

Machine Mixing: Mixing of concrete is almost invariably carried out by machine, for reinforced concrete work and for medium or large scale mass concrete work. Machine mixing is not only efficient, but also economical, when the quantity *of* concrete to be produced is large.

Many types of mixers are available for mixing concrete. They can be classified as batch-mixers and continuous mixers. Batch mixers produce concrete, batch by batch with time interval, whereas continuous mixers produce concrete continuously without stoppage till such time the plant is working. In this, materials are fed continuously by screw feeders and the materials are continuously mixed and continuously discharged. These types of mixers are used in large works such as dams. In normal concrete work, it is the batch mixers that are used. Batch mixer may be of pan type or drum type. The drum type may be further classified as tilting, non-tilting, reversing or forced action type.

Very little is known about the relative mixing efficiencies of the various types of mixers, but some evidences are there to suggest that pan mixers with a revolving star of blades are more efficient. They are specially suitable for stiff and lean mixes, which present difficulties with most other types of mixers, mainly due to sticking of mortar in the drum. The shape of the drum, the angle and size of blades, the angle at which the drum is held, affect the efficiency of mixer. It is seen that tilting drum to some extent is more efficient than non-tilting drum. In non-tilting drum for discharging concrete, *a* chute is introduced into the drum by operating a lever.

The concrete which is being mixed in the drum, falls into the inclined chute and gets discharged out. It is seen that a little more of segregation takes place, when a non-tilting mixer is used. It is observed in practice that, generally, in any type of mixer, even after thorough mixing in the drum, while it is discharged, more of coarse aggregate comes out first and at the end matrix gets discharged. It is necessary that a little bit of re-mixing is essential, after discharged from mixer, on the platform to off-set the effect of segregation caused while concrete is discharged from the mixer.

As per I.S. 1791-1985, concrete mixers are designated by a number representing its nominal mixed batch capacity in litres. The following are the standardized sizes of three types:

- Tilting: 85 T, 100 T, 140 T, 200 T
- Non-Tilting: 200 NT, 280 NT, 375 NT, 500 NT, 1000 NT
- Reversing: 200 R, 280 R, 375 R, 500 R and 1000 R

The letters T, NT, R denote tilting, non-tilting and reversing respectively. Normally, a batch of concrete is made with ingredients corresponding to 50 kg cement. If one has a choice for indenting a mixer, one should ask for such a capacity mixer that should hold all the materials for one bag of cement. This of course, depends on the proportion of the mix. For example, for 1 : 2 : 4 mix, the ideal mixer is of 200 litres capacity, whereas if the ratio is 1 : 3 : 6, the requirement will be of 280 litres capacity to facilitate one bag mix. Mixer of 200 litres capacity is insufficient for 1: 3: 6 mix and also mixer of 280 litres is too big, hence uneconomical for 1: 2: 4 concrete.

To get better efficiency, the sequence of charging the loading skip is as under:

Firstly, about half the quantity of coarse aggregate is placed in the skip over which about half the quantity of fine aggregate is poured. On that, the full quantity of cement *i . e* , one bag is poured over which the remaining portion of coarse aggregate and fine aggregate is deposited in sequence. This prevents spilling of cement, while discharging into the drum and also this prevents the blowing away of cement in windy weather.

Before the loaded skip is discharged to the drum, about 25 per cent of the total quantity of water required for mixing is introduced into the mixer drum to wet the drum and to prevent any cement sticking to the blades or at the bottom of the drum.

Immediately, on discharging the dry material into the drum, the remaining 75 per cent of water is added to the drum. If the mixer has got an arrangement for independent feeding of water, it is desirable that the remaining 75 per cent of water is admitted simultaneously along with the other materials. The time is counted from the moment all the materials, particularly; the complete quantity of water is fed into the drum.

Reversible drum concrete mixer / mini batching plant

When plasticizer or super plasticizer is used, the usual procedure could be adopted except that about one litre of water is held back. Calculated quantity of plasticizer or super plasticizer is mixed with that one litre of water and the same is added to the mixer drum after about one minute of mixing. It is desirable that concrete is mixed little longer (say 1/2 minute more) so that the plasticizing effect is fully achieved by proper dispersion.

When plasticizers are used, generally one has to do number of trials in the laboratory for arriving at proper dosage and required slump. Small scale laboratory mixers are inefficient and do not mix the ingredients properly. Plasticizers in small quantity do not get properly dispersed with cement particles. To improve the situations, the following sequence may be adopted.

Mixing Time:

Concrete mixers are generally designed to run at a speed of 15 to 20 revolutions per minute. For proper mixing, it is seen that about 25 to 30 revolutions are required in a well designed mixer. In site, the normal tendency is to speed up the outturn of concrete by reducing the mixing time. This results in poor quality of concrete. On the other hand, if the concrete is mixed for a comparatively longer time, it is uneconomical from the point of view of rate of production of concrete and fuel consumption.

Therefore, it is of importance to mix the concrete for such a duration which will accrue optimum benefit. It is seen from the experiments that the quality of concrete in terms of compressive strength will increase with the increase in the time of mixing, but for mixing time beyond two minutes, the improvement in compressive strength is not *very* significant. Concrete mixer is not a simple apparatus. Lot of considerations have gone as input in the design of the mixer drum. The shape of drum, the number of blades, inclination of blades with respect to drum surface, the length of blades, the depth of blades, the space between the drum and the blades, the space between metal strips of blades and speed of rotation etc., are important to give uniform mixing quality and optimum time of mixing.

Generally mixing time is related to the capacity of mixer. The mixing time varies between 1 ° to 2° minutes. Bigger the capacity of the drum more is the mixing time. However, modern high speed pan mixer used in RMC, mixes the concrete in about 15 to 30 secs. One cubic meter capacity high speed Pan Mixer takes only about 2 minutes for batching and mixing. The batching plant takes about 12 minutes to load *a* transit mixer of 6 m^3 capacity.

Sometimes, at a site of work concrete may not be discharged from the drum and concrete may be kept rotating in the drum for long time, as for instance when some quarrel or dispute takes place with the workers, or when unanticipated repair or modification is required to be done on the formwork and reinforcement. Long-time mixing of concrete will generally result in increase of compressive strength of concrete within limits.

Due to mixing over long periods, the effective water/cement ratio gets reduced, owing to the absorption of water by aggregate and evaporation. It is also possible that the increase in strength may be due to the improvement in workability on account of excess of fines, resulting from the abrasion and attrition of coarse aggregate in the mix, and from the coarse aggregates themselves becoming rounded.

The above may not be true in all conditions and in all cases. Sometimes, the evaporation of water and formation of excess fines may reduce the workability and hence bring about reduction in strength. The excess of fine may also cause greater shrinkage.

Modern ready mixed concrete plant.

In case of long haul involved in delivering ready-mixed concrete to the site of work, concrete is mixed intermittently to reduce the bad effect of continuous mixing. A pertinent point to note in this connection is that when the concrete is mixed or agitated from time to time with a short interval, the normal rule of initial setting time is not becoming applicable. The concrete that is kept in agitation, does not exactly follow the setting time rule as applicable to concrete kept in an unagitated and quiescent condition.

Transporting of concrete:

Concrete can be transported by variety of methods and equipments. The precaution to be taken while transporting concrete is that the homogeneity obtained at the time of mixing should be maintained while being transported to the final place of deposition. The methods adopted for transportation of concrete are:

- Mortar Pan
- Crane, Bucket and Rope way
- Belt Conveyors
- Skip and Hoist
- Pump and Pipe line
- Wheel Barrow, Hand Cart
- Truck mixer and Dumpers
- Chute
- Tansit Mixer

Mortar Pan:

Use of mortar pan for transportation of concrete is one of the common methods adopted in this country. It is labour intensive. In this case, concrete is carried in small quantities. Mortar pan method of conveyance of concrete can be adopted for concreting at the ground level, below or above the ground level without much difficulties.

Wheel barrow:

Wheel barrows are normally used for transporting concrete to be placed at ground level. This method is employed for hauling concrete for comparatively longer distance as in the case of concrete road construction. If concrete is conveyed by wheel barrow over a long distance, on rough ground, it is likely that the concrete gets segregated due to vibration. The coarse aggregates settle down to the bottom and matrix moves to the top surface. To avoid this situation, sometimes, wheel barrows are provided with pneumatic wheel to reduce vibration. A wooden plank road is also provided to reduce vibration and hence segregation.

Crane, Bucket and Rope Way:

A crane and bucket is one of the right equipment for transporting concrete above ground level. Crane can handle concrete in high rise construction projects and are becoming familiar sites in big cities. Cranes are fast and versatile to move concrete horizontally as well as vertically along the boom and allows the placement of concrete at the exact point. Cranes carry skips or buckets containing concrete. Skips have discharge door at the bottom, whereas buckets are tilted for emptying. For a medium scale job the bucket capacity may be 0.5 m^3.

Rope way and bucket of various sizes are used for transporting concrete to a place, where simple method of transporting concrete is found not feasible. For the concrete works in a valley or the construction work of a pier in the river or for dam construction, this method of transporting by rope way and bucket is adopted. The mixing of concrete is done on the bank or abutment at a convenient place and the bucket is brought by a pulley or some other arrangement. It is filled up and then taken away to any point that is required. The vertical movement of the bucket is also controlled by another set of pullies. Sometimes, cable and car arrangement is also made for controlling the movement of the bucket. This is one of the methods generally adopted for concreting dam work or bridge work. Since the size of the bucket is considerably large and concrete is not exposed to sun and wind there would not be much change in the state of concrete or workability.

For discharging the concrete, the bucket may be tilted or sometimes, the concrete is made to discharge with the help of a hinged bottom. Discharge of concrete may also be through a gate system operated by compressed air. The operation of controlling the gate may be done manually or mechanically. It should be practised that concrete is discharged from the smallest height possible and should not be made to freely fall from great height.

Truck Mixer and Dumpers:

For large concrete works particularly for concrete to be placed at ground level, trucks and dumpers or ordinary open steel-body tipping lorries can be used As they can travel to any part of the work, they have much advantage over the jubilee wagons, which require rail tracks. Dumpers are of usually 2 to 3 cubic metre capacity, whereas the capacity of truck may be 4 cubic metre or more. Before loading with the concrete, the inside of the body should be just wetted with water. Tarpaulins or other covers may be provided to cover the wet concrete during transit to prevent evaporation when the haul is long; it is advisable to use agitators which prevent segregation and stiffening. The agitators help the mixing process at a slow speed.

For road construction using Slip Form Paver large quantity of concrete is required to be supplied continuously. A number of dumpers of 6 m^3 capacity are employed to supply concrete. Small dumper called Tough Riders are used for factory floor construction.

Belt Conveyors:

Belt conveyors have very limited applications in concrete construction. The principal objection is the tendency of the concrete to segregate on steep inclines, at transfer points or change of direction, and at the points where the belt passes over the rollers. Another disadvantage is that the concrete is exposed over long stretches which causes drying and stiffening particularly, in hot, dry and windy weather. Segregation also takes place due to the vibration of rubber belt. It is necessary that the concrete should be remixed at the end of delivery before placing on the final position.

Modern Belt Conveyors can have adjustable reach, travelling diverter and variable speed both forward and reverse. Conveyors can place large volumes of concrete quickly where access is limited. There are portable belt conveyors used for short distances or lifts. The end discharge arrangements must be such as to prevent segregation and remove all the mortar on the return of belt. In adverse weather conditions (hot and windy) long reaches of belt must be covered.

Chute:

Chutes are generally provided for transporting concrete from ground level to a lower level. The sections of chute should be made of or lined with metal and all runs shall have approximately the same slope, not flatter than 1 vertical to 2 1/2 horizontal. The lay-out is made in such a way that the concrete will slide evenly in a compact mass without any separation or segregation. The required consistency of the concrete should not be changed in order to facilitate chuting. If it becomes necessary to change the consistency the concrete mix will be completely redesigned.

Transporting and placing concrete by chute

This is not a good method of transporting concrete. However, it is adopted, when movement of labour cannot be allowed due to lack of space or for fear of disturbance to reinforcement or other arrangements already incorporated.

Skip and Hoist:

This is one of the widely adopted methods for transporting concrete vertically up for multistorey building construction. Employing mortar pan with the staging and human ladder for transporting concrete is not normally possible for more than 3 or 4 storeyed building constructions. For laying concrete in taller structures, chain hoist or platform hoist or skip hoist is adopted. At the ground level, mixer directly feeds the skip and the skip travel up over rails upto the level where concrete is required. At that point, the skip discharges the concrete automatically or on manual operation. The quality of concrete *i.e.* the freedom from segregation will depend upon the extent of travel and rolling over the rails. If the concrete has travelled a considerable height, it is necessary that concrete on discharge is required to be turned over before being placed finally.

Tower Hoist and Winch, for lifting concrete to higher level.

Transit Mixer:

Transit mixer is one of the most popular equipments for transporting concrete over a long distance particularly in Ready Mixed Concrete plant (RMCJ. In India, today (2000 AD) there are about 35 RMC plants and a number of central batching plants are working. It is a fair estimate that there are over 600 transit mixers in operation in India. They are truck mounted having a capacity of 4 to 7 m^3. There are two variations. In one, mixed concrete is transported to the site by keeping it agitated all along at a speed varying between 2 to 6 revolutions per minute. In the other category, the concrete is batched at the central batching plant and mixing is done in the truck mixer either in transit or immediately prior to discharging the concrete at site.

Transit-mixing permits longer haul and are less vulnerable in case of delay. The truck mixer the speed of rotating of drum is between 4 -16 revolutions per minute. A limit of 300 revolutions for both agitating and mixing is laid down by ASTM C 94 or alternatively, the concretes must be placed within 14- of mixing. In case of transit mixing, water need not be added till such time the mixing is commenced BS 5328 - 1991, restrict the time of 2 hours during which, cement and moist sand are allowed to remain in contact. But the above restrictions are to be on the safe side. Exceeding these limit is not going to be harmful if the mix remains sufficiently workable for full compaction.

Transit Mixer, a popular mathod of transporting concrete over a long distance.

With the development of twin fin process mixer, the transit mixers have become more efficient in mixing. In these mixers, in addition to the outer spirals, have two opposed inner spirals. The outer spirals convey the mix materials towards the bottom of the drum, while the opposed mixing spirals push the mix towards the feed opening. The repeated counter current mixing process is taking place within the mixer drum Sometimes a small concrete pump is also mounted on the truck carrying transit mixer.

This pump, pumps the concrete discharged from transit mixer. Currently we have placer boom also as part of the truck carrying transit mixer and concrete pump and with their help concrete is transported, pumped and placed into the formwork of a structure easily.

Pumping arrangements

Placing Concrete:

It is not enough that a concrete mix correctly designed, batched, mixed and transported; it is of utmost importance that the concrete must be placed in systematic manner to yield optimum results. The precautions to be taken and methods adopted while placing concrete in the under-mentioned situations will be discussed.

- Placing concrete within earth mould.
- (Example: Foundation concrete for a wall or column).
- Placing concrete within large earth mould or timber plank formwork.
- (Example: Road slab and Airfield slab).
- Placing concrete in layers within timber or steel shutters.
- (Example. Mass concrete in dam construction or construction of concrete abutment or pier).
- Placing concrete within usual from work.
- (Example: Columns, beams and floors).
- Placing concrete under water.

Concrete is invariably laid as foundation bed below the walls or columns. Before placing the concrete in the foundation, all the loose earth must be removed from the bed. Any root of trees passing through the foundation must be cut, charred or tarred effectively to prevent its further growth and piercing the concrete at a later date.

The surface of the earth, if dry, must be just made damp so that the earth does not absorb water from concrete.

On the other hand if the foundation bed is too wet and rain-soaked, the water and slush must be removed completely to expose firm bed before placing concrete. If there is any seepage of water taking place into the foundation trench, effective method for diverting the flow of water must be adopted before concrete is placed in the trench or pit.

Mould with floating suspension for simultaneous casting of parapetwall

For the construction of road slabs, airfield slabs and ground floor slabs in buildings, concrete is placed in bays. The ground surface on which the concrete is placed must be free from loose earth, pool of water and other organic matters like grass, roots, leaves etc. The earth must be properly compacted and made sufficiently damp to prevent the absorption of water from concrete. If this is not done, the bottom portion of concrete is likely to become weak. Sometimes, to prevent absorption of moisture from concrete, by the large surface of earth, in case of thin road slabs, use of polyethylene film is used in between concrete and ground. Concrete is laid in alternative bays giving enough scope for the concrete to undergo sufficient shrinkage. Provisions for contraction joints and dummy joints are given. It must be remembered that the concrete must be dumped and not poured. It is also to be ensured that concrete must be placed in just required thickness. The practice of placing concrete in a heap at one place and then dragging it should be avoided.

When concrete is laid in great thickness, as in the case of concrete raft for a high rise building or in the construction of concrete pier or abutment or in the construction of mass concrete dam, concrete is placed in layers. The thickness of layers depends upon the mode of compaction. In reinforced concrete, it is a good practice to place concrete in layers of about 15 to 30 cm thick and in mass concrete, the thickness of layer may vary anything between 35 to 45 cm. Several such layers may be placed in succession to form one lift, provided they follow one another quickly enough to avoid cold joints. The thickness of layer is limited by the method of compaction and size and frequency of vibrator used.

Before placing the concrete, the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush. In case of dam, even sand blasting is also adopted. The old surface is sometimes hacked and made rough by removing all the laitance and loose material. The surface is wetted. Sometimes, neat cement slurry or a very thin layer of rich mortar with fine sand is dashed against the old surface, and then the fresh concrete is placed

The whole operation must be progressed and arranged in such a way that, cold joints are avoided as far as possible. When concrete is laid in layers, it is better to leave the top of the layer rough, so that the succeeding layer can have a good bond with the previous layer. Where the concrete is subjected to horizontal thrust, bond bars, bond rails or bond stones are provided to obtain a good bond between the successive layers. Of course, such arrangements are required for placing mass concrete in layers, but not for reinforced concrete.

Certain good rules should be observed while placing concrete within the formwork, as in the case of beams and columns. Firstly, it must be checked that the reinforcement is correctly tied, placed and is having appropriate cover. The joints between planks, plywoods or sheets must be properly and effectively plugged so that matrix will not escape when the concrete is vibrated. The inside of the formwork should be applied with mould releasing agents for easy stripping. Such purposes made mould releasing agents are separately available for steel or timber shuttering. The reinforcement should be clean and free from oil. Where reinforcement is placed in a congested manner, the concrete must be placed very carefully, in small quantity at a time so that it does not block the entry of subsequent concrete. The above situation often takes place in heavily reinforced concrete columns with close lateral ties, at the junction of column and beam and in deep beams. Generally, difficulties are experienced for placing concrete in the column.

Placing concrete by pump and placing boom

Often concrete is required to be poured from a greater height. When the concrete is poured from a height, against reinforcement and lateral ties, it is likely to segregate or block the space to prevent further entry of concrete. To avoid this, concrete is directed by tremie, drop chute or by any other means to direct the concrete within the reinforcement and ties. Sometimes, when the formwork is too narrow, or reinforcement is too congested to allow the use of tremie or drop chute, a small opening in one of the sides is made and the concrete is introduced from this opening instead of pouring from the top. It is advisable that care must be taken at the stage of detailing of reinforcement for the difficulty in pouring concrete. In long span bridges the depth of prestressed concrete girders may be of the order of even 4-5 meters involving congested reinforcement. In such situations planning for placing concrete in one operation requires serious considerations on the part of designer.

Form work:

Form work shall be designed and constructed so as to remain sufficiently rigid during placing and compaction of concrete. The joints are plugged to prevent the loss of slurry from concrete.

Stripping Time:

Formwork should not be removed until the concrete has developed a strength of at least twice the stress to which concrete may be subjected at the time of removal of formwork. In special circumstances the strength development of concrete can be assessed by placing companion cubes near the structure and curing the same in the manner simulating curing conditions of structures. In normal circumstances, where ambient temperature does not fall below I 5°C and where ordinary Portland cement is used and adequate curing is done.

Compaction of Concrete:

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In the process of mixing, transporting and placing of concrete air is likely to get entrapped in the concrete. The lower the workability, higher is the amount of air entrapped. In other words, stiff concrete mix has high percentage of entrapped air and, therefore, would need higher compacting efforts than high workable mixes.

If this air is not removed fully, the concrete loses strength considerably. In order to achieve full compaction and maximum density, with reasonable compacting efforts available at site, it is necessary to use a mix with adequate workability. It is also of common knowledge that the mix should not be too wet for easy compaction which also reduces the strength of concrete. For maximum strength, driest possible concrete should be compacted 100 per cent. The overall economy demands I 00 per cent compaction with a reasonable compacting efforts available in the field.

The following methods are adopted for compacting the concrete:

a. Hand Compaction

   i.Rodding
   ii.Ramming
   iii.Tamping

b.Compaction by Vibration

   i. Internal vibrator (Needle vibrator)
   ii. Formwork vibrator (External vibrator)
   iii. Table vibrator
   iv. Platform vibrator
   v. Surface vibrator (Screed vibrator)
   vi. Vibratory Roller.

- Compaction by Pressure and Jolting
- Compaction by Spinning.

Hand Compaction:

Hand compaction of concrete is adopted in case of unimportant concrete work of small magnitude. Sometimes, this method is also applied in such situation, where a large quantity of reinforcement is used, which cannot be normally compacted by mechanical means. Hand compaction consists of rodding, ramming or tamping. When hand compaction is adopted, the consistency of concrete is maintained at a higher level. The thickness of the layer of concrete is limited to about 15 to 20 cm. Rodding is nothing but poking the concrete with about 2 metre long, 16 mm diameter rod to pack the concrete between the reinforcement and sharp corners and edges. Rodding is done continuously over the complete area to effectively pack the concrete and drive away entrapped air. Sometimes, instead of iron rod, bamboos or cane is also used for rodding purpose.

Ramming should be done with care. Light ramming can be permitted in unreinforced foundation concrete or in ground floor construction. Ramming should not be permitted in case of reinforced concrete or in the upper floor construction, where concrete is placed in the formwork supported on struts. If ramming is adopted in the above case the position of the reinforcement may be disturbed or the formwork may fail, particularly, if steel rammer is used.

Tamping is one of the usual methods adopted in compacting roof or floor slab or road pavements where the thickness of concrete is comparatively less and the surface to be finished smooth and level. Tamping consists of beating the top surface by wooden cross beam of section about 10 x 10 cm. Since the tamping bar is sufficiently long it not only compacts, but also levels the top surface across the entire width.

Compaction by Vibration:

It is pointed out that the compaction by hand, if properly carried out on concrete with sufficient workability, gives satisfactory results, but the strength of the hand compacted concrete will be necessarily low because of higher water cement ratio required for full compaction.

Plate Vibrator　Screed Board Vibrator

Table Vibrator　Needle Vibrator Electric　Needle Vibrator Petrol

Where high strength is required, it is necessary that stiff concrete, with low water/cement ratio be used. To compact such concrete, mechanically operated vibratory equipment, must be used. The vibrated concrete with low water/cement ratio will have many advantages over the hand compacted concrete with higher water/cement ratio.

The modern high frequency vibrators make it possible to place economically concrete which is impracticable to place by hand. A concrete with about 4 cm slump can be placed and compacted fully in a closely spaced reinforced concrete work, whereas, for hand compaction, much higher consistency say about 12 cm slump may be required. The action of vibration is to set the particles of fresh concrete in motion, reducing the friction between them and affecting a temporary liquefaction of concrete which enables easy settlement.

While vibration itself does not affect the strength of concrete which is controlled by the water/cement ratio, it permits the use of less water. Concrete of higher strength and better quality can, therefore, be made with a given cement factor with less mixing water. Where only a given strength is required, it can be obtained with leaner mixes than possible with hand compaction, making the process economical. Vibration, therefore, permits improvement in the quality of concrete and in economy.

Double beam screed board vibrator

Compaction of concrete by vibration has almost completely revolutionized the concept of concrete technology, making possible the use of low slump stiff mixes for production of high quality concrete with required strength and impermeability. The use of vibration may be essential for the production of good concrete where the congestion of the reinforcement or the inaccessibility of the concrete in the formwork is such that hand compaction methods are not practicable. Vibration may also be necessary if the available aggregates are of such poor shape and texture which would produce a concrete of poor workability unless large amount of water and cement is used. In normal circumstances, vibration is often adopted to improve the compaction and consequently improve the durability of structures. In this way, vibration can, under suitable conditions, produce better quality concrete than by hand compaction Lower cement content and lower water-cement ratio can produce equally strong concrete more economically than by hand compaction.

Although vibration properly applied is a great step forward in the production of quality concrete, it is more often employed as a method of placing ordinary concrete easily than as a method for obtaining high grade concrete at an economical cost. All the potential advantages of vibration can be fully realized only if proper control is exercised in the design and manufacture of concrete and certain rules are observed regarding the proper use of different types of vibrators.

Internal Vibrator:

Of all the vibrators, the internal vibrator is most commonly used. This is also called, "Needle Vibrator", "Immersion Vibrator", or "Poker Vibrator". This essentially consists of a power unit, a flexible shaft and a needle. The power unit may be electrically driven or operated by petrol engine or air compressor. The vibrations are caused by eccentric weights attached to the shaft or the motor or to the rotor of a vibrating element Electromagnet, pulsating equipment is also available. The frequency of vibration varies upto 12,000 cycles of vibration per minute.

The needle diameter varies from 20 mm to 75 mm and its length varies from 25 cm to 90 cm. The bigger needle is used in the construction of mass concrete dam. Sometimes, arrangements are available such that the needle can be replaced by a blade of approximately the same length. This blade facilitates vibration of members, where, due to the congested reinforcement, the needle would not go in, but this blade can effectively vibrate. They are portable and can be shifted from place to place very easily during concreting operation. They can also be used in difficult positions and situations.

Formwork Vibrator (External Vibrator):

Formwork vibrators are used for concreting columns, thin walls or in the casting of precast units. The machine is clamped on to the external wall surface of the formwork. The vibration is given to the formwork so that the concrete in the vicinity of the shutter gets vibrated. This method of vibrating concrete is particularly useful and adopted where reinforcement, lateral ties and spacers interfere too much with the internal vibrator. Use of formwork vibrator will produce a good finish to the concrete surface. Since the vibration is given to the concrete indirectly through the formwork, they consume more power and the efficiency of external vibrator is lower than the efficiency of internal vibrator.

Table Vibrator:

This is the special case of formwork vibrator, where the vibrator is clamped to the table, or table is mounted on springs which are vibrated transferring the vibration to the table. They are commonly used for vibrating concrete cubes. Any article kept on the table gets vibrated. This is adopted mostly in the laboratories and in making small but precise prefabricated R.C.C. members.

Platform Vibrator:

Platform vibrator is nothing but a table vibrator, but it is larger in size. This is used in the manufacture of large prefabricated concrete elements such as electric poles, railway sleepers, prefabricated roofing elements etc. Sometimes, the platform vibrator is also coupled with jerking or shock giving arrangements such that a through compaction is given to the concrete.

Surface Vibrator:

Surface vibrators are sometimes knows as, "Screed Board Vibrators". A small vibrator placed on the screed board gives an effective method of compacting and leveling of thin concrete members, such as floor slabs, roof slabs and road surface. Mostly, floor slabs and roof slabs are so thin that internal vibrator or any other type of vibrator cannot be easily employed. In such cases, the surface vibrator can be effectively used. In general, surface vibrators are not effective beyond about 15 cm. In the modern construction practices like vaccum dewatering technique, or slip-form paving technique, the use of screed board vibrator are common feature. In the above situations double beam screed board vibrators are often used.

Compaction by Pressure and Jolting:

This is one of the effective methods of compacting very dry concrete. This method is often used for compacting hollow blocks, cavity blocks and solid concrete blocks. The stiff concrete is vibrated, pressed and also given jolts. With the combined action of the jolts vibrations and pressure, the stiff concrete gets compacted to a dense form to give good strength and volume stability. By employing great pressure, a concrete of very low water cement ratio can be compacted to yield very high strength.

Compaction by Spinning:

Spinning is one of the recent methods of compaction of concrete. This method of compaction is adopted for the fabrication of concrete pipes. The plastic concrete when spun at a very high speed, gets well compacted by centrifugal force. Patented products such a "Hume Pipes", "spun pipes" are compacted by spinning process.

Vibratory Roller:

One of the recent developments of compacting very dry and lean concrete is the use of Vibratory Roller. Such concrete is known as Roller Compacted Concrete. This method of concrete construction originated from Japan and spread to USA and other countries mainly for the construction of dams and pavements. Heavy roller which vibrates while rolling is used for the compaction of dry lean concrete. Such roller compacted concrete of grade M 10 has been successfully used as base course, 15 cm thick, for the Delhi-Mathura highway and Mumbai-Pune express highways.

CURING OF CONCRETE

Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a process continuing for long time. Of course, the rate of hydration is fast to start with, but continues over a very long time at a decreasing rate. The quantity of the product of hydration and consequently the amount of gel formed depends upon the extent of hydration. It has been mentioned earlier that cement requires a water/cement ratio about 0.23for hydration and *a* water/cement ratio of 0.1 5 for filling the voids in the gel pores. In other words, a water/cement ratio of about 0.38 would be required to hydrate all the particles of cement and also to occupy the space in the gel pores. Theoretically, for a concrete made and contained in a sealed container a water cement ratio of 0.38 would satisfy the requirement of water for hydration and at the same time no capillary vavities would be left. However; it is seen that practically a water/cement ratio of 0.5 will be required for complete hydration in a sealed container for keeping up the desirable relative humidity level.

Cracks on concrete surface due to inadequate curing

In the field and in actual work, it is a different story. Even though a higher water/cement ratio is used, since the concrete is open to atmosphere, the water used in the concrete evaporates and the water available in the concrete will not be sufficient for effective hydration to take place particularly in the top layer. If the hydration is to continue unbated, extra water must be added to replenish the loss of water on account of absorption and evaporation. Alternatively, some measures must be taken by way of provision of impervious covering or application of curing compounds to prevent the loss of water from the surface of the concrete. Therefore, the curing can be considered as creation of a favourable environment during the early period for uninterrupted hydration. The desirable conditions are, a suitable temperature and ample moisture.

Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately, it can be described as the process of maintaining satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service.

Curing is being given a place of increasing importance as the demand for high quality concrete is increasing. It has been recognized that the quality of concrete shows all round improvement with efficient uninterrupted curing. If curing is neglected in the early period of hydration, the quality of concrete will experience a sort of irreparable loss. An efficient curing in the early period of hydration can be compared to a good and wholesome feeding given to a new born baby.

A concrete laid in the afternoon of a hot summer day in a dry climatic region, is apt to dry out quickly. The surface layer of concrete exposed to acute drying condition, with the combined effect of hot sun and drying wind is likely to be made up of poorly hydrated cement with inferior gel structure which does not give the desirable bond and strength characteristics. In addition, the top surface, particularly that of road or floor pavement is also subjected to a large magnitude of plastic shrinkage stresses. The dried concrete naturally being weak, cannot withstand these stresses with the result that innumerable cracks develop at the surface.The top surface of such hardened concrete on account of poor gel structure, suffers from lack of wearing quality and abrasion resistance. Therefore, such surfaces create mud in the rainy season and dust in summer.

The quick surface drying of concrete results in the movement of moisture from the interior to the surface. This steep moisture gradient cause high internal stresses which are also responsible for internal micro cracks in the semi-plastic concrete. Concrete, while hydrating, releases high heat of hydration. This heat is harmful from the point of view of volume stability. If the heat generated is removed by some means, the adverse effect due to the generation of heat can be reduced. This can be done by a thorough water curing.

Curing Methods:

Curing methods may be divided broadly into four categories:

- Water curing
- Membrane curing
- Application of heat
- Miscellaneous

Water Curing:

This is by far the best method of curing as it satisfies all the requirements of curing, namely, promotion of hydration, elimination of shrinkage and absorption of the heat of hydration. It is pointed out that even if the membrane method is adopted, it is desirable that a certain extent of water curing is done before the concrete is covered with membranes.

Water curing can be done in the following ways:

Immersion
Ponding
Spraying or Fogging
Wet covering

The precast concrete items are normally immersed in curing tanks for certain duration. Pavement slabs, roof slab etc. are covered under water by making small ponds. Vertical retaining wall or plastered surfaces or concrete columns etc. are cured by spraying water. In some cases, wet coverings such as wet gunny bags, hessian cloth, jute matting, straw etc., are wrapped to vertical surface for keeping the concrete wet. For horizontal surfaces saw dust, earth or sand are used as wet covering to keep the concrete in wet condition for a longer time so that the concrete is not unduly dried to prevent hydration.

Membrane Curing:

Sometimes, concrete works are carried out in places where there is acute shortage of water. The lavish application of water for water curing is not possible for reasons of economy. It has been pointed out earlier that curing does not mean only application of water; it means also creation of conditions for promotion of uninterrupted and progressive hydration. It is also pointed out that the quantity of water, normally mixed for making concrete is more than sufficient to hydrate the cement, provided this water is not allowed to go out from the body of concrete. For this reason, concrete could be covered with membrane which will effectively seal off the evaporation of water from concrete. It is found that the application of membrane or a sealing compound, after a short spell of water curing for one or two days is sometimes beneficial.

Sometimes, concrete is placed in some inaccessible, difficult or far off places. The curing of such concrete cannot be properly supervised. The curing is entirely left to the workmen, who do not quite understand the importance of regular uninterrupted curing. In such cases, it is much safer to adopt membrane curing rather than to leave the responsibility of curing to workers.

Large number of sealing compounds have been developed in recent years. The idea is to obtain a continuous seal over the concrete surface by means of a firm impervious film to prevent moisture in concrete from escaping by evaporation. Sometimes, such films have been used at the interface of the ground and concrete to prevent the absorption of water by the ground from the concrete. Some of the materials that can be used for this purpose are bituminous compounds, polyethylene or polyester film, waterproof paper, rubber compounds etc.

Bituminous compound being black in colour absorbs heat when it is applied on the top surface of the concrete. This results in the increase of temperature in the body of concrete which is undesirable. For this purpose, other modified materials which are not black in colour are in use. Such compounds are known as "Clear Compounds". It is also suggested that a lime wash may be given over the black coating to prevent heat absorption.

Membrane curing by spraying

Membrane curing is a good method of maintaining a satisfactory state of wetness in the body of concrete to promote continuous hydration when original water/cement ratio used is not less than 0.5. To achieve best results, membrane is applied after one or two days' of actual wet curing. Since no replenishing of water is done after the membrane has been applied it should be ensured that the membrane is of good quality and it is applied effectively. Two or three coats may be required for effective sealing of the surface to prevent the evaporation of water.

Increase in volume of construction, shortage of water and need for conservation of water, increase in cost of labour and availability of effective curing compounds have encouraged the use of curing compounds in concrete construction. Curing compound is an obvious choice for curing canal lining, sloping roofs and textured surface of concrete pavements.

It is seen that there are some fear and apprehension in the mind of builders and contractors regarding the use of membrane forming curing compounds. No doubt that curing compounds are not as efficient and as ideal as water curing. The efficiency of curing compounds can be at best be 80% of water curing. But this 80% curing is done in a foolproof manner. Although water curing is ideal in theory, it is often done intermittently and hence, in reality the envisaged advantage is not there, in which case membrane curing may give better results.

When waterproofing paper or polyethylene film are used as membrane, care must be taken to see that these are not punctured anywhere and also see whether adequate laping is given at the junction and this lap is effectively sealed.

Curing vertical surface by wet covering.

Application of Heat:

The development of strength of concrete is a function of not only time but also that of temperature. When concrete is subjected to higher temperature it accelerates the hydration process resulting in faster development of strength. Concrete cannot be subjected to dry heat to accelerate the hydration process as the presence of moisture is also an essential requisite. Therefore, subjecting the concrete to higher temperature and maintaining the required wetness can be achieved by subjecting the concrete to steam curing.

A faster attainment of strength will contribute to many other advantages mentioned below:

a . Concrete is vulnerable to damage only for short time.

b . Concrete member can be handled very quickly.

c . Less space will be sufficient in the casting yerd.

d . A smaller curing tank will be sufficient.

e . A higher outturn is possible for a given capital outlay.

f . The work can be put on to service at a much early time,

g . A fewer number of formwork will be sufficient or alternatively with the given number of formwork more outturn will be achieved.

h . Prestressing bed can be released early for further casting.

From the above mentioned advantages it can be seen that steam curing will give not only economical advantages, but also technical advantages in the matter of prefabrication of concrete elements.

The exposure of concrete to higher temperature is done in the following manner:

Steam curing at ordinary pressure.

Steam curing at high pressure.

Curing by Infra-red radiation.

Electrical curing.

Steam curing at ordinary pressure:

This method of curing is often adopted for prefabricated concrete elements. Application of steam curing to insitu construction will be a little difficult task. However, at some places it has been tried for insitu construction by forming a steam jacket with the help of tarpaulin or thick polyethylene sheets. But this method of application of steam for insitu work is found to be wasteful and the intended rate of development of strength and benefit is not really achieved

Beam under steam curing

Steam curing at ordinary pressure is applied mostly on prefabricated elements stored in a chamber. The chamber should be big enough to hold a day's production. The door is closed and steam is applied. The steam may be applied either continuously or intermittently. An accelerated hydration takes place at this higher temperature and the concrete products attain the 28 days strength of normal concrete in about 3 days.

In large prefabricated factories they have tunnel curing arrangements. The tunnel of sufficient length and size is maintained at different temperature starting from a low temperature in the beginning of the tunnel to a maximum temperature of about 90°C at the end of the tunnel. The concrete products mounted on trollies move in a very slow speed subjecting the concrete products progressively to higher and higher temperature. Alternatively, the trollies are kept stationary at different zones for some period and finally come out of tunnel.

It is interesting to note that concrete subjected to higher temperature at the early period of hydration is found to lose some of the strength gained at a later age. Such concrete is said to undergo "Retrogression of Strength". The phenomenon of retrogression of strength explains that faster hydration will result in the formation of poor quality gels with porous open structure, whereas the gel formed slowly but steadily at lower temperature are of good quality which are compact and dense in nature. This aspect can be compared to the growth of wood cells. It is common knowledge that a tree which grows faster, will yield timber *of* poor and non-durable quality, whereas a tree, which grows slowly will yield good durable timber. Similarly, concrete subjected to higher temperature in the early period of hydration will yield poor quality gels and concrete which is subjected to rather low temperature (say about 13 degree Centigrade) will yield the best quality gel, and hence good concrete.

It has been emphasized that a very young concrete should not be subjected suddenly to high temperature. Certain amount of delay period on casting the concrete is desirable. It has been found that if 49°C is reached in a period shorter than 2 to 3 hours or 99°C is reached in less than 6 to 7 hours from the time of mixing, the gain of strength beyond the first few hours is effected adversely.

Concrete subjected to steam curing exhibits a slightly higher drying shrinkage and moisture movement. Subjecting the concrete to higher temperature may also slightly effect the aggregate quality in case of some artificial aggregate. Steam curing of concrete made with rapid hardening cement will generate a much higher heat of hydration. Similarly, richer mixes may have more adverse effect than that of lean mixes.

In India', steam curing is often adopted for precast elements, specially prestressed concrete sleepers. Concrete sleepers are being introduced on the entire Indian Railway. For rapid development of strength, they use special type of cement namely IRST 40 and also subject the sleepers to steam curing.

Large numbers of bridges are being built for infrastructural development in India. There are requirements for casting of innumerable precast prestressed girders. These girders are steam cured for faster development of strength which has many other associated advantages.

A steam-curving cycle consists of

- an initial delay prior to steaming,
- a period for increasing the temperature,
- a period for retaining the temperature,
- a period for decreasing the temperature.

High Pressure Steam Curing:

In the steam curing at atmospheric pressure, the temperature of the steam is naturally below 100°C. The steam will get converted into water, thus it can be called in a way, as hot water curing. This is done in an open atmosphere.

The high pressure steam curing is something different from ordinary steam curing, in that the curing is carried out in a closed chamber. The superheated steam at high pressure and high temperature is applied on the concrete. This process is also called "Autoclaving". The autoclaving process is practised in curing precast concrete products in the factory, particularly, for the lightweight concrete products. In India, this high pressure steam curing is practised in the manufacture of cellular concrete products, such as Siporex, Celcrete etc.

The following advantages are derived from high pressure steam curing process:

- High pressure steam cured concrete develops in one day or less the strength as much as the 28 days' strength of normally cured concrete. The strength developed does not show retrogression.
- High pressure steam cured concrete exhibits higher resistance to sulphate attack, freezing and thawing action and chemical action. It also shows less efflorescence.
- High pressure steam cured concrete exhibits lower drying shrinkage, and moisture movement.
- In high pressure steam curing, concrete is subjected to a maximum temperature of about 175°C which corresponds to a steam pressure of about 8.5 kg/sq.cm.

When the concrete is to be subjected to high pressure steam curing, it is invariably made by admixing with 20 to 30 per cent of pozzolanic material such as crushed stone dust. In case of normal curing, the liberation of $Ca(OH)_2$ is a slow process. Therefore, when pozzolanic materials are added, the pozzolanic reactivity also will be a slow process. But in case of high pressure steam curing a good amount of $Ca(OH)_2$ will be liberated in a very short time and reaction between $Ca(OH)_2$and pozzolanic material takes place in an accelerated manner. A good amount of technical advantage is achieved by admixing the concrete with pozzolanic material.

High pressure steam curing exhibits higher strength and durability particularly in the case of cement containing a proportionately higher amount of C_3S. A sample of cement containing higher proportion of C_2S is not benefited to the same extent, as it produces lower amount of $Ca(OH)_2$

It is also observed that improvement in durability is more for the concrete made with higher water/cement ratio, than for the concrete made with low water/cement ratio.

Owing to the combination of $Ca(OH)_2$ with siliceous material within a matter of 24 hours in the case of high steam curing, concrete becomes impervious and hence durable. The fact is that the concrete in the absence of free Calcium Hydroxide becomes dense and less permeable, and also accounts for higher chemical resistance and higher strength.

The higher rate of development of strength is attributed to the higher temperature to which a concrete is subjected. Earlier it is brought out that if the concrete is subjected to very high temperature, particularly in the early period of hydration, most of the strength gained will be lost because of the formation of poor quality gel. The above is true for steam cured concrete at atmospheric pressure. The high pressure steam cured concrete does not exhibit retrogression of strength. The possible explanation is that in the case of high pressure steam curing, the quality and uniformity of pore structure formed is different. At high temperature the amorphous calcium silicates are probably converted to crystalline forms. Probably due to high pressure the frame work of the gel will become more compact and dense. This perhaps explains why the retrogression of strength does not take place in the case of high pressure steam curing.

In ordinarily cured concrete, the specific surface of the gel is estimated to be about two million sq cm per gram of cement, whereas in the case of high pressure steam cured concrete, the specific surface of gel is in the order of seventy thousand sq cm per gram. In other words, the gels are about 20 times coarser than ordinarily cured concrete. It is common knowledge that finer material shrinks more than coarser material. Therefore, ordinary concrete made up of finer gels shrinks more than high pressure steam cured concrete made up of coarser gel. In quantitative terms, the high pressure steam cured concrete undergoes shrinkage of 1 /3 to I /6 of that of concrete cured at normal temperature. When pozzolanic material is added to the mix, the shrinkage is found to be higher, but still it shrinks only about 1 /2 of the shrinkage of normally cured concrete.

Due to the absence of free calcium hydroxide no efflorescence is seen in case of high pressure steam cured concrete. Due to the formation of coarser gel, the bond strength of concrete to the reinforcement is reduced by about 30 per cent to 50 per cent when compared with ordinary moist-cured concrete. High pressure steam cured concrete is rather brittle and whitish in colour. On the whole, high pressure steam curing produces good quality dense and durable concrete:

The concrete products as moulded with only a couple of hours delay period is subjected to maximum temperature over a period of 3 to 5 hours. This is followed by about 5 to 8 hours at this temperature. Pressure and temperature is realeased in about one hour. The detail steaming cycle depends on the plant, quality of material thickness of member etc. The length of delay period before subjecting to high pressure steam curing does not materially affect the quality of high pressure steam cured concrete.

Curing by Infra-red Radiation:

Curing of concrete by Infra-red Radiation has been practised in very cold climatic regions in Russia. It is claimed that much more rapid gain of strength can be obtained than with steam curing and that rapid initial temperature does not cause a decrease in the ultimate strength as in the case of steam curing at ordinary pressure. The system is very often adopted for the curing of hollow concrete products. The normal operative temperature is kept at about 90°C.

Electrical Curing:

Another method of curing concrete, which is applicable mostly to very cold climatic regions, is the use of electricity. This method is not likely to find much application in ordinary climate owing to economic reasons.

Concrete can be cured electrically by passing an alternating current (Electrolysis trouble will be encountered if direct current is used) through the concrete itself between two electrodes either buried in or applied to the surface of the concrete. Care must be taken to prevent the moisture from going out leaving the concrete completely dry. As this method is not likely to be adopted in this country, for a long time to come, this aspect is not discussed in detail.

Miscellaneous Methods of Curing:

Calcium chloride is used either as a surface coating or as an admixture. It has been used satisfactorily as a curing medium. Both these methods are based on the fact that calcium chloride being a salt shows affinity for moisture. The salt not only absorbs moisture from atmosphere but also retains it at the surface. This moisture held at the surface prevents the mixing water from evaporation and thereby keeps the concrete wet for a long time to promote hydration.

Formwork prevents escaping of moisture from the concrete, particularly, in the case of beams and columns. Keeping the formwork intact and sealing the joint with wax or any other sealing compound prevents the evaporation of moisture from the concrete. This procedure of promoting hydration can be considered as one of the miscellaneous methods of curing.

UNIT 3

HARDENED CONCRETE

WATER/CEMENT RATIO

Strength of concrete primarily depends upon the strength of cement paste. Strength of cement paste depends upon the dilution of paste or in other words, the strength of paste increases with cement content and decreases with air and water content. In 1918 Abrams presented his classic law in the form:

$$\mathbf{S = A/ B^x}$$

Where x =water/cement ratio by volume and for 28 days results

The constants A and B are 14,000 lbs/sq. in. and 7 respectively.

Abrams water/cement ratio law states that the strength of concrete is only dependent upon water/cement ratio provided the mix is workable. In the past many theories have been propounded by many research workers. Some of them held valid for some time and then underwent some changes while others did not stand the test of time and hence slowly disappeared. But Abrams water/cement ratio law stood the test of time and is held valid even today as a fundamental truth in concrete-making practices. No doubt some modifications have been suggested but the truth of the statement could not be challenged.

Strictly speaking, it was Feret who formulated in as early as 1897, a general rule defining the strength of the concrete paste and concrete in terms of volume fractions of the constituents by the equation:

$$\mathbf{S = K (c/c+e+a)^2}$$

Where S = strength of concrete

c, e and a = volume of cement, water and air respectively and K = a constant

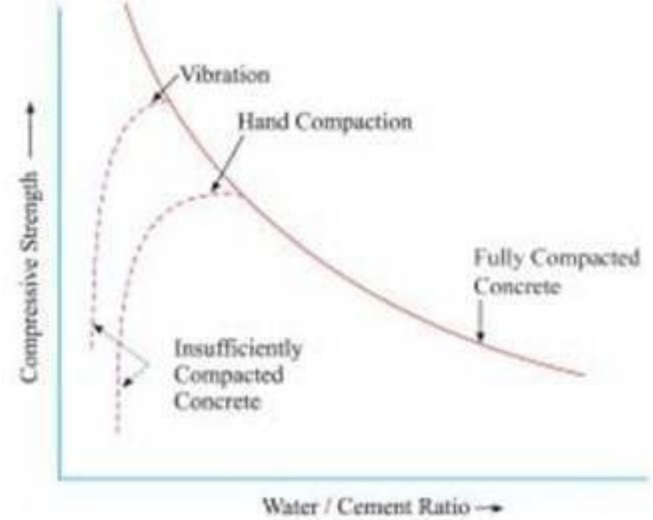


Figure: The relation between strength and water/cement ratio of concrete.

In this expression the volume of air is also included because it is not only the water/ cement ratio but also the degree of compaction, which indirectly means the volume of air filled voids in the concrete is taken into account in estimating the strength of concrete. The relation between the water/cement ratio and strength of concrete is shown in Fig (a). It can be seen that lower water/cement ratio could be used when the concrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio is required when concrete is hand compacted. In both cases when the water/cement ratio is below the practical limit the strength of the concrete falls rapidly due to introduction of air voids.

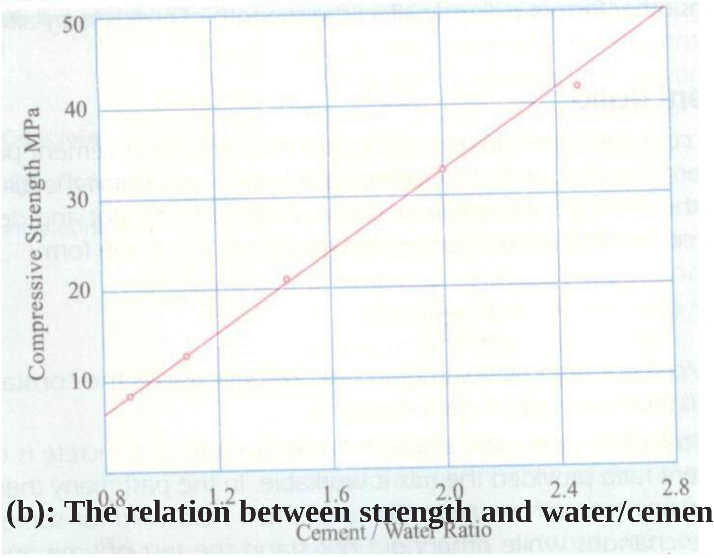


Fig (b): The relation between strength and water/cement ratio

The graph showing the relationship between the strength and water/cement ratio is approximately hyperbolic in shape. Sometimes it is difficult to interpolate the intermediate value. From geometry it can be deduced that if the graphs is drawn between the strength and the cement/water ratio an approximately linear relationship will be obtained. This linear relationship is more convenient to use than water/cement ratio curve for interpolation. Fig (b) shows the relationship between compressive strength and cement/water ratio.

Gel/Space Ratio

Many research workers commented on the validity of water/cement ratio law as propounded by Duff Abrams. They have forwarded a few of the limitations of the water/ cement ratio law and argued that Abrams water/cement ratio law can only be called a rule and not a law because Abrams' statement does not include many qualifications necessary for its validity to call it a law. Some of the limitations are that the strength at any water/cement ratio depends on the degree of hydration of cement and its chemical and physical properties, the temperature at which the hydration takes place, the air content in case of air entrained concrete, the change in the effective water/cement ratio and the formation of fissures and cracks due to bleeding or shrinkage.

Instead of relating the strength to water/cement ratio, the strength can be more correctly related to the solid products of hydration of cement to the space available for formation of this product. Powers and Brownyard have established the relationship between the strength and gel/space ratio. This ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of volumes of the hydrated cement and of the capillary pores.

Power's experiment showed that the strength of concrete bears a specific relationship with the gel/space ratio. He found the relationship to be $240\ x^3$, where x is the gel/space ratio and 240 represents the intrinsic strength of the gel in MPa for the type of cement and specimen used. The strength calculated by Power's expression holds good for an ideal case.

The relationship between strength and gel/space ratio. It is pointed out that the relationship between the strength and water/cement ratio will hold good primarily for 28 days strength for fully compacted concrete, whereas, the relationship between the strength and gel/space ratio is independent of age. Gel/space ratio can be calculated at any age and for any fraction of hydration of cement.

The following examples show how to calculate the gel/space ratio.

Calculation of gel/space ratio for complete hydration

Let C = weight of cement in gm.

V_C = specific volume of cement = 0.319 ml/gm.

W_O = volume of mixing water in ml.

Assuming that 1 ml. of cement on hydration will produce 2.06 ml of gel, Volume of gel = C x 0.319 x 2.06

Space available = C x 0.319 + W_O

∴Gel/Space ratio = x = Volume of gel / Space available = 0.657 C / 0.319 C+ W_O

Maturity Concept of Concrete:

While dealing with curing and strength development, we have so far considered only the time aspect. It has been pointed out earlier that it is not only the time but also the temperature during the early period of hydration that influences the rate of gain of strength of concrete. Since the strength development of concrete depends on both time and temperature it can be said that strength is a function of summation of product of time and temperature. This summation is called maturity of concrete.

$$\text{Maturity} = \Sigma\ (\text{time x temperature})$$

The temperature is reckoned from an origin lying between -12 and -10°C. It was experimentally found that the hydration of concrete continues to take place upto about -11°C. Therefore, -11°C is taken as a datum line for computing maturity.

Maturity is measured in degree centigrade hours (°C hrs) or degree centigrade days (°C days)..

A sample of concrete cured at 18°C for 28 days is taken as fully matured concrete. Its maturity would be equal to

$$28 \text{ x } 24 \text{ x } [18 - (-11)] = 19488°\text{C h.}$$

However, in standard calculations the maturity of fully cured concrete is taken as 19,800°Ch.. (The discrepancy is because of the origin or the datum is not exactly being -11 C as used in calculation).

If the period is broken into smaller intervals and if the corresponding temperature is recorded for each interval of time, the summation of the product of time and temperature will give an accurate picture of the maturity of concrete. In the absence of such detailed temperature history with respect to the time interval, the maturity figure can be arrived at by multiplying duration in hours by the average temperature at which the concrete is cured. Of course, the maturity calculated as above will be less accurate.

Maturity concept is useful for estimating the strength of concrete at any other maturity as a percentage of strength of concrete of known maturity. In other words, if we know the strength of concrete at full maturity (19,800°Ch), we can calculate the percentage strength of identical concrete at any other maturity by using the following equation given by Plowman.

Strength at any maturity as a percentage of strength at maturity of

$19{,}800^0$Ch = A+B log 10 (maturity) / 10^3

The values of coefficients, A and B depend on the strength level of concrete. The value are given in Table

Plowman's coefficients for Maturity Equation

Strength after 28 days at 18°C (Maturity of 19,800°Ch): MPa	Coefficient	
	A	B
Less than 17.5	10	68
17.5 – 35.0	21	61
35.0 – 52.5	32	54
52.5 – 70.0	42	46.5

The values of A and B are plotted against the cube strength at the maturity of 19,800° Ch. A straight line relationship will be obtained indicating that they are directly proportional to the strength. Plowman divided the strength into 4 zones as shown in Table and has assigned the values of A and B for each zone. It is to be noted that the maturity equation holds good for the initial temperature of concrete less than about 38^0C.

Influence of properties of coarse aggregate on strength

Although the relation between strength and the water/cement ratio is generally valid, it is not independent of other factors.

Vertical cracking in a specimen subjected to uniaxial compression starts under a load equal to 50 to 75 per cent of the ultimate load. This has been determined from measurements of the velocity of sound transmitted through the concrete, and also using ultrasonic pulse velocity techniques. The stress at which the cracks develop depends largely on the properties of the coarse aggregate: smooth gravel leads to cracking at lower stresses than rough and angular crushed rock, probably because mechanical bond is influenced by the surface properties and, to a certain degree, by the shape of the coarse aggregate.

The properties of aggregate affect thus the cracking load, as distinct from the ultimate load, in compression and the flexural strength in the same manner, so that the relation between the two quantities is independent of the type of aggregate used. Figure(a) shows Jones and Kaplan's results, each symbol representing a different type of coarse aggregate. On the other hand, the relation between the flexural and compressive strengths depends on the type of coarse aggregate used [see Fig(b)] because (except in high strength concrete) the properties of aggregate, especially its shape and surface texture, affect the ultimate strength in compression very much less than the strength in tension or the cracking load in compression. This behaviour was confirmed by Knab. In experimental concrete, entirely smooth coarse aggregate led to a lower compressive strength, typically by 10 per cent, than when roughened.

The influence of the type of coarse aggregate on the strength of concrete varies in magnitude and depends on the water/cement ratio of the mix. For water/cement ratios below 0.4, the use of crushed aggregate has resulted in strengths up to 38 per cent higher than when gravel is used. The behaviour at a water/cement ratio of 0.5 is shown in Fig.(c). With an increase in the water/cement ratio, the influence of aggregate falls off, presumably because the strength of the hydrated cement paste itself becomes paramount and, at a water/cement ratio of 0.65, no difference in the strengths of concretes made with crushed rock and gravel has been observed.

The influence of aggregate on flexural strength seems to depend also on the moisture condition of the concrete at the time of test.

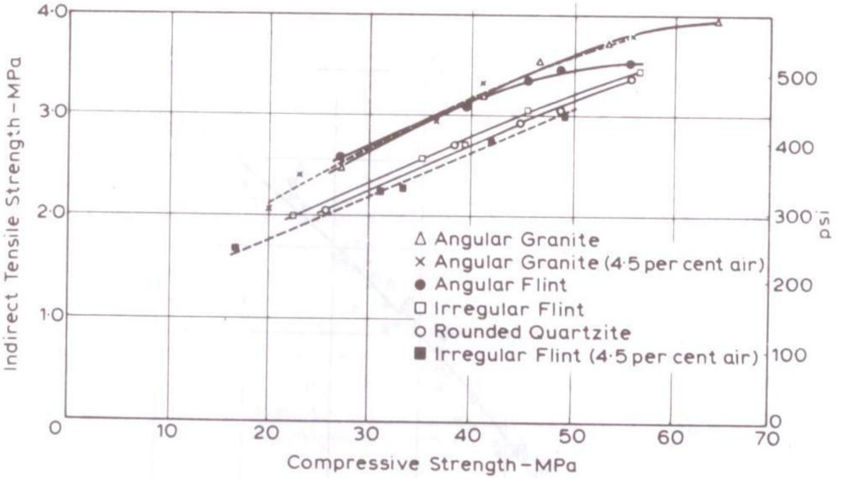


Fig (b): Relation between compressive strength and indirect tensile strength for concretes of constant workability made with various aggregates (water/cement ratio between 0.33 and 0.68, aggregate/cement ratio between 2.8 and 10.1

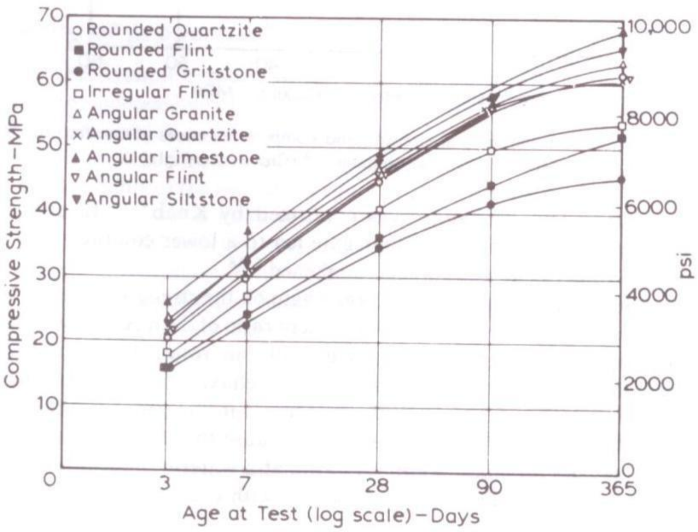


Fig (c): Relation between compressive strength and age for concretes made with various aggregates (water/cement ratio =0.5)

The shape and surface texture of coarse aggregate affect also the impact strength of concrete, the influence being qualitatively the same as on the flexural strength.

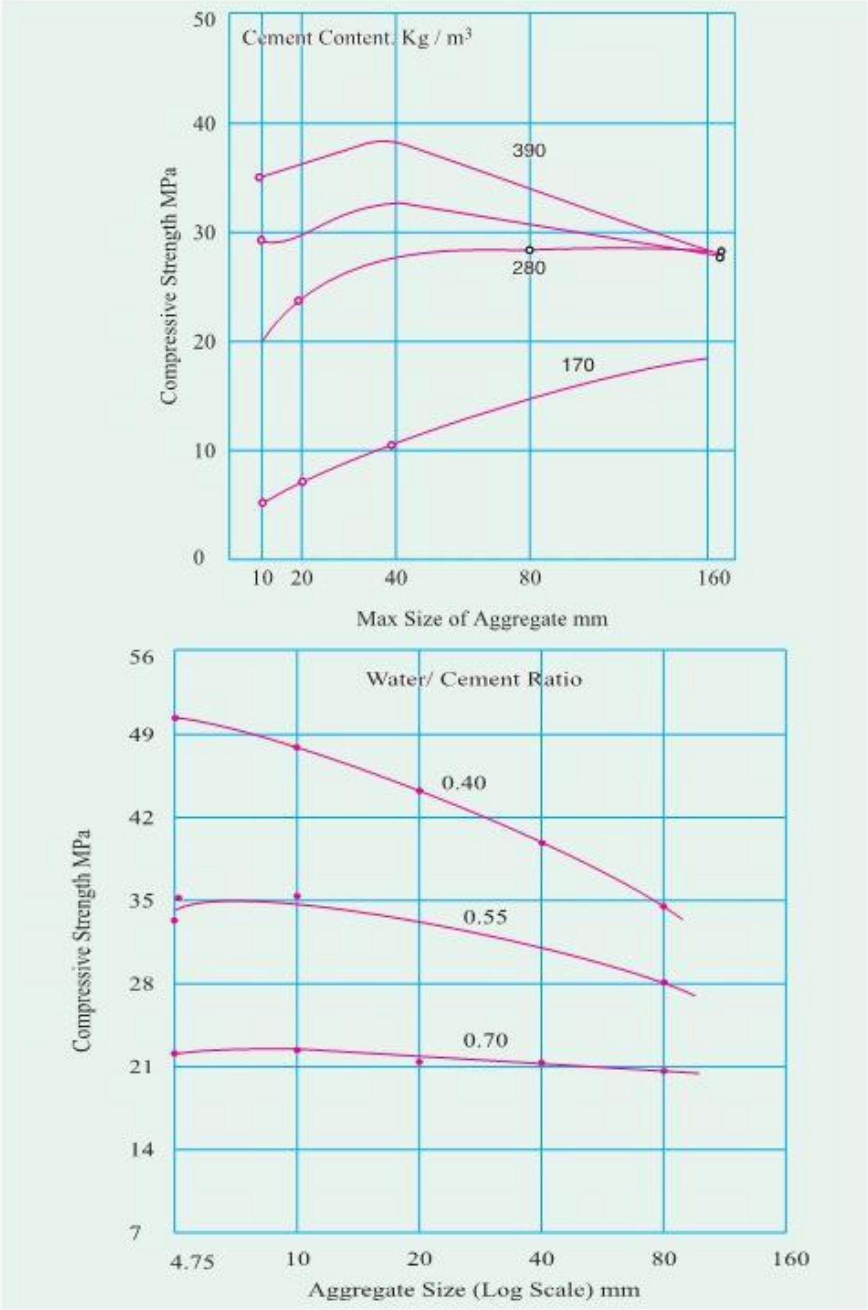
Kaplan observed that the flexural strength of concrete is generally lower than the flexural strength of corresponding mortar. Mortar would thus seem to set the upper limit to the flexural strength of concrete and the presence of the coarse aggregate generally reduces this strength. On the other hand, the compressive strength of concrete is higher than that of mortar, which, according to Kaplan, indicates that the mechanical interlocking of the coarse aggregate contributes to the strength of concrete in compression. This behaviour has not, however, been confirmed to apply generally, and the question of the influence of aggregate on strength is considered further in the next section. At this stage, it is useful to note that coarse aggregate particles act as crack arresters so that, under an increasing load, another crack is likely to open. Failure is, therefore, gradual and, even in tension, there exists a descending part of the stress - strain curve.

Relation between Compressive and Tensile Strength

In reinforced concrete construction the strength of the concrete in compression is only taken into consideration. The tensile strength of concrete is generally not taken into consideration. But the design of concrete pavement slabs is often based on the flexural strength of concrete. Therefore, it is necessary to assess the flexural strength of concrete either from the compressive strength or independently.

As measurements and control of compressive strength in field are easier and more convenient, it has been customary to find out the compressive strength for different conditions and to correlate this compressive strength to flexural strength. Having established a satisfactory relationship between flexural and compressive strength, pavement, can be designed for a specified flexural strength value, or this value could be used in any other situations when required.

It is seen that strength of concrete in compression and tension (both direct tension and flexural tension) are closely related, but the relationship is not of the type of direct proportionality. The ratio of the two strengths depends on general level of strength of concrete. In other words, for higher compressive strength concrete shows higher tensile strength, but the rate of increase of tensile strength is of decreasing order



Cement Content. Kg / m³
390
280
170
Compressive Strength MPa
0
10
20
30
40
50
10
20
40
80
160
Max Size of Aggregate mm
Water/ Cement Ratio
0.40
0.55
0.70
Compressive Strength MPa
7
14
21
28
35
42
49
56
4.75
10
20
40
80
160
Aggregate Size (Log Scale) mm

Figure (i): Influence of maximum size of aggregate on 28 day compressive strength of concrete of different richness

Figure (ii): The influence of maximum size of aggregate on compressive strength of concrete

The type of coarse aggregate influences this relationship. Crushed aggregate gives relatively higher flexural strength than compressive strength. This is attributed to the improved bond strength between cement paste and aggregate particles. The tensile strength of concrete, as compared to its compressive strength, is more sensitive to improper curing. This may be due to the inferior quality of gel formation as a result of improper curing and also due to the fact that improperly cured concrete may suffer from more shrinkage cracks.

The use of pozzolanic material increases the tensile strength of concrete.

From the extensive study, carried out at Central Road Research Laboratory (CRRI) the following statistical relationship between tensile strength and compressive strength were established.

- $y = 15.3x - 9.00$ for 20 mm maximum size aggregate.
- $y = 14.1x - 10.4$ for 20 mm maximum size natural gravel.
- $y = 9.9x - 0.55$ for 40 mm maximum size crushed aggregate.
- $y = 9.8x - 2.52$ for 40 mm maximum size natural gravel.

Where y is the compressive strength of concrete MPa and x is the flexural strength of concrete MPa.

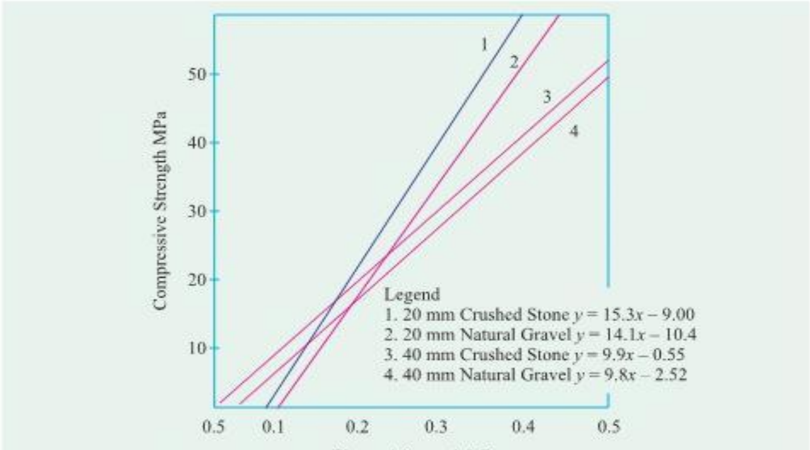


Fig (iii): Statistical relation between flexural and compressive strength of concrete with different types and sizes of aggregate.

Subjecting all the data to statistical treatment the following general relationship has been established at CRRI between flexural and compressive strength of concrete:

$$y = 11x - 3.4$$

The flexural to compressive strength ratio was higher with aggregate of 40 mm maximum size than with those of 20 mm maximum size. In general the ratio was found to be slightly higher in the case of natural gravel as compared to crushed stone.

Flexural strength of concrete is usually found by testing plain concrete beams. Two methods of loading of the beam specimen for finding out flexural strength are practiced.

Bond Strength:

The bond strength can be considered from two different angles; one is the bond strength between paste and steel reinforcement and the other is the bond strength between paste and aggregate. Firstly, let us consider the bond strength between paste and steel reinforcement.

Bond strength between paste and steel reinforcement is of considerable importance. A perfect bond, existing between concrete and steel reinforcement is one of the fundamental assumptions of reinforced concrete. Bond strength arises primarily from the friction and adhesion between concrete and steel. The roughness of the steel surface is also one of the factors affecting bond strength. The bond strength of concrete is a function of compressive strength and is approximately proportional to the compressive strength upto about 20 MPa. For higher strength, increase in bond strength becomes progressively smaller.

The bond strength, is also a function of specific surface of gel. Cement which consists of a higher percentage of C_2S will give higher specific surface of gel, thereby giving higher bond strength. On the other hand, concrete containing more C_3S or the concrete cured at higher temperature results in smaller specific surface of gel which gives a lower bond strength. It has been already pointed out that high pressure steam cured concrete produces gel whose specific surface is about 1/20 of the specific surface of the gel produced by normal curing. Therefore, bond strength of high pressure steam cured concrete is correspondingly lower.

Modulus of Rupture

Modulus of rupture is defined as the normal tensile stress in concrete, when cracking occurs in a flexure test. This tensile stress is the flexural strength of concrete and is calculated by the use of the formula, which assumes that the section is homogeneous.

$S= Mc / I$,

where S = stress in the extreme fibre in kg/cm2.

M = bending moment in kg cm at the failure section.

C = extreme fibre-distance in cms. (from the neutral axis).

I = moment of inertia of the cross-section in cm4.

The loading arrangement is shown in Fig (a). The symmetrical two point loading creates a pure bending zone with constant bending moment in the middle third span and thus the modulus of rupture obtained is not affected by shear, as in the case of a single concentrated load acting on the specimen. The concrete test specimen is a prism of cross-section 10 cm x 10 cm and 40 cms long. It is loaded on a span of 30 cms as shown in figure.

Modulus of rupture is useful as a design criterion for concrete pavements and for evaluating the cracking moment (M_{cr}.), which is the moment that causes the first crack in a prestressed concrete or partially prestressed concrete beam. The modulus of rupture is found to be related to compressive (cylinder) strength of concrete (f'c) and the relationship is given in Fig (b). The use of rough textured or angular or flaky aggregates may cause higher flexural strengths, whereas the compressive strength is not affected.

From Fig (a) the modulus of rupture can be calculated by simple strength of materials knowledge. If P is the load which causes fracture of the prism specimen in kgs, then the modulus of rupture is given by the following formulae

If fracture occurs within the middle third of the span, then
$S = PL/bd^2$

If the fracture occurs outside the middle third, but deviating by not more than 5 percent of the span length, then
$S = 3 Pa/bd2$

where

L = span in centimetres,

a = distance between line of fracture and the nearest- support in cms.

b =average breadth of specimen in cms.

And d =average depth f the specimen in cms.

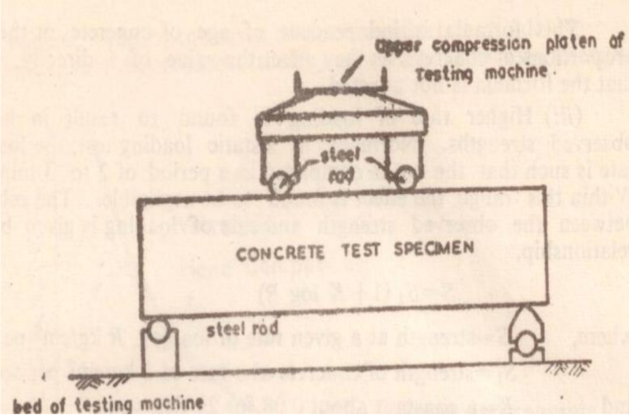


Fig (a) Flexure test for determination of modulus of rupture

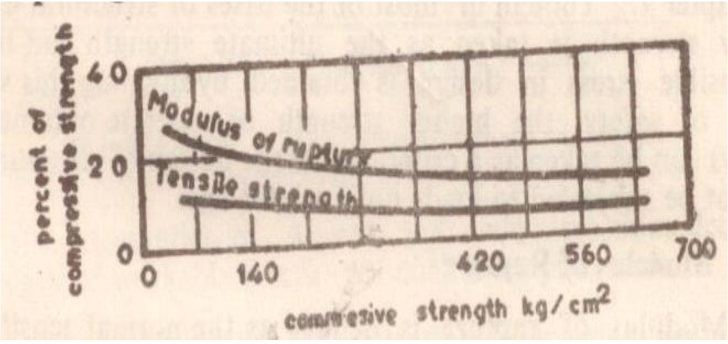


Fig (b): Relationship between compressive strength and modulus of rupture, tensile strength

Accelerated Curing test:

In the accelerated curing test the standard cubes are cast, they are covered with top plate and the joints are sealed with special grease to prevent drying. Within 30 minutes of adding water, the cubes having sealed effectively, are placed in an air-tight oven which is then switched on. The oven temperature is brought to 93°C in about one hour time. It is kept at this temperature for 5 hours. At the end of this period the cubes are removed from oven, stripped, cooled, and tested. The time allowed for this operation is 30 minutes.

The strength of concrete is determined within 7 hours of casting and this accelerated strength shows good relationship with 7 and 28 days strengths of normally cured concrete. Fig 1 shows relationship between accelerated strength and normally cured concrete strength at 7 and 28 days.

One of the main factors that affects the rate of gain of strength is the fineness of cement. It has been estimated that particles of cement over 40 micron in size contribute to the compressive strength of concrete only over long periods, while those particles smaller than 25 to 30 micron contribute to the 28 days strength, those particles smaller than 20 to 25 micron contribute to the 7 days strength, and particles smaller than 5 to 7 micron contribute to the 1 or 2 days strength. Relative gain of strength with the time of concretes made with different water/cement ratio using ordinary Portland cement is shown in Fig (b)

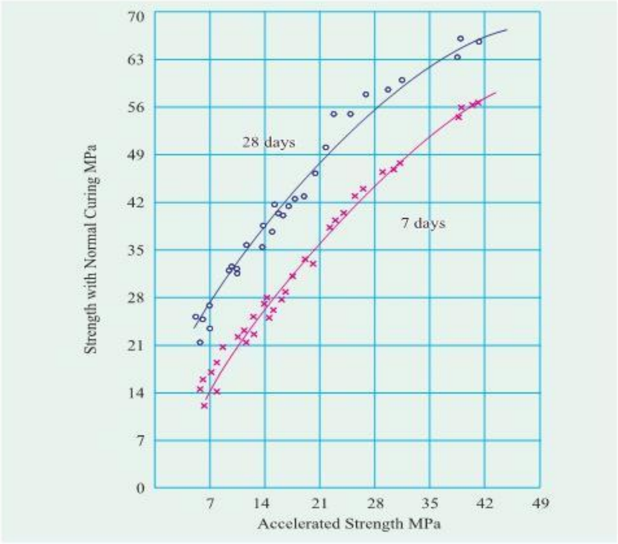


Fig (a): The relation between strength determined by Kings accelerated curing test and the 7 and 28 – days strength of concrete moist – cured at 20^0C

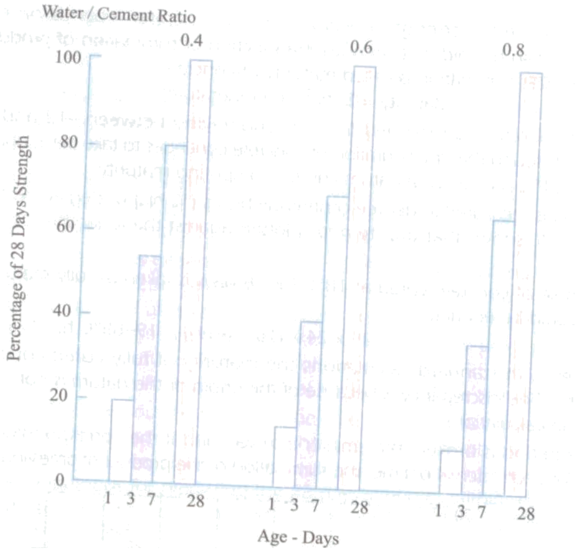


Fig (b): Relative gain of strength with time of concretes with different water/ cement ratios, made with ordinary Portland cement.

Aggregate-Cement Bond Strengths

Concrete can be regarded as a chain in which aggregates are the links bonded together by cement paste. Just as the strength of a chain as a whole is depending upon the strength of welding of the individual links, the strength of concrete as a whole is depending upon the strength (bond strength) of the hydrated hardened cement paste (hcp). By and large the strength of hcp is depending upon w/c ratio which determines the quality, continuity, density, porosity of the products of hydration in particular the C-S-H gel. Stronger the gel bond stronger is the concrete. Aggregates generally being much stronger than the paste (gel bond), its strength is not of consequence in normal strength concrete. The strength of aggregate is of consideration in high strength concrete and light weight concrete.

The explanation that the strength of Concrete is limited by strength of the paste will hold good when we consider concrete as two phase material. If we take a closer look into the structure of the concrete, a third phase comes into consideration i.e., inter-face between the paste and aggregate known as Transition Zone. In the ultimate analysis it is the integrity of the transition zone that influences the strength of concrete.

Bleeding takes place in fresh concrete. The bleeding water in the process of coming up gets intercepted by aggregates, particularly large size flaky and elongated aggregate and gets accumulated at the inter-face between paste and aggregates. The extra water remaining at the inter-face, results in poor paste structure and poor gel bond at the transition zone. The paste shrinks while hardening. The magnitude of shrinkage is higher with higher water content, in which case, a higher shrinkage takes place at the transition zone which results in greater shrinkage cracks at the transition zone.

In case of shrinkage taking place on account of heat of hydration, the weak gel structure at the transition zone also suffers a higher degree of shrinkage. The same situation will take place if the concrete is subjected to heat or cold during the service life.

It can be deduced that there are considerable microcracks or what you call “faults”, exists in the transition zone even before the concrete structures are subjected to any load or stress. When subjected to some stress, the existing micro cracks in transition zone propagate much faster with tiny jumps and develop bigger cracks than rest of the body of concrete and structure fails much earlier than the general strength of concrete. Therefore, the transition zone is the weakest link of the chain. It is the strength limiting phase in concrete.

The w/c ratio that again influences the quality of transition zone in low and medium strength concrete. The w/c ratio is not exerting the same influence on high strength concrete ie., for very low w/c ratio. It has been seen that for w/c less than 0.3, disproportionately high increase in compressive strength can be achieved for very small reduction in w/c. This phenomenon is attributed mainly to a significant improvement in the strength of transition zone at very low w/c ratio.

Aggregate characteristics other than strength, such as size, shape, surface texture and grading are known to affect the strength of concrete. The increase in strength is generally attributed to indirect change in w/c ratio. Recent studies have shown that the above characteristics of aggregates have independent influence on the strength properties of concrete other than through w/c ratio by improving the quality of transition zone.

•Flyover at Mumbai where high strength, high performance concrete 75 MPa was used for the first time in India (2002).

• COMPRESSIVE STRENGTH OF CONCRETE

Objective:

To determine the Compressive strength of concrete cubes.

Scope and Significance

Concrete is primarily strong in compression and in actual construction, the concrete is used in compression. Concrete besides strong in compression is also good in other qualities. Higher the compressive strength better is the durability. Bond strength also improves with the increase in compressive strength and is important in R.C.C. work. Compressive strength also indicates extent of control exercised during construction. Resistance to abrasion and volume stability improves with the compressive strength. Test for compressive strength is, therefore, very important in quality control of concrete. Preparation and conduct of compressive strength is comparatively easy and give more consistent results than tensile strength or flexure strength. This test for determining compressive strength of concrete has, therefore attained maximum importance. For acceptance compressive strength of concrete has, therefore attained maximum importance. For acceptance criteria, refer to IS : 456. Generally 15 cm cubes are used for testing at 28 days.

Apparatus

Cube moulds 150 mm size as per IS: 516, Trowels, GI sheet for mixing, 16 mm dia, 400 mm long tamping rod with bullet pointed at the lower end, Glass plate thicker than 6.5 mm or 13 thick machined plate and of dimensions greater than 17.5 mm, 100 ton compression testing machine

Procedure

- Fill concrete into the mould in layers approximately 5 cm deep by moving the scoop around the top edge of the mould. This is done in order to ensure a symmetrical distribution of the concrete within the mould.
- Compaction: If compaction is done by hand, tamp the concrete with the standard rod, strokes being uniformly distributed over the cross-section of the mould. For 15 cm cube, number of strokes should not be less than 35 per layer. Strokes should penetrate into the underlying layer. Tamp the sides of the mould to close the voids left by tamping bars.

- If compaction is done by vibration, then each layer is compacted by means of suitable vibrating hammer or vibrator or vibrating table. Mode and quantum of vibration of laboratory specimen shall be as nearly the same as those adopted in actual operations.

Curing: Store the specimen in a water bath at temperature of $27^0 \pm 2^0$C for 24 ± ½ hour from the time of addition of water to dry ingredients. Remove the specimen from the mould and keep it immediately submerged in clean, fresh water and keep there until taken out just prior to test. Water in which specimen is submerged shall be renewed every seven days Test for compressive strength:
Age at test: Usually testing is done after 7 days and 28 days, the days being measured from the time the water is added to the dry ingredients.
Test at least three specimens at a time.

Test specimens, after about half an hour an removal from the water, till it is in surface saturated dry condition. If the specimens are received dry, keep them in water for 24 hours before testing.

Note down the dimensions of the specimens nearest to 0.2 mm and also note down their weight.

Placing specimen in the machine:
Place the specimen in such a manner that the load shall be applied to opposite sides of cubes as cast, i.e. not to the tope and bottom.
Align carefully the centre of thrust of the spherically seated platen.
Apply load slowly and at the rate of 140 kg/cm^2/min till the cube breaks

Note the maximum load and appearance of the concrete failure i.e. whether aggregate has broken or cement paste has separated from the aggregate etc.

Observations, Calculations & Results

Date of casting

Date of testing

Standard Values

IS 456 gives seven grade designations as M10, M15, M20, M25, M30, M35 and M40.

The compressive strength requirements for various grades of concrete are given below.

Grade designation	M10	M15	M20	M25	M30	M35	M40
Compressive strength at 28 days N/mm^2	10	15	20	25	30	35	40

Elastic strains *These are the instantaneous deformations that occur when an external stress is first applied*

Shrinkage strains *These deformations occur either on loss of moisture from the concrete on cooling of concrete*

Creep *It is the time-dependent deformation that occurs on the prolonged application of stress*

Deformation Effect

Any one or combinations of the above types of deformations in a hardened concrete leads to cracking.

1. Elastic Strains

Elastic strain in concrete, as defined above, depends on the externally applied stress and the modulus of elasticity of concrete:

Elastic strain

= Externally applied stress/Modulus of elasticity of concrete

Modulus of Elasticity of Concrete

Typical Stress-Strain Plot of Concrete

- At stress below 30% of ultimate strength, the transition zone cracks remain stable. The stress-strain plot remains linear.
- At stress between 30% and 50% of ultimate strength, the transition zone microcracks begin to increase in length, width and numbers. The stress-strain plot becomes non-linear.
- At 50 to 60% of the ultimate stress, cracks begin to form in the matrix. With further increase to about 75% of the ultimate stress, the cracks in the transition become unstable, and crack propagation in the matrix will increase. The stress-strain curve bends towards the horizontal.
- At 75 to 80% of the ultimate stress, the stress reaches a critical stress level for spontaneous crack growth under a sustained stress. Cracks propagate rapidly in both the matrix and the transition zone. Failure occurs when the cracks join together and become continuous.
- Since the stress-strain curve for concrete is nonlinear, following methods for computing the modulus of elasticity of concrete are used yielding various types of modulus of elasticity for concrete:

1. The "initial tangent modulus"

It is given by the slope of a line drawn tangent to the stress-strain curve at the origin

2. The "tangent modulus"

It is given by the slope of a line drawn tangent to the stress-strain curve at any point on the curve

3. The "secant modulus"

It is given by the slope of a line drawn from the origin to a point on the curve corresponding to a 40% stress of the failure stress

4. The "chord modulus"

It is given by the slope of a line drawn between two points on the stress-strain curve

- Calculation of the above four types of moduli of elasticity for concrete has been explained below using a typical stress-strain curve, as shown in the following Modulus of elasticity for concrete determined from an experimental stress-strain relation curve, as described above, is generally termed as *static modulus of elasticity (E_c)* whereas the modulus of elasticity determined through the longitudinal vibration test is termed as *dynamic modulus of elasticity (E_d)*

Static modulus of elasticity (E_c)for concrete

Static modulus of elasticity of concrete has been related to its compressive strength by the various Standards

Relationship between modulus of elasticity of concrete and compressive strength

BS 8110:Part 2:1985 has recommended the following expression for 28-day E_c in terms of 28-day cube compressive strength (f_{cu}), for normal weight concrete (*i.e. concrete with density,* $\rho \approx 2400$ *kg/m*^{3}):

$$E_{c28} = 20 + 0.2\, f_{cu28} \; (\text{where } E_{c28} \text{ is in GPa and } f_{cu28} \text{ is in MPa})$$

Note: For lightweight concrete the above values of E_{c28} should be multiplied by the factors $(\rho/2400)^2$ and $(\rho/150)^2$ respectively.

ACI Building Code 318-89 recommends the following expression for (E_c) in terms of cylinder compressive strength (f_{cyl}), for normal weight concrete (*i.e. concrete with density,* $\rho \approx 2400$ *kg/m*^{3}):

$E_c = 4.7\,(f_{cyl})^{0.5}$	*(where E_c is in GPa and f_{cyl} is in MPa)*
$E_{c,\,28} = 9.1 f_{cu}^{0.33}$	- for normal weight concrete of density = 2400 kg/m^3,

And $E_{c,\,28} = 1.7\rho^2\, f_{cu}^{0.33} \times 10^{-6}$ for lightweight concrete - (ρ) =1400–2400 kg/m^3

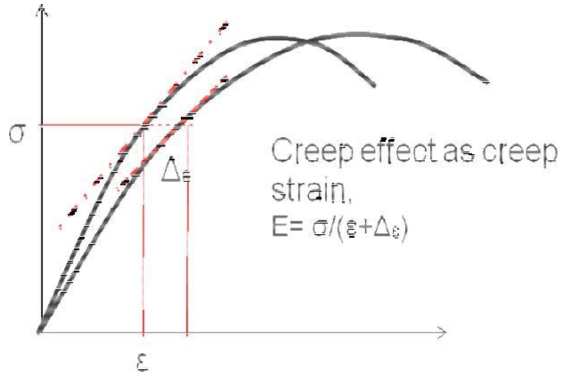
CEB - FIP Model Code (Euro-International)
$E = 2.15 \times 10^4\,(f_{cm}/10)^{1/3}$, E in MPa and f_{cm} in MPa.

Static modulus of elasticity (E_d) for concrete

Experimental stress-strain relation curve, as described above, is generally termed as static modulus of elasticity (E_c) and is short term modulus.
If creep effect is considered at a given load, the modulus determined is referred to as long term modulus of elasticity.
$E_{Long} = E_{Short}/(1+\theta)$,

Where θ is creep coefficient and Creep coefficient is the ratio of creep strain to elastic strain

ELong < Eshort



Dynamic modulus of elasticity (E_d) for concrete

Modulus of elasticity determined through the longitudinal vibration test by velocity of sound or frequency of sound is termed as dynamic modulus of elasticity (E_d) Dynamic modulus of elasticity of concrete (E_d) is approximately taken as equal to the initial tangent modulus of elasticity of concrete. Ed is more as creep effect is not considered.

Dynamic modulus of elasticity for normal and light weight concrete in GN/m^2 (GPa) is given by

$E_c = 1.25\ E_d - 19$ - for Normal weight concrete
and $E_c = 1.04\ E_d - 4.1$ - for light weight concrete,
GN/m^2

If M20 NWC is used, Ec = 22.4 GPa, Ed = 33.12 GPa, 48% more, Conduct NDT on concrete prism Subject beam to longitudinal vibration at its natural frequency and measure the resonant frequency (n, Hz) or the UPV (km/s) through it.

$E_d = Kn^2L^2\rho$; If L in mm,

in kg/m^3, then
$E_d = 4 \times 10^{-15} n^2 L^2 \rho$, in GPa

Appx. Ranges of Resonant Frequencies of Concrete beam 100 x 100 x 500
mm Transverse 900–1600 Hz, Longitudinal 2500–4500 Hz.

If n= 4000 Hz, Ed = 38.4 GPa

Conduct NDT on concrete prism and measure the UPV (km/s) through it. UPV = Path length/Transit time

$$E_d = \rho V^2 \frac{(1+\mu)(1-2\mu)}{(1-\mu)}$$

= Poisson's ratio, 0.2 - 0.24 If V in km/s, ρ *in kg/m*^{3}

Ed in MPa

Let V= 4km/s, $\mu = 0.2$, $\rho = 2400$
kg/m^3 *Ed = 34560 MPa = 34.6 GPa*

Here Ed is more as there is no creep

Determination of modulus of elasticity of concrete

Testing of cube or cylinder in uni-axial compression test.

Measure load and the corresponding deformation as the load is increased. Draw the stress strain curve.

Strain =Dial gauge reading/gauge length = dl/L

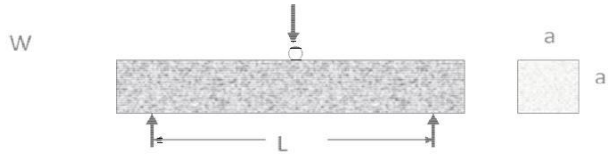
Stress = Load/Cross sectional area= P/A

Use Compressometer and Extensometer to measure deformations. Draw stress strain diagram and determine the required modulus.

Deflection: E can be determined from testing of beam also.

For central point load

Max. deflection, δ = $\mathbf{WL^3/48EI_{xx}}$



Poisson's ratio

In analysis and design of some type of structure the knowledge of poisson's ratio is required. When a material is compressed in one direction, it usually tends to expand in the other two directions perpendicular to the direction of compression. This phenomenon is called the Poisson effect. Poisson's ratio μ is a measure of the Poisson effect. The Poisson ratio is the ratio of the fraction (or percent) of expansion divided by the fraction (or percent) of compression, for small values of these changes. $\mu = 0.15 - 0.20$ – Actual value to be found from strain measurements on concrete cylinder using extensometer.

An alternate method for finding Poisson's ratio is from UPV test and by finding the fundamental natural frequency of longitudinal vibration of concrete beam. The Poisson's ratio can be found from the following equation. The Poisson's ratio is slightly higher and it ranges from 0.2 to 0.24.

Where V = Pulse velocity mm/s

n = Resonant frequency in Hz and

L= Length of the beam in mm.

= The density of concrete

E_d = Dynamic modulus of elasticity of concrete

$$\left(\frac{V^2}{2nL}\right)^2 = \frac{1-\mu}{(1+\mu)(1-2\mu)} \quad , \quad E_d = \rho V^2 \frac{(1+\mu)(1-2\mu)}{(1-\mu)}$$

Factors affecting modulus of elasticity

1.Cement and aggregate factors

Since concrete is a composite material, consisting of cement paste and aggregate, its modulus of elasticity depends on the moduli of elasticity and the volume fractions of cement paste and aggregate, as follows:

$E_c = [\ \{(1-V_a)E_p + (1+V_a)\ E_a\} /\ \{(1+V_a)E_p + (1-V_a)\ E_a\}]E_p$

Where, E_c = modulus of elasticity of concrete

E_p = modulus of elasticity of cement paste

E_a = modulus of elasticity of aggregate

V_a = volume fraction of aggregate = $1-V_p$

V_p = volume fraction of cement paste = $1-V_a$

E_p depends on the porosity of cement paste and the porosity of cement paste depends on the gel/space ratio (E_p is approximately proportional to the cube of the gel/space ratio) and gel/space ratio finally depends on the w/c ratio (gel/space ratio is inversely proportional to w/c ratio)
Note: The reason behind relating E_p with compressive strength of concrete lies in the fact that the compressive strength is also affected in the same way as, E_p

E_a for lightweight aggregates is found to be much lower than that for the normal weight aggregate. This is why the elastic modulus of lightweight concrete is less than that of the normal-weight aggregate ($E_{c,\text{ light weight concrete}}$ = 0.4 to 0.8 $E_{c,\text{ normal weight concrete}}$)

2. Moisture condition factor

The moisture condition of the specimen is a factor: a wet specimen has a modulus of elasticity higher than by 3 to 4 GPa than a dry one.

Note: The effect of moisture condition of specimen is reverse in case of the compressive strength.

3. Condition of curing

Another factor affecting the modulus of elasticity of concrete is the manner in which the test cylinders were cured. In general, concrete specimens that were cured in moist conditions resulted in a modulus value higher than those cured in dry conditions. This is due to the fact that in dry conditions concrete is more likely to have drying shrinkage. Drying shrinkage causes small cracks. These small cracks thus will cause the concrete to have a reduced modulus of elasticity.

Age of concrete: As age increases, E increases
Mix proportion (C + A + W): All ingredients will have its own effect. For a given mix, the effect of one variable should be considered keeping all other variables constant.

Strength of concrete: As strength increases, E increases as shown in Table

Variation of modulus of elasticity

(GPa) with compressive strength

(MPa) for concrete

Compressive strength, fck,	Modulus of elasticity, E, GPa

Rate of loading. As the rate of loading increases, E also increases as the creep effect is less. Size and shape of specimen - Cube vs cylinder, small vs large

Effect of transition zone
The void spaces and the micro cracks in the transition zone play a major role in affecting the stress-strain behavior of concrete.

The transition zone characteristics affect the elastic modulus more than it affects the compressive strength of concrete.

Silica fume, metakaolin, RHA in concrete have significant effect Shrinkage

Shrinkage is the reduction in the volume of a freshly hardened concrete exposed to the ambient temperature and humidity

Reduction in the volume due to shrinkage causes volumetric strain. Volumetric strain is equal to 3 times the linear strain
In practice, *shrinkage is measured simply as a linear strain*

Types of Shrinkage

Shrinkage in concrete is caused mainly by loss of water by evaporation or by hydration of cement. However, fall of temperature and carbonation may also cause the shrinkage

Following are the various classifications of the shrinkage depending upon the cause of shrinkage:

Types of shrinkages, caused *due to loss of water*

Plastic shrinkage occurs due to loss of water by evaporation from *freshly placed concrete* while the cement paste is plastic
Plastic shrinkage is higher at a higher rate of evaporation of water, which in turn depends on the air temperature, the concrete temperature, the relative humidity of the air and wind speed
Plastic shrinkage of concrete is higher at a larger cement content (i.e. smaller the aggregate content by volume) of the mix.

Drying shrinkage occurs due to loss of water by evaporation from *freshly hardened concrete* exposed to air
When the concrete which has undergone to drying shrinkage is subsequently placed in water (or at higher humidity) it will swell due to absorption of water by the cement paste getting partial recovery from the shrinkage

The amount of shrinkage recovered on placing the concrete in water (or at higher humidity) is called *"reversible moisture movement or reversible shrinkage"* and the un-recovered shrinkage is called "*residual or irreversible shrinkage"*

∴ Drying shrinkage = reversible shrinkage + irreversible shrinkage
Reversible shrinkage = 40 to 70 % of drying shrinkage

Reversible shrinkage will form a greater proportion of the drying shrinkage if concrete is cured so that it is fully hydrated before being exposed to drying

Irreversible shrinkage will form a greater proportion of the drying shrinkage if concrete is not fully hydrated before being exposed to drying, or drying is accompanied by extensive carbonation, or both

Autogenous shrinkage occurs due to loss of water by *self-desiccation* of concrete during hydration
Note: Self-desiccation is a phenomenon by virtue of which concretes, with a low w/c ratio (theoretically below 0.42), begin to dry out due to the internal consumption of water during hydration and not due to the loss of water to the outside by evaporation

Autogenous shrinkage is very small, typically 50×10^{-6} to 100×10^{-6}.

Types of shrinkages, caused *due to cooling and carbonation*
(a) *Thermal shrinkage* occurs due to excessive fall in temperature
(b) *Carbonation shrinkage* occurs due to carbonation

"Carbonation" is the process in which the CO_2 gas present in the atmosphere forms carbonic acid in the presence of moisture. The carbonic acid reacts with the $Ca(OH)_2$ of hydrated cement to form $CaCO_3$. This process of carbonation causes contraction of concrete known as carbonation shrinkage.

Carbonation shrinkage depends on the rate of carbonation and the rate of carbonation depends on the various factors, namely; permeability of concrete, its moisture content, and on the 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 influencing shrinkage

1. *Effect of cement paste and aggregate content*

- In concrete, shrinkage is induced by the cement paste but restrained by the aggregate
-
- For a constant water/cement ratio, and at a given degree of hydration, the relation between shrinkage of concrete (s_{hc}), shrinkage of neat cement paste (s_{hp}), and the volumetric content of aggregate (V_a) is given as:

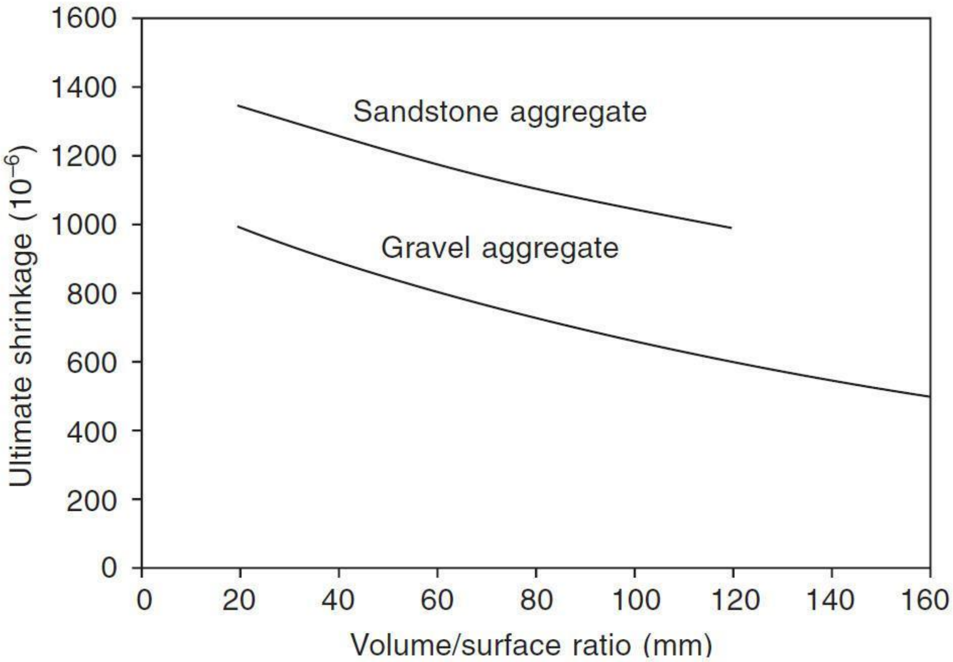
$s_{hc} = s_{hp}\,(1-V_a)^n = s_{hp}\,(V_p)^n$

where, n = a constant which depends on the moduli of elasticity and Poisson's

ratios of the aggregate and of the concrete V_a =
volumetric fraction of aggregate = 1 - V_p

2. *Effect of type of aggregate*
(Strictly speaking effect of modulus of elasticity of aggregate)

A *lightweight concrete* made with lightweight aggregate *exhibits a higher shrinkage than normal weight concrete* made with normal weight aggregate. This is because of the lower modulus of elasticity of lightweight concrete as compared to normal weight concrete



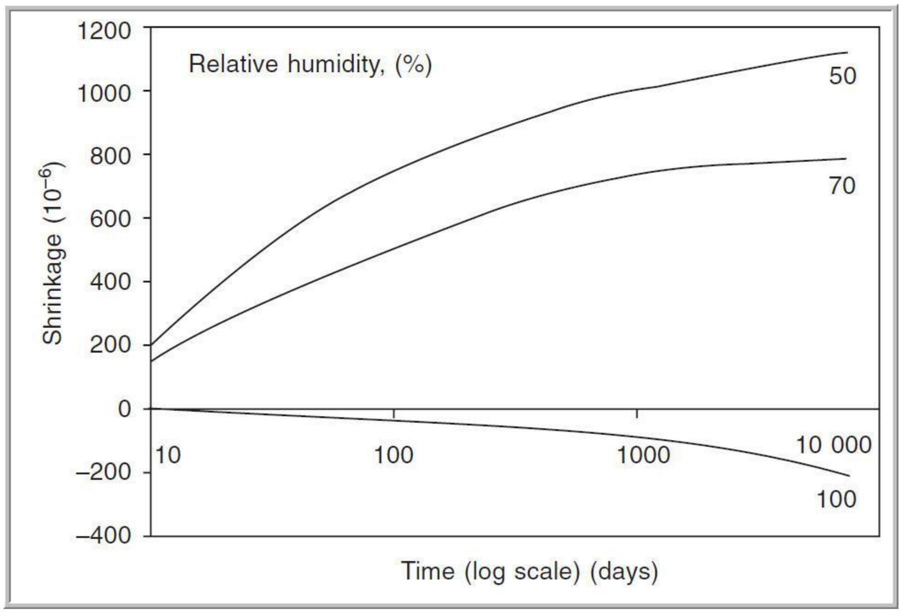
Influence of volume/surface ratio on shrinkage of concrete

3. *Effect of water/cement ratio*

For a given aggregate content, shrinkage of concrete is a function of the water/cement ratio
Higher the water/cement ratio the larger the shrinkage

4. Effect of relative humidity

As shown in the following Fig., the relative humidity of the air surrounding the concrete greatly affects the magnitude of shrinkage



- Shrinkage is more at lower relative humidity

5. Effect of time

Shrinkage takes place over long periods. However, *large fraction* of the ultimate shrinkage (which is mainly the drying shrinkage) *takes place at early times* and the *small fraction* of the ultimate shrinkage (which is mainly the carbonation shrinkage) *takes place over long periods*

Percent of 20-year shrinkage	*Occurs in*
14 to 34	2 weeks
40 to 80	3 months
66 to 85	1 year

6. Effect of size and shape of the concrete member

The actual shrinkage of a given concrete member is affected by its size and shape Generally, *shrinkage* is expressed as a *function of* the *ratio volume/exposed surface*

Following Fig shows that there is a linear relation between the logarithm of ultimate shrinkage and the volume/surface ratio

CREEP

Creep is defined as the increase in strain under a sustained constant stress after taking into account other time-dependent deformations not associated with stress (viz. shrinkage, swelling and thermal deformations

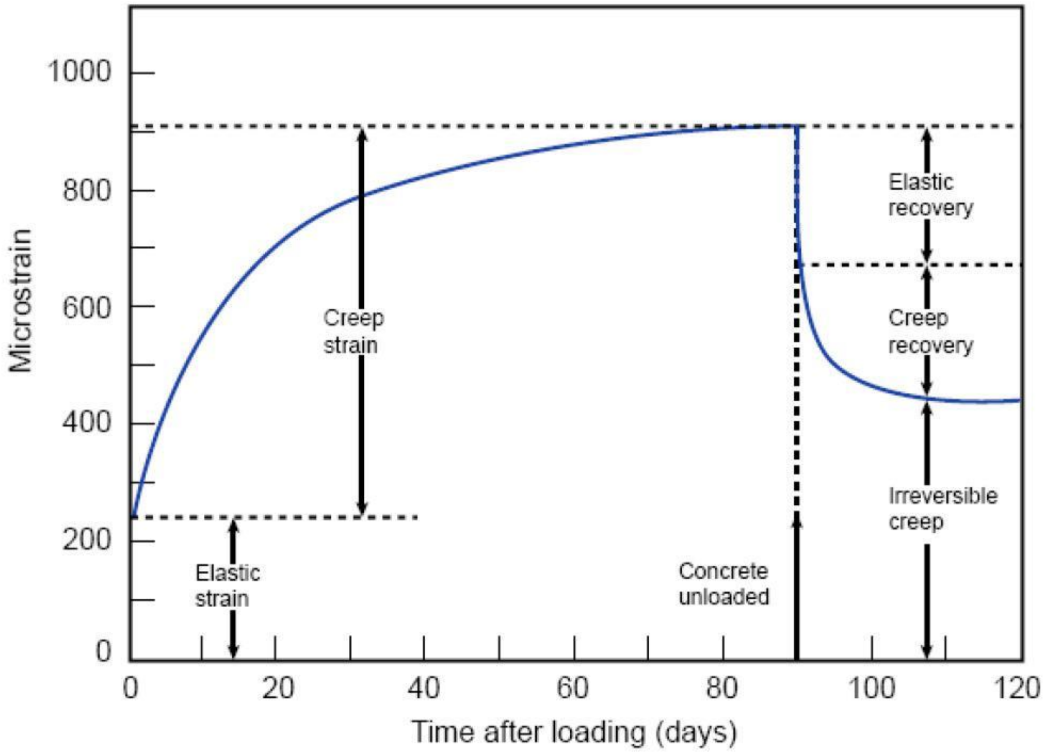
The creep is counted from the initial elastic strain, σ_0/E, (where σ_0 is compressive stress applied to the concrete after curing for time t_0 and E is the secant modulus of elasticity of concrete).

Stress relaxation

It is decrease in stress with time due to creep of a concrete member loaded and restrained so that it is subjected to a constant strain.

Creep and creep recovery

The creep and creep recovery are illustrated with the help of a typical creep curve for plain concrete, as follows:



Factors influencing creep

1. Effect of modulus of elasticity of aggregate.
2. Effect of aggregate content
3. Effect of water/cement ratio
4. Effect of age at application of load
5. Effect of relative humidity
6. Effect of volume/surface ratio of member
7. Effect of temperature

Creep development with time

Percent of 20-year creep	*Occurs in*
25	2 weeks
50	3 months
75	1 year

Factors Affecting Drying Shrinkage and Creep

(1) Effects of Cement Paste and Aggregate - Drying shrinkage and creep increase as the cement paste volume fraction increases.

* Equation for predicting drying shrinkage of concrete (S_c) from the drying shrinkage of the cement paste (S_p):

$S_c = S_p (1 - g)^n$

where g = volume fraction of aggregate + unhydrated cement

n = 1.2 to 1.7, depending on the elastic modulus of the aggregate. (n decreases as the elastic modulus increases.)

Equation for predicting the creep of concrete (Cc) from the creep of the cement paste (Cp):
$Cc = Cp (1 - g)n$

Similarities between Drying Shrinkage and Creep •

1. Their strain-time curves are similar.
2. Both originate from the same source, the hydrated cement paste.
3. The factors that influence drying shrinkage also influence the creep in generally the same manner.
4. Both are partially reversible.
5. Strains from both drying shrinkage and creep can not be ignored in structural design.

Terminology used in Drying Shrinkage and Creep

Thermal Shrinkage: Thermal Properties of Concrete

Coefficient of thermal expansion (μ)

The length change per unit length per degree of temperature change.
It can be estimated from the weighted average of the coefficients of thermal expansion of its components, i.e. the aggregate and the cement mortar. – Typical value of α for concrete varies from 6 to 12 X 10-6 /°C and for steel = 11 X 10-6 /°C
Concrete expands on heating and contract on cooling.
Thermal expansion or contraction strain (εT) is linearly related to coefficient of thermal expansion (μ) and the change in temperature (εT), $\varepsilon T = \mu T$
If the concrete is fully restrained, the induced stress due to the temperature change (T) will be equal to: $\sigma T = E (\mu T - \varepsilon cr)$

- At the early ages of concrete, concrete usually rises in temperature as the cement hydrates. This results in compressive stresses. However, stress relaxation is high and E is low at early ages. Therefore, the resulting compressive stress will be small, and usually does not cause any problem.
  However, when the concrete cools down to the ambient temperature from its peak temperature, the temperature drop will cause thermal shrinkage and may induce a tensile stress in the concrete.
- In mass concrete, the difference between the peak temperature of the concrete and the ambient temperature could be very large, and the temperature drop could induce a tensile stress to cause thermal cracking of the concrete.

UNIT 4

CONCRETE MIX DESIGN

Introduction

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking.

The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

2. Requirements of concrete mix design

The requirements which form the basis of selection and proportioning of mix ingredients are:

- The minimum compressive strength required from structural consideration
- The adequate workability necessary for full compaction with the compacting equipment available.

- Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions.

- Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

2.1 Types of Mixes

i. Nominal Mixes

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

ii. Standard mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

iii. Designed Mixes

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm^2. No control testing is necessary reliance being placed on the masses of the ingredients.

- **Factors affecting the choice of mix proportions**

The various factors affecting the mix design are:

Compressive strength

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

Workability

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

Durability

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

Maximum nominal size of aggregate

In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate.

IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

Grading and type of aggregate

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive.

The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

Quality Control

The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

Mix Proportion designations

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass

Factors to be considered for mix design

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The cement content is to be limited from shrinkage, cracking and creep.

The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

Examples of concrete mix proportioning

Problems - M40 pumpable concrete		
A-1 Design stipulations for proportioning		**Data**
a)	Grade designation	: M40
b)	Type of cement	: OPC 43 grade confirming to IS 8112
c)	Maximum nominal size of aggregates	: 20 mm
d)	Minimum cement content	: 320 kg/m^3
e)	Maximum water cement ratio	: 0.45
f)	Workability	: 100 mm (slump)
g)	Exposure condition	: Severe (for reinforced concrete)
h)	Method of concrete placing	: Pumping
i)	Degree of supervision	: Good
j)	Type of aggregate	: Crushed angular aggregate
k)	Maximum cement content	: 450 kg/m^3

l)	Chemical admixture type	: Superplsticiser
A-2 TEST DATA FOR MATERIALS		
a)	Cement used	: OPC 43 grade confirming to IS 8112
b)	Specific gravity of cement	: 3.15
c)	Chemical admixture	: Superplasticiser conforming to IS 9103
d)	Specific gravity of	
	Coarse aggregate	: 2.74
	Fine aggregate	: 2.74
e)	Water absorption	
	Coarse aggregate	: 0.5 percent
	Fine aggregate	: 1.0 percent
f)	Free (surface) moisture	
	Coarse aggregate	: Nil (absorbed moisture also nil)
	Fine aggregate	: Nil
g)	Sieve analysis	
	Coarse aggregate	: Conforming to Table 2 of IS: 383
	Fine aggregate	: Conforming to Zone I of IS: 383

A-3 TARGET STRENGTH FOR MIX PROPORTIONING

$$f'_{ck} = f_{ck} + 1.65\, s$$

Where

f'_{ck} = Target average compressive strength at 28 days,

f_{ck} = Characteristic compressive strength at 28 days, s= Standard deviation

From Table 1 standard deviation, s = 5 N/mm^2

Therefore target strength = 40 + 1.65 x 5 = 48.25 N/mm^2

A-4 SELECTION OF WATER CEMENT RATIO

From Table 5 of IS:456-2000, maximum water cement ratio = 0.45

Based on experience adopt water cement ratio as 0.40 0.4 < 0.45, hence ok

A-5 SELECTION OF WATER CONTENT

From Table-2, maximum water content = 186 liters (for 25mm – 50mm slump range and for 20 mm aggregates)

Estimated water content for 100 mm slump = 186 + 6/100 x186 = 197 liters

As superplsticiser is used, the water content can be reduced up to 20 percent and above Based on trials with SP water content reduction of 29 percent has been achieved. Hence the water content arrived = 19 x 0.71 =140 liters

A-6 CALCULATION OF CEMENT CONTENT

Water cement ratio = 0.40

From Table 5 of IS: 456, minimum cement content for severe exposure condition = 320 kg/m^3 350 kg/m^3 > 320 kg/m^3, hence OK

A-7 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60

In the present case w/c= 0.40. The volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As w/c ratio is lower by 0.10, increase the coarse aggregate volume by 0.02 (at the rate of -/+ 0.01 for every +/- 0.05 change in water cement ratio). Therefore corrected volume of coarse aggregate for w/c of 0.40 =0.62

Note: In case the coarse aggregate is not angular, then also the volume of CA may be required to be increased suitably based on experience

For pumpable concrete these values should be reduced by 10 percent

Therefore volume of coarse aggregate = 0.62 x 0.9 = 0.56

Volume of fine aggregate content = 1- 0.56 = 0.44

A-8 MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows:

a. Volume of concrete = 1 m3

b. • Volume of cement = (Mass of Cement x 1)/ Specific gravity x 1000

c. • Volume of water =[350/3.15] x [1/1000] = 0.111 m3

d. • Volume of chemical admixture (SP 2%by mass of cement) = •

[140/1] x [1/1000] = 0.140 m3

[7/1.145] x [1/1000] = 0.006 m3

e Volume of all in aggregates = a – (b + c + d)

• Volume of coarse aggregates = . 1 – (0.111 + 0.140 + 0.006) = 0.743 m3

• Volume of fine aggregates = . e x Volume of CA x specific gravity of CA

. 0.743 x 0.56 x 2.74 x 1000 = 11140 kg

e x Volume of FA x specific gravity of FA

0.743 x 0.44 x 2.74 x 1000 = 896 kg

A-9 MIX PROPORTIONS FOR TRIAL NUMBER 1

Cement	= 350 kg/m^3
Water	= 140 kg/m^3
Fine aggregate	= 896 kg/m^3
Coarse aggregates	= 1140 kg/m^3
Chemical admixture	= 7 kg/m^3
Water cement ratio	= 0.40

Aggregates are assumed to be in SSD. Otherwise corrections are to be applied while calculating the water content. Necessary corrections are also required to be made in mass of aggregates.

A-10 The slump shall be measured and the water content and dosages of admixture shall be adjusted for achieving the required slump based on trials, if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

A-11 Two more trials having variation of ± 10 percent of water cement ratio in **A-10** shall be carried out keeping water content constant, and a graph between three water cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, durability requirements shall be met.

UNIT 5

SPECIAL CONCRETE

Introduction

- Special types of concrete are those with out-of-the-ordinary properties or those produced by unusual techniques. Concrete is by definition a composite material consisting essentially of a binding medium and aggregate particles, and it can take many forms.
- These concretes do have advantages as well as disadvantages.

Types of special concrete

1. High Volume Fly Ash Concrete.
2. Silica fumes concrete.
3. GGBS, Slag based concrete.
4. Ternary blend concrete.
5. Light weight concrete.
6. Polymer concrete.
7. Self-Compacting Concrete.
8. Coloured Concrete.
9. Fibre-reinforced Concrete.
10. Pervious Concrete.
11. Water-proof Concrete.
12. Temperature Controlled Concrete.

High Volume Fly Ash Concrete.

- Is used to replace a portion of the Portland cement used in the mix.
- According to IS: 456 – 2000 replacement of OPC by Fly-ash up to 35% as binding material is permitted.
- HVFAC is a concrete where excess of 35% of fly-ash is used as replacement.
- Use of fly ash is because of many factors such as

a) Abundance of fly ash i.e. 110million tons of fly ash is produced in India every year.

b) Fly ashes from major TPP are of very high quality i.e. quality of fly ash.

c) Economic factor i.e. Cost of fly ash within 200 km from a TPP is as low as 10% to 20% of the cost of cement.

d) Environmental factors i.e. reduction in CO2 emission.

Silica fume concrete

- Very fine non-crystalline silica produced in electric arc furnaces as a by-product.
- Highly reactive pozzolana used to improve mortar and concrete.
- Silica fume in concrete produces two types of effect viz.
- Physical effect
- Chemical effect
- The transition zone is a thin layer between the bulk hydrated cement paste and the aggregate particles in concrete. This zone is the weakest component in concrete, and it is also the most permeable area. Silica fume plays a significant role in the transition zone through both its physical and chemical effects.

Physical Effect

- The presence of any type of very small particles will improve concrete properties. This effect is termed either "particle packing" or "micro filling".
- Physical mechanisms do play a significant role, particularly at early ages.

Chemical Effect

- Silica fume is simply a very effective pozzolanic material.
- Pozzolanic means a siliceous or siliceous and aluminous material, which in itself possess little or no cementious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementious properties.

GGBS, Slag based concrete

- By-product of the iron manufacturing industry, replacement of Portland cement with GGBS will lead to significant reduction of carbon dioxide gas emission.

- GGBS powder is almost white in colour in the dry state Fresh GGBS concrete may show mottled green or bluish-green areas on the surface mainly due to the presence of a small amount of sulphide.
- GGBS concrete requires longer setting times than Portland cement concrete, probably due to the smooth and glassy particle forms of GGBS. If the temperature is 23oC or replacement level of portland cement by GGBS is less than 30%, the setting times will not significantly be affected.

When GGBS replacement level is less than 40%, bleeding is generally unaffected. At higher replacement levels, bleeding rates may be higher.

- GGBS concrete has lower early strengths because the rate of initial reaction of GGBS is slower than that of Portland cement. GGBS is therefore generally grounded to a finer state than Portland cement i.e. from around 4000 cm2/g to 6000 cm2/g resulting in significant increase in 28-day strength.
- It was also reported that the early strengths (up to 28 days) of concrete mixes (with 25%, 35%, 50%, and 60% GGBS replacements) were lower than that of Portland cement concrete mixes. By 56 days, the strength of 50% and 60% GGBS mixes exceeded that of the Portland cement mix, and by one year all GGBS mixes were stronger than the Portland cement mixes.
- Due to its longer setting time, it can be transported to distant places but care should be taken while casting because there are chances that bleeding may take place.

Light weight concrete

- Structural lightweight concrete is similar to normal weight concrete except that it has a lower density.
- Made with lightweight aggregates.
- Air-dry density in the range of 1350 to 1850 kg/m^3
- 28-day compressive strength in excess of 17 Mpa.
- Structural lightweight concrete is used primarily to reduce the dead-load weight in concrete members, such as floors in high-rise buildings.
- **Structural Lightweight Aggregates:**

➢ Rotary kiln expanded clays, shales, and slates

➢ Sintering grate expanded shales and slates

➢ Pelletized or extruded fly ash

➢ Expanded slags

- **Compressive Strength:**

The compressive strength of structural lightweight concrete is usually related to the cement content at a given slump and air content, rather than to a water-to-cement ratio. This is due to the difficulty in determining how much of the total mix water is absorbed into the aggregate and thus not available for reaction with the cement.

- **Slump:**

1. Due to lower aggregate density, structural lightweight concrete does not slump as much as normal-weight concrete with the same workability.
2. A lightweight air-entrained mixture with a slump of 50 to 75 mm (2 to 3 in.) can be placed under conditions that would require a slump of 75 to 125 mm (3 to 5 in.)
3. With higher slumps, the large aggregate particles tend to float to the surface, making finishing difficult.

Polymer concrete

Polymer concrete is part of group of concretes that use polymers to supplement or replace cement as a binder. The types include polymer-impregnated concrete, polymer concrete, and polymer-Portland-cement concrete.

- In polymer concrete, thermosetting resins are used as the principal polymer component due to their high thermal stability and resistance to a wide variety of chemicals.
- Polymer concrete is also composed of aggregates that include silica, quartz, granite, limestone, and other high quality material.
- Polymer concrete may be used for new construction or repairing of old concrete.
- The low permeability and corrosive resistance of polymer concrete allows it to be used in swimming pools, sewer structure applications, drainage channels, electrolytic cells for base metal recovery, and other structures that contain liquids or corrosive chemicals.
- It is especially suited to the construction and rehabilitation of manholes due to their ability to withstand toxic and corrosive sewer gases and bacteria commonly found in sewer systems.
- It can also be used as a replacement for asphalt pavement, for higher durability and higher strength.
- Polymer concrete has historically not been widely adopted due to the high costs and difficulty associated with traditional manufacturing techniques.

Self-compacting concrete

- Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement.
- The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.
- Very close to the Kolhapur there is project of steel industry, sand used for the formation of mould when the moulds are opened the waste sand is dumped for the filling the low lying areas while doing this the agriculture areas is converted into barren area. Because there is no space for the waste other than the land filling. similar case is in case of aluminium industry where red mud is concluded to be waste, which contains lot amount of bauxite and that is why red mud is also dump in the nearby areas here it is causing big threat for the society and it is disturbing the eco system of the environment. So it is the need to use this particular otherwise waste material for the constructive in such fashion in the case of concrete so that concrete which became cost effective as well as eco-friendly.
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Types

1. **Powder type of self-compacting concrete**: This is proportioned to give the required self-compatibility by reducing the water-powder ratio and provide adequate segregation resistance.
2. **Viscosity agent type self-compacting concrete**: This type is proportioned to provide self-compaction by the use of viscosity modifying admixture to provide segregation resistance.
3. **Combination type self-compacting concrete**: This type is proportioned so as to obtain self-compatibility mainly by reducing the water powder ratio.

Fresh SCC Properties

1. Filling ability (excellent deformability)
2. Passing ability (ability to pass reinforcement without blocking)
3. High resistance to segregation.

- It has been observed that the compressive strength of self-compacting concrete produced with the combination of admixtures goes on increasing up to 2% addition of red mud.

- After 2% addition of red mud, the compressive strength starts decreasing, i.e. the compressive strength of self-compacting concrete produced is maximum when 2% red mud is added.

The percentage increase in the compressive strength at 2% addition of red mud is +9.11 .

Fibre reinforced concrete

- Fibre reinforced concrete (FRC) may be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibres.
- The role of randomly distributes discontinuous fibres is to bridge across the cracks that develop provides some post- cracking “ductility”.
- The real contribution of the fibres is to increase the toughness of the concrete under any type of loading.
- The fibre reinforcement may be used in the form of three – dimensionally randomly distributed fibres throughout the structural member when the added advantages of the fibre to shear resistance and crack control can be further utilised.