ATME College of Engineering

13th K M Stone, Bannur Road, Mysore – 570028

DEPARTMENT OF CIVIL ENGINEERING

(ACADEMIC YEAR 2025-26)

Concrete Technology

SUB CODE: BCV503

SEMESTER: V

Vision of the Institute

Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

Mission of the Institute

To keep pace with advancements in knowledge and make the students competitive and capable at the global level.

To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torchbearers of tomorrow's society.

To strive to attain ever-higher benchmarks of educational excellence.

Vision of the Department

To develop globally competent civil engineers who excel in academics, research and are ethically responsible for the development of the society.

Mission of the Department

To provide quality education through faculty and state of the art infrastructure To identify current problems in the society pertaining to Civil Engineering disciplines and to address them effectively and efficiently

To inculcate the habit of research and entrepreneurship in our graduates to address current infrastructure needs of society

PEO's

Graduates who complete their UG course through our institution will be,

PEO I- Engaged in professional practices, such as construction, environmental, geotechnical, structural, transportation, or water resources engineering by using technical, communication and management skills.

PEO 2- Engaged in higher studies and research activities in various Civil Engineering fields and a life time commitment to learn ever changing technologies to satisfy increasing demand of sustainable infrastructural facilities

PEO 3- Serve in a leadership position in any professional or community organization, or local/state engineering board

PEO 4- Registered as a professional engineer or developed a strong ability leading to professional licensure being an entrepreneur.

PROGRAM OUTCOMES

1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. Problem analysis: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PSO’s

PSO1: Provide the necessary infrastructure for all situations through competitive plans, maps and designs with the aid of a thorough Engineering Survey and Quantity Estimation.

PSO 2: Assess the impact of anthropogenic activities leading to environmental imbalance on land, in water & in air and provide necessary viable solutions revamping water resources and transportation for a sustainable development.

CONCRETE TECHNOLOGY

Subject Code	**:**	**BCV503**		**I.A. Marks**	**:**	**50**
Hours/Week	**:**	**03**		**Exam Hours**	**:**	**03**
Total Hours	**:**	**40**		**Exam Marks**	**:**	**100**

Syllabus

Module 1 - Concrete Ingredients

Cement manufacturing process, chemical composition and their importance, hydration of cement, types of cement. Testing of cement, steps to reduce carbon footprint. Fine aggregate: Functions, requirement, Alternatives to River sand, M-sand introduction, and manufacturing. Coarse aggregate: Importance of size, shape and texture. Grading and blending of aggregate. Testing on aggregate, requirement. Recycled aggregates Water – qualities of water. Chemical admixtures – plasticizers, accelerators, retarders, and air entraining agents. Mineral admixtures – Pozzolanic and cementitious materials, Fly ash, GGBS, silica fumes, Metakaolin and rice husk ash. **8 Hours**

Module 2 - Fresh Concrete

Factors affecting workability. Measurement of workability–slump, Compaction factor and Vee-Bee Consistometer tests, flow tests. Segregation and bleeding. Process of manufacturing of concrete- Batching, Mixing, Transporting, Placing and Compaction. Curing – Methods of curing – Water curing, membrane curing, steam curing, accelerated curing, self- curing. Good and Bad practices of making and using fresh concrete and Effect of heat of hydration during mass concreting at project sites. **8 Hours**

Module 3 - Hardened Concrete

Factors influencing strength, W/C ratio, gel/space ratio, Maturity concept, testing of hardened concrete, Creep – factors affecting creep. Shrinkage of concrete – plastic shrinking and drying shrinkage, Factors affecting shrinkage. Definition and significance of durability. Internal and external factors influencing durability, Mechanisms- Sulphate attack – chloride attack, carbonation, freezing and thawing. Corrosion, Durability requirements as per IS-456, In situ testing of concrete- Penetration and pull-out test, rebound hammer test, ultrasonic pulse velocity, core extraction – Principal, applications and limitations. **8 Hours**

Module 4 - Concrete Mix Design

Principles of concrete mix design, Parameters and factors influencing mix design, Concept of Mix Design with and without admixtures, variables in proportioning and Exposure conditions, Selection criteria of ingredients used for mix design, Procedure of mix proportioning. Numerical Examples of Mix Proportioning using IS: 10262:2019. **8 Hours**

Module 5

RMC-manufacture and requirement as per QCI-RMCPCS, properties, advantages, and disadvantages. Self-Compacting concrete- concept, materials, tests, properties, application and typical mix Fiber reinforced concrete - types of fibres, properties, application of FRC. Light weight concrete-material properties and types. Typical light weight concrete mix proportion and applications, materials, requirements, mix proportion and properties of Geo polymer Concrete, High Strength Concrete and High-Performance Concrete**.** **8 Hours**

Text Books:

1. Neville A.M. “Properties of Concrete”-4th Ed., Longman.

2. M.S. Shetty, Concrete Technology - Theory and Practice Published by S. Chand and Company, New Delhi.

Reference Books:

1. Kumar Mehta. P and Paulo J.M. Monteiro “Concrete-Microstructure, Property and Materials”, 4th Edition, McGraw Hill Education, 2014

2. A.R. Santha Kumar, “Concrete Technology”, Oxford University Press, New Delhi (New Edition).

Course objectives: This course will enable students to:

1. To recognize material characterization of ingredients of concrete and its influence on properties of concrete
2. To study the properties of fresh concrete and hardened concrete
3. Proportion ingredients of Concrete to arrive at most desirable mechanical properties of Concrete.
4. Ascertain various types of special concrete with their properties.

Course outcomes: After studying this course, students will be able to:

CO1: Relate material characteristics and their influence on microstructure of concrete.

CO2: Distinguish concrete behavior based on its fresh and hardened properties.

CO3: Illustrate proportioning of different types of concrete mixes for required fresh and hardened properties using professional codes.

CO4: Select a suitable type of concrete based on specific application.

Module - 1 Concrete Ingredients

Contents:-

1.1 Cement

1.1.1 Introduction to cement

1.1.2 Objective

1.1.3 History of cement

1.1.4 Characteristics of cement

1.1.5 Properties of cement

1.1.6 Chemical Composition

1.1.7 Hydration of cement

1.1.8 Types of cement

1.1.9 Manufacturing process of cement

1.1.10 Testing on cement

1.1.11 Steps to reduce Carbon foot print in manufacturing process

1.2 Aggregates

1.2.1 Introduction

1.2.2 Classification of aggregate

Fine aggregates

1.2.3 Quality of a good aggregate

1.2.4 Function of aggregates

1.2.5 Grading of aggregates

1.2.6 Tests on fine aggregate

1.2.7 Alternative to river sand

1.2.8 Manufacture Sand

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1.3.3 Recycled aggregates

1.3.4 Process of manufacturing recycled aggregates

1.3.5 Blending of aggregates

1.4 Water

1.4.1 Quality of water

1.4.2 Use of sea water for mixing concrete

1.5 Admixtures

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Chemical Admixture

1.5.1.1 Plasticizers

1.5.1.2 Super Plasticizers

1.5.1.3 Retarders

1.5.1.4 Retarding Plasticizers

1.5.1.5 Accelerators

1.5.1.6 Accelerating Plasticizers

1.5.1.7 Air entraining admixtures

Mineral admixtures

1.5.1.8 Fly ash

1.5.1.9 Ground Granulated Blast Furnace Slag

1.5.1.10 Silica Flume

1.5.1.11 High reactive Metakaolin

1.5.1.12 Rice Husk Ash

1.6 Assignment questions

1.7 Outcome

1.8 Future study

Introduction

Materials that are required for manufacturing concrete such as cement, aggregates, chemical admixture and water are called as concrete ingredients.

Objectives

- To know the chemical composition of cement, different types of cements, field and laboratory tests
- To know the classification, functions, properties and test performed on aggregates.
- To know the importance of admixtures.

1.1. Introduction to Cement

Cement is a well known building material which has occupied indispansible (means no other substitute) place in the construction works

1.1.2 History of cement

Cement can be primary classified as 1) **Natural cements** and 2) **Artificial cements**

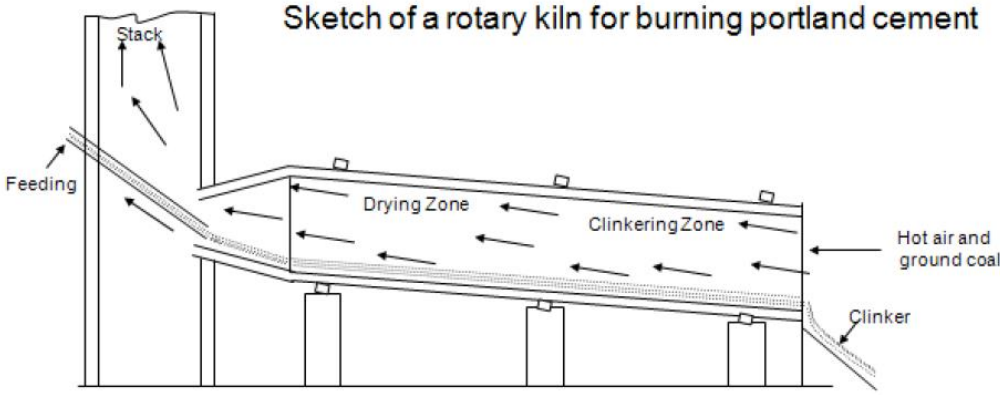
Natural cements are manufactured by burning and crushing of stones containing clay, carbonates of lime and small amount of carbonates of magnesia. Clay content in such stones may vary about 20 to 40%. Natural cements are brown in color and best variety of natural cement is **Roman cement** which resembles like hydraulic lime. Because of presence of hydraulic lime, it sets the cement at faster rate after the addition of water to the cement. Even though Natural cements resist water action, but not strong as Artificial cements.

Artificial cements are manufactured by burning a mixture of Calcareous (calcium carbonates predominates) and Argillaceous (clay predominates) materials at very high temperature of about 1400º to 1500º in **Rotating Kiln**. Kiln is the heart of cement plant, which is 50m long, 5m dia and placed in inclined position. The mixture of ingredients should have close contact with each other and should be mixed in proper proportion. **Calcination** process takes place in the kiln. Because of this process a calcined product ie. Cement balls are formed and this calcined product is called **Clinker.** To the clinker, a small amount of gypsum is added and mixture is finely grinded, and obtained product is called artificial cement. Best varieties of artificial cements are ordinary cements and normal setting cements. This cement was invented by Joseph Aspdin in 1824 and he patented this cement as Portland cement, because the color of the obtained cement resembles the color of sandstone which is abundant in Portland of England.

Note: Calcination is the process of reduction of carbonates to oxides with the release of carbon dioxide

$$CaCO_3 \rightarrow CaO + CO_2$$

(Carbonates) → (oxide) + (Carbon dioxide)



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1.1.3 Characteristics of cement

1. The color of the cement is grey with greenish shade. It gives an indication of excess or lime or clay and the degree of burning.

2. It should feel smooth when touched or rubbed in between fingers.

3. If hand is inserted in a bag of cement or in a heap of cement, it should feel cool and not warm.

4. It should be free from any hard lumps.

5. It should not contain any excess amount silica, lime, alumina and alkalies.

1.1.4 Properties of cement

(a) Physical properties: Physical properties of cement mainly depend on chemical composition, degree of burning and fineness of grinding.

1. It gives strength to the masonry.

2. It is an excellent binding material.

3. It is easily workable.

4. It offers greater resistance to moisture.

5. It possesses a good plasticity.

6. It stiffens or hardens early.

7. A thin paste of cement held in water should feel sticky between the fingers.

8. When cement thrown in water should sink and should not float on the surface.

9. The particles should have uniformity of fineness and surface area of should not be less than 2250 cm^2/gm.

10. The **standard consistency** of cement should be checked with **Vicat apparatus**. If the settlement of plunger is between 5 to 7mm from bottom of the mould, the amount of water added is correct, otherwise repeat the process with different percentages of water till the desired penetration is achieved.

11. The **initial setting time** of ordinary cement is about 30minutes. This initial setting time is the interval between the addition of water to cement and the stage when the square needle of **Vicat apparatus** ceases to penetrate.

12. The **final setting time** for ordinary cement is about 10hrs. The final setting time is the difference between the time at which water was added to cement and time required for needle with annular collar of **Vicat's apparatus** ceases to make an impression on test block.

13. The cement should be tested for **soundness** using **Le-Chatelier apparatus**. This test is to detect the presence of uncombined lime in cement. The expansion of cement after heating and cooling the mould should not exceed 10mm.

(b) Mechanical properties

1. The **compressive strength** at the end of 3 days should not be less than 11.5 N/mm^2 and at the end of 7 days should not be less than 17 N/mm^2.

2. The **tensile strength** of cement at the end of 3 days should not be less than 2 N/mm^2 and at the end of 7 days should not be less than 2.5 N/mm^2.

(c) Chemical properties

1. Total loss of ignition should not exceed 4%.

Note:- Loss of ignition can be calculated by heating up cement sample at 900-1000ºC until a constant weight is obtained. The weight loss due to heating is then determined. A high loss on ignition can indicate prehydration and carbonation, which may be caused by improper and prolonged storage. Maximum of 4% is limited to OPC.

2. Total sulphur content should not be more than 2.75%.
3. Weight of magnesia should not exceed 5%.
4. Weight of insoluble residue should not be more than 1.5%.

1.1.5 Chemical composition of cement

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement, in addition to the rate of cooling and fineness of grinding.

Approximate oxide composition limits of Ordinary Portland cement

Ingredients	Percentage	Range
Lime	(CaO)……………… 62	62 to 67
Silica	(SiO_2) ……………... 22	17 to 25
Alumina	(Al_2O_3) ……………. 5	3 to 8
Calcium sulphate	($CaSO_4$) …………… 4	3 to 4
Iron oxide	(Fe_2O_3) ……………. 3	3 to 4
Magnesia	(MgO) ……………... 2	1 to 3
Sulphur	(S) ………………….. 1	1 to 3
Alkalies	(K_2O, Na_2O) ……….. 1	0.2 to 1
	Total = 100	

Effect of ingredients on properties of cement

Lime: If lime is excess in cement, it imparts unsoundness to the cement. If lime content is deficient in cement, it decreases the strength and helps in faster setting of cement.

Silica: Imparts strength to the cement due to formation of C_3S and C_2S after the addition of water to the cement. If silica content exceeds, it increases the strength and also prolong the setting time of cement.

Alumina: Imparts faster setting property to the cement. Alumina content should not be present in excess amount as it weekens the cement.

Calcium sulphate: This ingredient in the form of gypsum and its function is to increase the initial setting time of cement.

Iron oxide: This ingredient imparts color, hardness and strength to the cement.

Magnesia: This ingredient, if present in small amount, imparts hardness and color to the cement. A high content of magnesia makes the cement unsound.

Sulphur: A very small amount of sulphur is used for making sound cement. If it is in excess, it causes cement to become unsound.

Alkalies: The most of the alkalies present in raw materials are carried away by foul gases during heating and the cement contains only small amount of alkalies. If it is in excess, it troubles by forming Alkali-aggregate reaction, efflorescence etc.

Harmful constituents of cement

(1) **Alkali oxide k_2O and Na_2O**: if amount of these alkali oxides exceeds by 1%, it leads to failure of concrete.

(2) **Magnesium oxide MgO**: if it exceeds 5%, it causes cracks in hardened concrete.

The identification of major compounds of cement is largely based on **Bogue's** equations and hence it is called as **Bogue's compounds**. The four compounds are usually regarded as major compounds are listed below

Name of compound	Formula	Abbreviated formula		Percentage by mass in cement
Tricalcium silicate	$3CaO.SiO_2$	C_3S	Alite	30-50
Dicalcium silicate	$2CaO.SiO_2$	C_2S	Belite	20-45
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	Celite	08-12
Tetracalcium alminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	Felite	06-10

It is to be noted that for simplicity's sake abbreviated notations are used. C stands for CaO, S stands for SiO_2, A for Al_2O_3, F for Fe_2O_3 and H for H_2O. The equations suggested by Bogue for calculating the percentages of major compounds are given below

$C_3S = 4.07\ (CaO) – 7.60\ (SiO_2) – 6.72\ (Al_2O_3) – 1.43\ (Fe_2O_3) – 2.85\ (SO_3)$

$C_2S = 2.87\ (SiO_2) – 0.754\ (3CaO.SiO_2)$

$C_3A = 2.65\ (Al_2O_3) – 1.69\ (Fe_2O_3)$

$C_4AF = 3.04\ (Fe_2O_3)$

1.1.6 Hydration of cement

Anhydrous cement does not bind the fine and coarse aggregates. It acquires adhesive property only when it is mixed with water. The chemical reaction that takes place between cement and water is known as **hydration of cement**.

When anhydrous cement mixed with water, it starts to dissolve and chemically combines with it to form products. Those products are known as **hydrates** and these hydrates are less soluble in water.

Hydration of cement can be visualized in two ways.

(1) **Through solution mechanism**: In this mechanism, when cement is mixed with water, cement compounds dissolve to form super saturated solution from which different hydrated products get precipitated.

(2) **Solid state mechanism**: In this mechanism, water attacks chemical compounds of cements which are in solid state and converting them to hydrated products starting from surface to interior compounds with time.

There is a possibility of occurrence of both stages in same course of reaction. Solution phase occurs first only when there is large availability of water and then solid state mechanism occurs in the next stage.

Note: **23% of water by weight of cement is required for chemical reaction of cement with water and another 15% of water required for filling up gel pores. Therefore total 38% of water is required for hydration of cement.**

Heat of hydration

The quantity of heat evolved in cal/gm of cement after complete hydration of cement.

For 7 days → 89 – 90 cal/gm

28 days → 90 – 100 cal/gm of heat will be evolved.

Structure of hydrated cement paste

When water is mixed with cement, the chemical compounds react with water to form hydrated products such as

$C_3S + H_2O \rightarrow$ hydrated Tricalcium silicate + $Ca(OH)_2$

$C_2S + H_2O \rightarrow$ hydrated Dicalcium silicate + $Ca(OH)_2$

$C_3A + H_2O \rightarrow$ hydrated Tricalcium aluminate + $Ca(OH)_2$

$Ca(OH)_2$ in the above equation may be 20 to 30% crystalline in nature and hydrated silicates and aluminates are colloidal in nature. Calcium hydroxide crystals which are surrounded by hydrated silicates and aluminates colloids to form **cement gel** and this gel sets hard to give strength to cement paste.

Note: when calcium silicates react with water, it forms Calcium Silicate Hydrates gel called **C-S-H gel**; C_3A reacts to form Calcium Aluminate Hydrates **C-A-H** and C_4AF reacts to form Hydrated Calcium Ferrite **C-F-H**.

Role of Bogue's compounds with respect to strength and heat of hydration

C_3S and C_2S (Tri Calcium Silicates and Di Calcium Silicates):-

- **C_3S** is formed within one week or soon after the addition of water and it is responsible for the early strength to cement for 1^{st} 4 weeks.
- **C_2S** is formed very slowly, so it gives progressive strength to cement after 4 weeks.
- At the age of 1 year both contributes equal ultimate strength.
- **C_3S** & **C_2S** have strength of 70MPa @18 months, but **C_2S** has 0 when **C_3S** has 40MPa @7 days.
- During course of reaction of **C_3S** & **C_2S** with water calcium silicate hydrates **CSH** and $Ca(OH)_2$ are formed.
  $2(3CaO\ SiO_2) + 6H_2O \rightarrow 3CaO\ 2SiO_2\ H_2O + 3Ca(OH)_2$
  $2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$
  $2(2CaOSiO_2) + 4H_2O \rightarrow 3CaO\ 2SiO_2\ 3H_2O + Ca(OH)_2$
  $2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$

Note:- C_3S produce lesser CSH & more $Ca(OH)_2$ compared to C_2S.

Note: $Ca(OH)_2$ is not desirable in concrete because, when mass of $Ca(OH)_2$ is about 20 to 25% of volume of solids in hydrated paste it imparts low durability to concrete.
$Ca(OH)_2$ readily reacts with sulphates present in soil or water to calcium sulphates which further reacts with C_3A leads to deterioration of concrete. This is known as **sulphate attack**

- C_3S readily reacts with water to produce more heat of hydration & responsible for early strength. C_2S hydrates are formed slowly, hence it is responsible for progressive strength
- The quantity & density of product formed by C_3S is slightly inferior when compared to that of C_2S.

C_3A (Tri Calcium Aluminates):-

- The reaction of C_3A with water is very fast and may lead to an immediate stiffening of paste, and this process is termed as flash set.

- To prevent this flash set, 2 to 3 % gypsum is added at the time of grinding the cement clinkers.
- It provides early strength to cement upto 3 days, but causes deterioration of concrete at later stages.
- The hydrates of C_3A do not contribute to the strength of concrete. C_3A reacts with water to form calcium aluminate system $CaO – Al_2O_3 – H_2O$ is formed. The cubic compound C_3AH_6 is probably the only stable compound formed which remains upto 225ºC.

C_4AF (Tetra Calcium Alumina Ferrite) :-

- C_4AF hydrates rapidly.
- A hydrated calcium ferrite of the form C_3FH_6 is more stable but does not contribute anything to the strength of concrete.
- The hydrates of C_4AF show a comparatively more stable the hydrates of C_3A.
- The hydrates of C_4AF show a comparatively higher resistance to sulphate attack than the hydrates of C_3A.
- C_4AF acts as flux.

1.1.7 Types of cement

1. <u>**Ordinary Portland Cement (OPC)**</u>:

This type of cement is manufactured by mixing limestone and clay in proper proportion at very high temperature of about 1400-1500ºC in kiln. The resulting mixture is added with small amount of gypsum to delay the setting action.

Initial setting time is not less than 30min and final setting time not more than 600min or 10hrs.

<u>**Uses**</u>**:** Used for the construction of

- Road pavements
- RCC structures
- Water tanks, pipe lines, culverts.

2. <u>**Rapid Hardening Cement**</u>:

This cement is similar to that of OPC but with higher percentage of Tricalcium silicate (C_3S) and finer than OPC. The final strength obtained from this cement is almost same as that of OPC.

Initial setting time is not less than 30min and final setting time not more than 600min or 10hrs.

This cement is used where a rapid development of strength is desired. The rapid development of strength is accompanied by higher rate of heat of hydration, so it not suitable for mass concreting and it is about 10% costlier than OPC.

Uses: It is used for repair of bridges and roads etc.

3. **Quick Setting Cement**:
This cement sets much faster than OPC. This cement is produced by mixing small percentage of aluminium sulphate and by finely grinding the cement. Percentage of gypsum to be added is also reduced.
Initial setting time is 5min and final setting time is 30min.

Uses: It is used for making concrete that is required to set early as for laying under water or in running water.

4. **High Alumina Cement**:
It is manufactured by fusing together a mixture of limestone and bauxite in correct proportion at very high temperature and resulting product is grinded finely. The ultimate strength is much higher than OPC and color of this cement is black and proves to be costlier than OPC.
Initial setting time is not less than 30min and final setting time not more than 600min or 10hrs.

Uses:
- It can be used in low temperatures.
- They resist chemical attacks.

5. **Low Heat Cement**:
This cement is obtained by increasing the proportion of C_2S and decreasing C_3S and C_3A. This cement gains strength slowly but ultimate strength is same as that of OPC and not suitable for ordinary structures.
Initial setting time is not less than 60min and final setting time not more than 600min or 10hrs.

Uses: This cement is used only when the shuttering has to be kept for long period and curing is prolonged.

6. **Sulphate Resisting Cement**:
This cement is manufactured from well granulated slag (80 to 85%) & calcium sulphate (10 to 15%) along with 1 to 2% of OPC. It gives less heat of hydration, resistance to sulphate attack and strength and physical properties are same as that of OPC.

Initial setting time is 2.5 to 4hrs and final setting time is 4.5 to 7hrs.

Uses: Used in the construction of

- Marine works
- Mass concreting
- Underground waterworks and sewer works.

7. **Portland Slag Cement**:

This cement is made by intergrinding finely the mixture of clinkers, gypsum and granulated slag in proper portions. This cement is less reactive than OPC and gains strength slowly during 28 days and adequate curing is required.

Uses: this cement is used for marine works.

8. **Portland Puzzolana Cement**:

This cement has same properties as compared to that of OPC. This cement produces less heat of hydration and more resistant to sulphate attack. This cement can be used in marine works and mass concreting. This cement is manufactured by intergrinding of clinkers and Puzzolana with the addition of gypsum. Tim required to gain the strength is little more and ultimate strength is more than that of OPC.

9. **White Cement**:

This cement has pure white color and it posses same properties as that of OPC. The grey color of the cement is due to the presence of iron oxide. So if the percentage of iron oxide is kept very less, then the color of the cement will be white. This cement is manufacture by mixing white chalk and clay which is free from lime and oil is used instead of coal for burning of the cement. This is costlier than OPC and generally used for architectural and decorative purposes.

10. **Colored Cement**:

Colored cement is manufactured by adding suitable mineral pigments to ordinary cement at the time of grinding. The percentage of these pigments to be added varies from 5 to 10%. Pigments used in cement should be chemically inert and durable. Chromium oxide gives green color, Cobalt gives blue color and Iron oxide in different proportions gives brown, red or yellow color. This cement is used in flooring, exterior surfaces and decorative purposes.

11. **Air entraining cement**:

This is made by mixing a small amount of air entraining agent with OPC at the time of grinding. Some of the air entraining agents are

1. Alkali salts of wood resin.
2. Calcium lingo-sulphate

These agents in powder or in liquid form are added to the extent of 0.1 to 0.25% by weight of cement. Air entraining cement will produce at the time of mixing, a tough, tiny discrete air bubbles in the concrete which will modify the properties of plastic concrete wrt to workability, segregation, bleeding and hardness.

1.1.8 Manufacture of OPC

Following are three distinct operations are involved in the manufacture of cement.

(i) Mixing of raw material

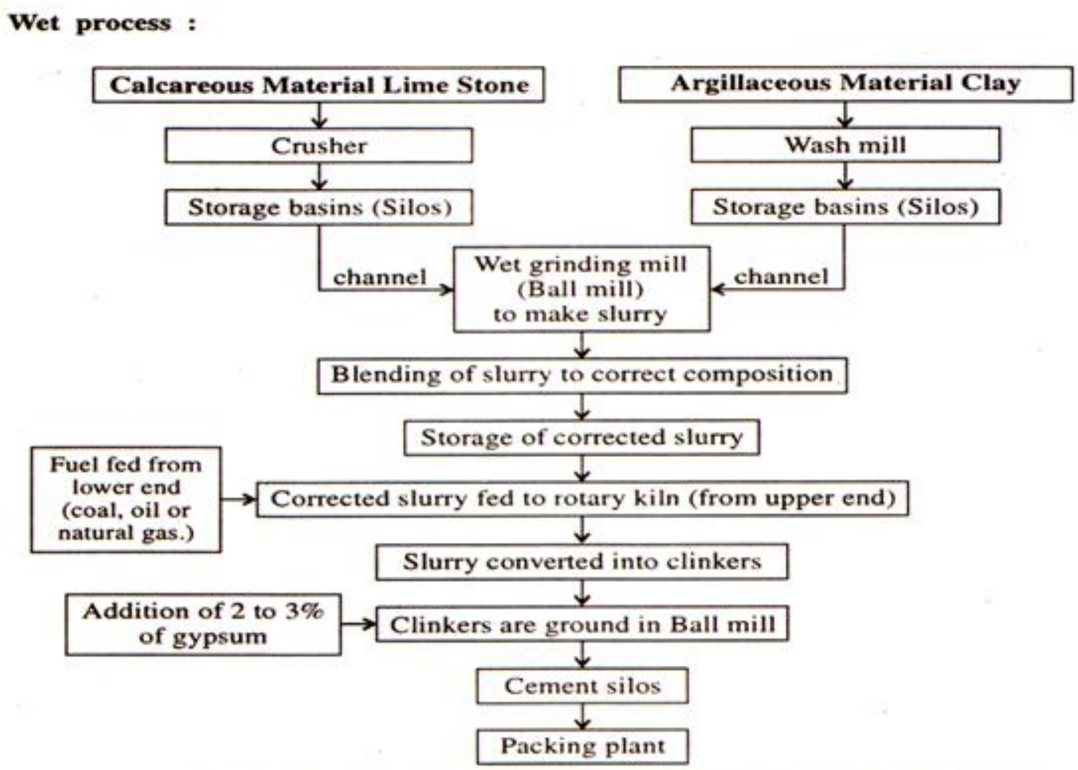
(ii) Burning

(iii) Grinding

- In the wet process, raw materials are mixed wet in required proportions and **slurry** is formed. While in the dry process raw materials are mixed in required proportions in dry form and dry **raw mix** is formed. The remaining two operations, namely, Burning, and Grinding are the same for both the processes.
- The correct slurry is fed into a rotary kiln from upper end. As the slurry gradually descends, there is rise in temperature and small lumps, known as nodules are formed. These nodules, reach to the burning zone, where the temperature is about 1400 ^{0}C to 1500 ^{0}C. In the burning zone, calcined product is formed and nodules are converted into small hard balls, known as clinkers.
- The size of clinkers varies from 3 mm to 20 mm.
- Clinker which is obtained from rotary kiln is finely ground in ball mills and tube mills. A small quantity about 2 to 3 % of gypsum is added to prevent flash-setting of the cement.
- The final ground cement is stored in silos. It is then weighted and packed in bags by automatic machine.
- Each bag of cement contains 50 kg of about 0.035 m^3 of cement.

Manufacturing of cement by Wet process (old technology)

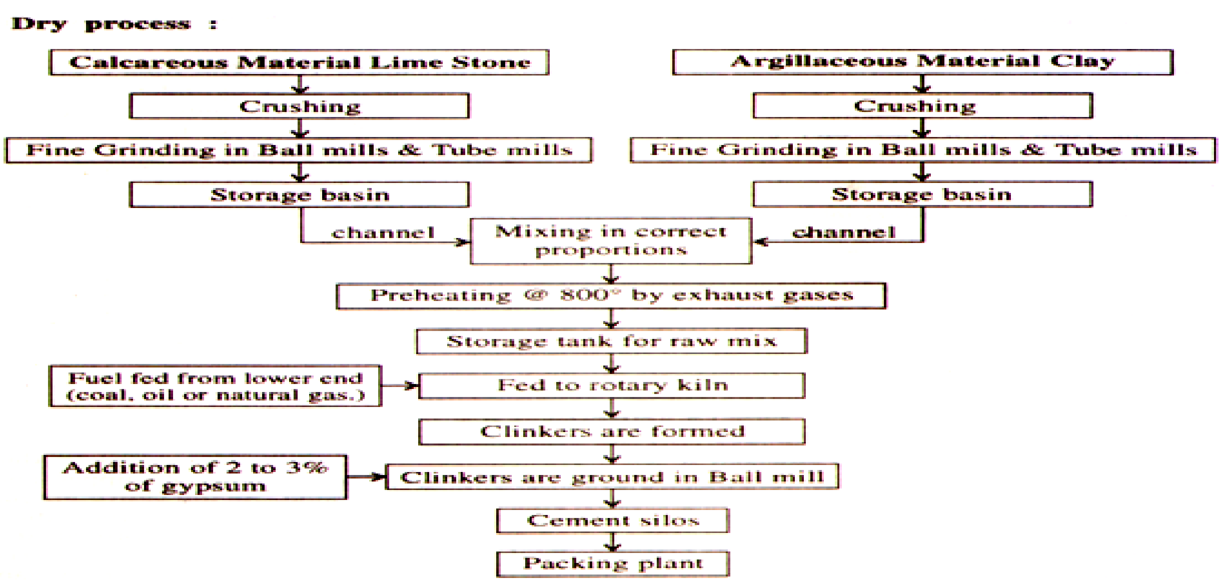
In this process, the calcareous materials such as limestone are crushed and stored in the silos or storage tanks. The argillaceous material such as clay is thoroughly mixed with water in a container known as the wash mill. This washed clay is stored in basins. Now crushed limestone from silos and wet clay from basins are allowed to fall in a channel in correct proportions. This channel leads the materials to grinding mills where they are brought into intimate contact to form slurry. The grinding is carried out either in ball mill or tube mill or both. The slurry is led to correcting basin where it is constantly stirred. At this stage, the chemical composition is adjusted as necessary. The corrected slurry is stored in storage tanks and kept ready to serve as feed for rotary kiln from upper end. Fuel (coal, oil or natural gas) is fed into rotary kiln from lower end and temperature in the kiln raises upto 1400 to 1500ºC and slurry is converted into Clinkers.



FLOW CHART FOR WET PROCESS OF CEMENT MANUFACTURING

Manufacturing of cement by Dry process (modern technology)

In this process, the raw materials are first reduced in size of about 25mm in crushers. A current of dry air then passed over these dried materilas. These dried materials are then pulverised into fine powdered in ball mills and tube mills. All these operations are carried separately for each



FLOW CHART FOR DRY-PROCESS OF CEMENT MANUFACTURING raw materials and they are stored in hoppers. They are then mixed in correct proportions and made ready for the feed of rotary kiln. This finely groung powder of raw materials is known as **raw mix** and it is stored in storage tank. Then raw mix is fed into the rotary kiln and fuel (coal, oil or natural gas) is added from lower end and temperature raises about 1400-1500ºC in the kiln to form clinkers . 2 to 3% of Gypsum is added to the clinker and finely grinded in ball mill to obtain cement and stored in silos and after it is packed in bags.

1.1.9 Testing of cement

It can be brought under two categories ie, 1. **Field testing** and 2. **Laboratory testing**

Field Testing of cement as per Indian standard:

The following field tests are necessary to perform, to ascertain the quality of cement at site.

- Open the bag and take a good look at the cement. There should be no visible lumps.
- The color of the cement should be greenish grey
- When hand is inserted in cement bag it should feel cool.
- Take a pinch of cement and feel between fingers. It should give a smooth feeling and not a gritty feeling.
- Take a handful of cement and throw it on a bucketful of water, the particles should float on water for some time before they sink.
- Take about 100gms of cement, add some water and prepare a stiff paste. From stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. The shape of the cake should not be disturbed, while taking it down to the bottom of the bucket. After 24 hours the cake should retain its original shape and at the same time it should also set and gain some strength.

Laboratory test

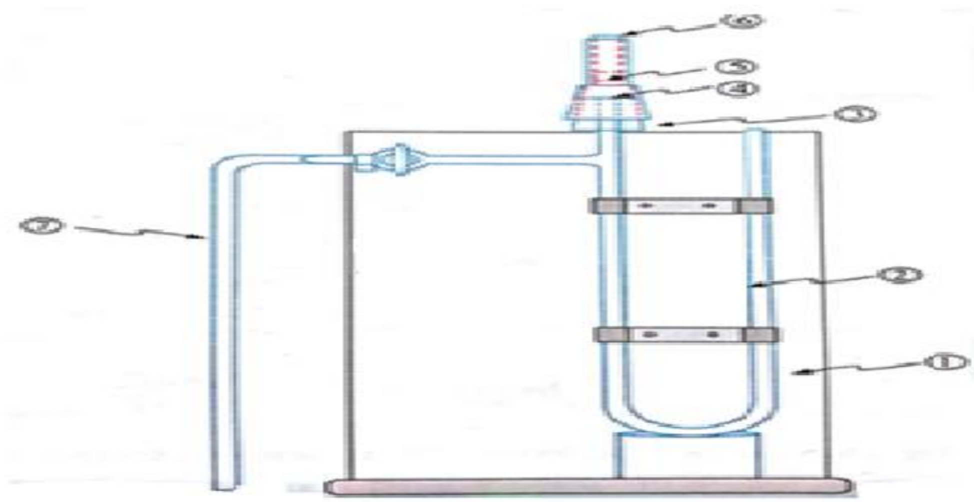
1. **Fineness test**: Fineness of cement has an important bearing on rate of hydration, rate of gain of strength and also on rate of evolution of heat. Finer the cement, greater will be the surface area and faster will be the development of strength.

Fineness of cement can be tested in two ways

1. **By sieving method**: Weigh correctly 100gms of cement and take it on a standard sieve of 90µ and breakdown the air set lumps in the sample by means of fingers. Sieve the sample continuously for 15mins and weigh the residue left out on the sieve. This weight should not exceed 10% of the sample for the OPC.

2. **By Blaine Air Permeability method:** The apparatus consists of

1. Wooden stand
2. Manometer
3. Rubber cork
4. Permeability cell
5. Perforated disc of size 1mm
6. Plunger
7. Tube
8. Dibutyphthalate



Procedure

Calibration of the Blaine apparatus

- Calculate the bulk volume of the compacted bed of cement V by the following formula
  $V = (W_A – W_B) / P$

  Where W_A = mass of the mercury required to fill permeability cell.
  W_B = mass of mercury to fill the portion of the cell not occupied by of the cement formed by 2.8gms of the standard cement sample
  P = density of mercury at the temperature of test.

The masses W_A and W_B are obtained by weighing the mercury in the crucible.

- Determine the mass of standard sample W, required to produce a bed having porosity of 0.500 ± 0.005 (e) as follows:
- $W = 3.15 V (1-e)$ where, V = bulk volume of compacted cement powder,

e = Desired porosity of bed of cement (0.500 ± 0.005)

- Determine the time taken by the manometer liquid to fall from second mark from the top to the third mark on the manometer when air is allowed to penetrate through the compacted bed of cement using the quantity of standard cement calculated in step 2
- Calculate the constant of the apparatus (k) by using the formula
  $Ss = K \sqrt{Ts}$

$$k = \frac{Ss}{\sqrt{T_s}}$$

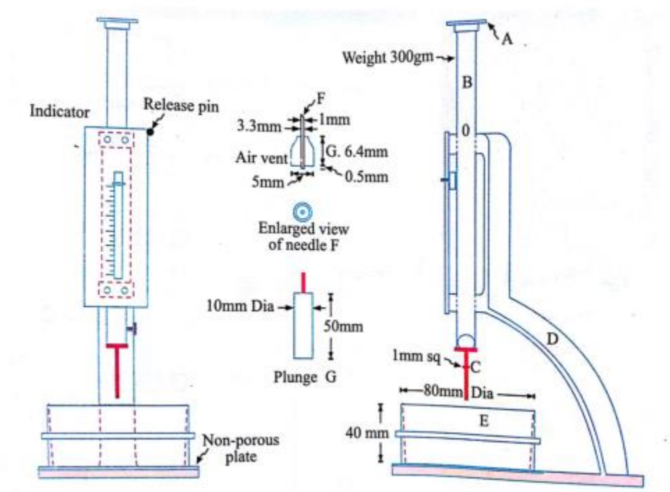
Where S_s = fineness of standard Portland cement in cm^2/gm.

- Using the same quantity of the cement, find the time (T_s) in sec required for the manometer liquid to fall from second mark to third mark.
- Calculate the specific surface of cement in cm^2/gm by using the formula,

$$S = K\sqrt{Ts}$$

2. **Standard Consistency test**: This test is used for finding out initial setting time, final setting time, soundness and also strength.

"Standard consistency of a cement paste is defined as that consistency which will permit the Vicat plunger having 10mm dia and 50m length to penetrate to a depth of 33-35mm from top of the mould**"**. The apparatus used for determination of standard consistency is known as Vicat apparatus. This apparatus is used to find out the percentage of water required to produce a cement paste of standard consistency.



Procedure

- Take about 400gm of cement
- Make the cement paste with a known quantity of water (let it be 24%)
- Fill this paste into the Vicat mould
- Shake the mould to expel the air
- Bring the mould near to the Vicat apparatus needle
- Make the needle of the Vicat plunger just to touch the top surface of the mould
- Note down the initial reading
- Allow the Vicat needle to plunge into the cement paste which is inside the mould
- Note down the final reading
- Take the difference of these readings. If the reading is not within 33-35mm, then repeat the procedure with the increase in % of water by 2% of weight of cement taken

- The particular % of water which allows the plunger to penetrate only to a depth of 33-35mm from top of the mould is known as % of water required to produce cement paste of standard consistency.

3. Setting time test

An arbitrary division has been made for the setting time of cement as

1. **Initial setting time**

2. **Final setting time**

It is difficult to draw rigid line between initial and final setting time. The initial and final setting time can be determined by using Vicat's apparatus

"Initial setting time is the time elapsed between the moments that the water is added to the cement, to the time that the paste starts losing its plasticity**"**.

Procedure

- Mix a known % of water to the cement to make a cement paste simultaneous start the stop clock
- Fill this cement paste into the Vicat mould
- Gently release the needle to the surface of cement paste, note down the initial reading
- Release the needle so that the needle fall freely, when the needle has penetrated to a depth of 33-35mm from top of the mould and note down the reading and time
- This period elapsed between the time when water is added to the cement and the time at which needle penetrates to a depth of 33-35mm from top is known as **initial setting time**.
- **"Final setting time** is the time elapsed between the moment water added to the cement and time taken when the paste lost completely its plasticity and has attained sufficient stiffness to resist certain definite pressure**"**.

Procedure

- Replace the needle of Vicat apparatus by means of a circular attachment
- The cement shall be considered as finally set, when upon lowering the attachment gently over the surface of the cement paste, the attachment fails to make an impression on test block. The period elapsed between the time when water is added to the cement and the time at which the circular attachment fails to make an impression on the surface of the hardened cement block is known as **finial setting time**.

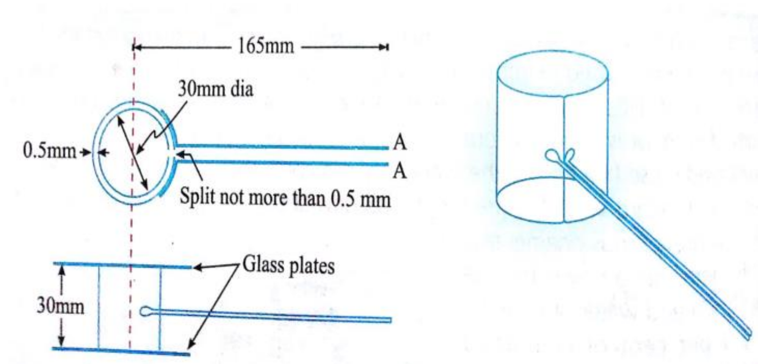
Note:-

False setting is the rapid development of rigidity in freshly mixed Portland cement paste, mortar, or concrete occurs after few minutes of mixing cement with water without the generation of much heat. It can be controlled by re-mixing without additional water or strength loss and causes for false setting are 1) drying of gypsum, 2) bad storage and 3) activate effective C_3A exposed to humidity.

Flash setting is a rapid development of rigidity in freshly mixed Portland – cement paste, mortar, or concrete. It happened due to rapid reaction of aluminates – when insufficient of sulphate content.

4. Soundness of cement

It refers to the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion. This destructive expansion is caused by excessive amount of free lime (CaO), sulphate (SO_3) or magnesia (MgO).Soundness of cement is tested with Le-Chatelier apparatus which consists of a small brass cylinder of 30mm dia, 30mm high and 0.5mm thick. 2 indicators with pointed ends are attached to the cylinder on either side of the split.



Procedure

- The cement paste is prepared. The % of water used will be equal to % of water determine by the standard consistency test.
- The cylinder is placed on a glass plate and is filled with cement paste. It is covered at top with another glass plate. A small weight is placed on the top of the glass plate.
- The whole assembly is immersed in water at 24ºC to 35ºC for 24hrs at the end of that period the distance between the indicators is measured. The mould is again immersed in water and brought to boil in 30min and after boiling for 1hr, the mould is removed and after cooling the distance between the indicators is measured again. The increase in this distance represents the expansion of the cement and according to IS specification it should not exceed 10mm for any type of cement.

1.1.10 Steps to reduce Carbon footprint in cement manufacturing process

Cement is a vital for a country's economic development and the basic ingredient required to build housing and infrastructure. However, cement manufacturing generates CO_2 and the industry as a whole represents around 5% of global CO_2 emission.

- Around 60% of these result from the transformation of lime stone at high temperature because of "Carbonation" to produce 'Clinker', the basic component of cement.
- Approximately 40% are generated from the energy used in the burning process.

There are three ways to reduce CO_2 emission associated with cement production.

I. Increasing energy efficiency by optimizing processes and modernizing factories.

Introducing new cement plants using the best available technology or upgrading old plants.

II. Substituting fossil fuels with other energy sources.

Alternative fuels such as biomass, tires and industrial waste can be used to replace fossil fuels in cement kilns. This allows not only a reduction in the consumption of fossil fuels but also the safe disposal of waste that would otherwise be incinerated or land filled.

III. Using additives in cement to develop a large range of products according to their application.

Natural products such as Puzzolanas or industrial by-products such as fly ash (a by-product of coal-fired power stations) or slag (a by-product of the steel industry) can be used in the cement production process as cement additives. These de-carbonated additives have hydraulic binding qualities and can be used to produce less carbon-intensive cements.

Aggregates

1.2.1 Introduction

Aggregates are defined as inert, granular and inorganic materials that normally consist of stone or stone like solids. Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete.

Since aggregates constitutes about 3/4th of the volume of concrete, it contributes significantly to the structural performance of concrete especially strength, durability and volume stability. Aggregates are formed from natural sources by the process of weathering and abrasion or by artificially by crushing a large parent rocks.

1.2.2 Classification of aggregates

Aggregates can be divided into several categories according to different criteria.

a) **In accordance with size**:

Coarse aggregate: if particle size is greater than 4.75mm are regarded as coarse aggregates

Fine aggregates: if particle size in between 75μ & 4.75mm are regarded as fine aggregates

b) **In accordance with sources**:

Natural aggregates: This kind of aggregates is taken from natural deposits without changing their nature during the process of production such as crushing and grinding. Some examples in this category are sand, crushed limestone and gravel.

Manufactured aggregates: This is a kind of man-made materials produced as main product or an industrial by-product. Some examples are blast furnace slag, lightweight aggregate (e.g. expanded perlite), and heavy weight aggregates (e.g. iron ore or crushed steel)

c) **In accordance with unit weight**:

Light weight aggregates: the unit weight of aggregates is less than 1120kg/m^3. The corresponding concrete has a bulk density less than 1800kg/m^3. (Cinder, blast-furnace slag, volcanic pumice).

Normal aggregates: The aggregates have unit weight of 1520-1680kg/m^3. The concrete made with this type of aggregates has a bulk density of bulk density of 2300-2400kg/m^3.

Heavy weight aggregate: The unit weight is greater than 2100kg/m^3. The bulk density of the corresponding concrete is greater than 3200kg/m^3. A typical example is magnesite limonite, a heavy iron ore. Heavy weight concrete is used in special structures such as radiation shields.

Fine Aggregates

1.2.3 Quality of a good aggregate

- Good sand should have coarser and angular grains of pure silica.
- The particles of aggregates should be hard, strong, durable and tough in nature.
- The aggregates should be free from silt, clay or any deleterious materials.
- The aggregate should not contain any organic substances.
- The aggregate should be well graded.
- The aggregate should not be porous in nature.

1.2.4 Function of Aggregates

- It fills the voids existing in coarse aggregates.
- It reduces shrinkage and cracking of concrete.
- It helps in hardening of cement by allowing water through its voids.
- By varying the proportions of fine aggregates, concrete can be prepared economically for any required strength.
- To form hard mass of silicates.

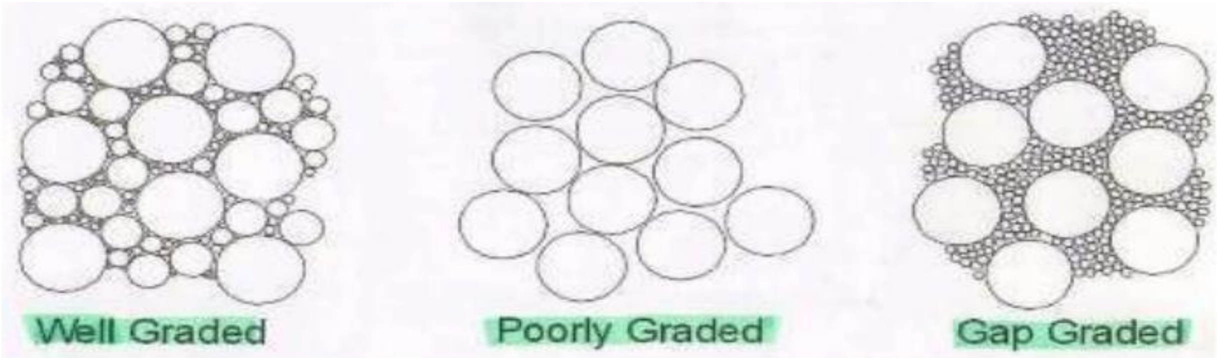
1.2.5 Grading of aggregates

- Particle size distribution of an aggregate is determined by sieve analysis is known as 'grading of the aggregate'
- Aggregate comprises about 55% of the volume of mortar and about 85% of volume of concrete. Mortar contains aggregates of size 4.75mm and the concrete contains aggregates up to a max. size of 150mm.
- Strength of concrete is dependent upon water-cement ratio. One of the most important factors for producing workable concrete is good grading of aggregates.
- Grading of aggregates are of 3 types

Good graded or well graded: It implies that a given sample of aggregates contains all standard fractions such there will be minimum number of voids.

Uniformly graded or poor graded: It contains aggregate particles that are almost of the same size. This means that the particles pack together, leaving relatively large voids in the concrete.

Gap graded: It consists of aggregate particles in which some intermediate size particles are missing.



A sample of good grading of aggregate containing min. voids will require min. paste to fill up the voids in the aggregate and this will produce a higher strength, lower shrinkage and greater durability.

Sieve: It is a circular disc consists of wire mesh of square apparture.

Sieve analysis: This is the name given to the operation of dividing the given sample of aggregates into various fractions each consisting of particles of same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregates which is also called as **Gradation**.

- The aggregates used for making concrete are normally of the maximum size 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600 micron, 300 micron and 150 micron.
- The aggregate fractions from 80 mm to 4.75 mm are termed as coarse aggregate and those fractions from 4.75 mm to 150 micron are termed as fine aggregate.

Sieves are placed one above the other, maximum size is placed at the top and minimum size in the bottom. Sieving can be done either manually or by mechanically with sieve shaker. From the sieve analysis, the particle size distribution in a sample is found out; from this fineness modulus can be determined.

Fineness Modulus: It is a relative index which indicates the particles are either coarser or finer. The sum of cumulative percentage retained on the sieves divided by 100 gives fineness modulus of given sample of aggregates.

For sand the following limits are taken as guidelines

Fine sand → 2.2 – 2.6

Medium sand → 2.6 – 2.9

Coarse sand → 2.9 – 3.2

1.2.6 Tests on Fine aggregates

Specific Gravity:

- The specific gravity of an aggregate is the ratio of the mass of solid in a given volume of sample to the mass of equal volume water at the same temperature.
- They are of two types 1) absolute specific gravity and 2) apparent specific gravity.
- Absolute specific gravity is defined as ratio of mass of solid to the mass of an equal void-free volume of water. If the volume of aggregate includes the voids, then resulting specific gravity is called apparent specific gravity.
- Average specific gravity of the rocks varies from 2.6 to 2.8.
- It's required for calculation of the quantity of aggregate for a given volume of concrete.

1) Determination of Specific gravity of fine aggregates by Pycnometer method

Procedure

1. Find the weight an empty Pycnometer with stopper. Let it be W_1 gms.

2. Take about 1/3rd the volume of Pycnometer full of sand. Find the weight of Pycnometer with sand and let it be W_3 gms.

3. Now fill the Pycnometer to its half with water so as to submerge the sand inside. Allow the entrapped air from sand to escape. Then fill the Pycnometer with water. Replace the stopper and find the total weight Pycnometer with its constituents and let it be W_3 gms.

4. Remove the constituents from the Pycnometer and clean it. Fill completely with water and replace the stopper. Find the weight with water and let it be W_4 gms.

$$\textbf{Specific gravity} = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)}$$

2) Bulking of sand

Bulking can be defined as that property of sand by virtue of which it expands in volume when it is wet. This is because, when water is added to the sand, each particle will be coated by a film of water and keeps far apart from each other due to surface tension. Hence it is necessary to take the moisture content into account while measuring the sand by volume for proportioning concrete. Bulking increases with the increase in water content up to 4% by weight and then decreases. Bulking also increases with fineness of particles.

Procedure

1. Take about 300gms of dry sand and pour it into a measuring jar. Note down the initial volume of sand.

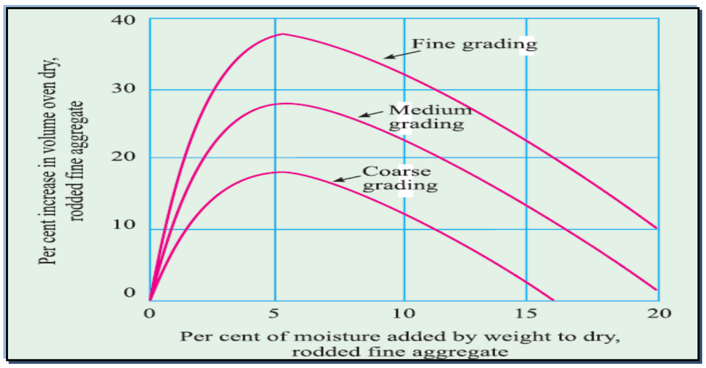
2. Transfer the sand into a non-absorbent pan and add 1% (by weight of sand) of water. Mix the sand thoroughly with a glass rod so that a uniform color is obtained.

3. Then pour the wet sand into the measuring jar and note down the rise in volume.

4. Again transfer the san into the pan and add another 1% of water by weight of sand. Mix thoroughly and pour back into the jar and note down the new volume.

5. Repeat this process by increasing the water content at the rate of 1% up to 3, 4, 5, 6% and so on until the volume starts decreasing.

6. Plot a graph of % increase in volume V/S % of water added.



3) Measurement of moisture content for fine aggregate

Moisture content means free water held on the surface of aggregate which includes the absorbed water and the water held in the interior portion of the aggregate.

1. **Drying method:** The drying method is carried out in an oven and the loss in weight before and after drying will give the moisture content of the aggregate. If drying is done at high temperature for long time, the loss in weight will include not only the surface water but also some absorbed water. A fairly quick result can be obtained by heating the aggregate in an open pan and the process can be speed up by pouring inflammable liquid like acetone on the aggregate and igniting it.

2. **Displacement method:** In the laboratory, the moisture content of aggregate can be determined by means of Pycnometer. The principle made use of is that specific gravity of normal aggregate is higher than that of water and that a given weight of wet aggregate will occupy a greater volume than the same weight of dry aggregate. By knowing the specific gravity of dry aggregate, specific gravity of wet aggregate can be calculated. From the difference between

specific gravity of wet and dry aggregates, the moisture content of the aggregate can be calculated.

3. **Calcium Carbide method:** A quick and reasonably accurate method of determining the moisture of fine aggregate is to mix with excess amount of calcium carbide in a strong air-tight vessel fitted with pressure gas. Calcium carbide reacts with surface moisture in the aggregate to produce acetylene gas. The pressure of acetylene gas generated depends upon the moisture content of the aggregates. The pressure gauge is calibrated by taking a measured quantity of aggregate of known moisture content and then such a calibrated pressure gauge could be used to read the moisture content of aggregate directly. The method is often used to find out the moisture content of fine aggregate at the site of work. The equipment consists of a small balance, a standard scoop and container fixed with dial gauge. The procedure is as follows; weigh 6gms of wet sand and pour it into the container. Take one scoop full of calcium carbide powder and put it into the container. Close the lid of the container and shake it rigorously. Calcium carbide reacts with surface moisture and produces acetylene gas, the pressure of which drives the indicator needle on the pressure gauge. The pressure gauge is so calibrated, that it gives directly the percentage of moisture present in the sample. The whole job takes only less than 5mins and as such, this test can be done at very close intervals of time at the site of work.

4. **Electrical meter method:** Recently electrical meters have been developed to measure instantaneous or continuous reading of the moisture content of the aggregate. The principle that the resistance gets changed with the change in moisture content of the aggregate has been made use in some sophisticated batching plant. Electrical meters are used to find out the moisture content and also to regulate the quantity of water to be added to the continuous mixture.

5. **Automatic measurement:** In modern batching plants surface moisture in aggregates is automatically recorded by means of some kind of sensor arrangements. The arrangement is made in such a way that, the quantity of free water going with aggregate is automatically recorded and simultaneously that much quantity of water is reduced. This sophisticated method results in an accuracy of ± 0.2 to 0.6%.

1.2.7 Alternatives to river sand

Sand is a vital ingredient in making two most used construction materials viz. Cement Concrete and mortar. Traditionally River sand, which is formed by natural weathering of rocks over many years, is preferred as fine aggregate. The economic development fueling the growth of infrastructure and housing generates huge demand for building materials like sand. The indiscriminate mining of sand from riverbeds is posing a serious threat to environment such as erosion of riverbed and banks, triggering landslides, loss of vegetation on the bank of rivers, lowering the ground water table etc. Demand for sand is increasing day by day and at the same time mining threats cannot be ignored. Hence, sand mining from riverbeds is being restricted or banned by the authorities like National Green Tribunal, State Environmental Impact Assessment Authority and Pollution Control Board

Some of the Alternatives to River sand

- Manufacture Sand
- Processes Quarry dust
- Processed Crushed rock fines
- Offshore Sand
- Processed glass
- Aluminum saw mill waste
- Granite fines slurry
- Washed soil (filtered sand)
- Fly ash (bottom ash/ pond ash)
- Slag sand
- Copper Slag sand
- Construction Demolition waste.

1.2.8 Manufacture Sand

Manufactured sand is crushed fine aggregate produced from a source material and designed for use in concrete or for other specific products. Only source materials with suitable strength, durability and shape characteristics should be used.

Production generally involves

- Crushing,
- Screening and
- Possibly Washing.

Crushing: - Manufactured Sand is produced by feeding hard stones of varying sizes to primary and secondary crushers (Jaw crusher and Cone crusher), for size reduction and these crushed stones are further crushed in Vertical Shaft Impact (VSI) crusher to reduce the particle size to that of sand. The VSI crusher by its unique design and action of attrition produces well shaped fine aggregate particles that are cubical and angular. The process of attrition also enables the reduction of surface roughness of the fine aggregate particles to some extent. The fine particles obtained, as a by-product during crushing of rocks to produce coarse aggregates (by jaw crusher and / or cone crusher) is known as Crusher Dust / Quarry Dust. This often contains higher percentage of dusty, flaky particles and particle sizes are un-controlled. This is not suitable for construction, as they result in higher water demand leading to lack of control on workability / retention of workability as well as strength issues.

Screening and Washing: - With built-in process of different stages of screening, Manufactured Sand plants ensure proper grading for better particle size distribution. By washing, the percentage of micro fines (passing 75 micron) is controlled below 15% by weight. The washing facility also provides keeps the Manufactured Sand in wet or partially wet condition. This will help to reduce the water absorption rate by Manufactured Sand during concrete manufacturing and hence better workability and workability retention.

Coarse Aggregates

1.3.1 Importance of size, shape and surface texture of aggregates on workability and strength

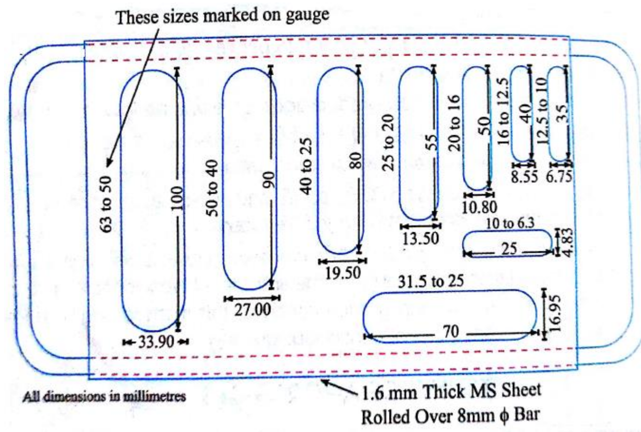
- **Size of aggregate:** Bigger the size of particles less will be the surface area and hence less amount of water is required and also less cement paste required for lubricating the surfaces of aggregates. So bigger the size, gives higher workability.
- **Shape of aggregate:** Angular, elongated or flaky aggregates make the concrete very harsh when compared to rounded or cubical aggregates. Contribution to better workability of rounded aggregate will come from the fact that for a given volume or weight. It will have a less surface area and less voids. Not only is that being in rounded in shape, the frictional resistance between the aggregates also reduced. Hence the workability will be more in case of rounded than compared to flaky aggregates. Hence the strength will be more by using rounded or cubical aggregates.
- **Surface texture:** 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 on hardness, grain size, pore structure and structure of the rock.

  Total surface area of rough texture aggregate is more than that of surface area of smooth rounded aggregates of same volume. Rough textured aggregates will show poor workability and smooth textured aggregates will give better workability because of lesser frictional resistance of inner surface particle.

1.3.2 Testing of Coarse Aggregates

- **Test for determination of flakiness index**

An aggregate having least dimension less than 3/5th of mean dimension is termed as flaky. This test is not applicable to aggregates less than 6.3mm. This test is conducted by using a metal thickness gauge. A sufficient quality of aggregates is taken ie, a minimum of 200 pieces of any fraction to be tested. Each fraction is gauged in terms of thickness on metal gauge. The total amount of aggregate pieces passing through each gauge is weighed accurately. **Flakiness index is calculated by taking the ratio of total weight of materials passing through the various thickness gauges to the total weight of aggregate sample taken.**



➢ **Test for determination of elongation index**

The elongation index of an aggregate is the particle having largest dimension (length) is greater than 9/5th of mean dimension. The elongation index is not applicable to sizes lesser than 6.3mm. This test is conducted by using metal length gauge. A sufficient quantity of aggregate is taken to provide a minimum number of pieces of 200 of any fraction to be tested. Each fraction shall be gauged individually for the length on metal gauge. The amount retained by the gauge length shall be weighed to an accuracy of 0.1% of the weight of sample taken. **The elongation index is calculated in percentage by taking the ratio of total weight of materials retained on various length gauges to the total weight of aggregate sample taken.**

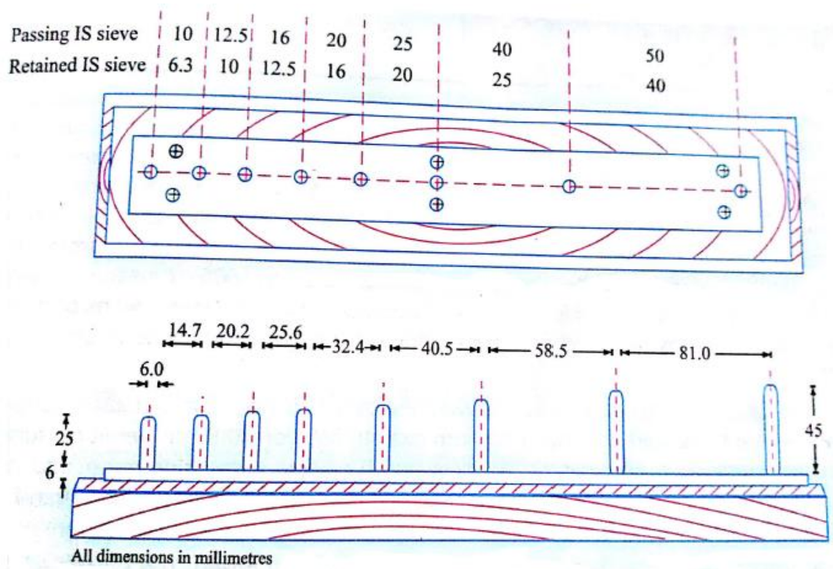


Fig. 3.10. Length Gauge.

➢ **Test to determine Specific Gravity of coarse aggregate by wire basket method**

1. Take about 5kg of coarse aggregates passing through 4.75mm sieve.

2. Wash thoroughly to remove dust, dry to constant mass at a temperature of 105± 5ºC.

3. Immerse the sample in water in water at 22 to 32ºC for a period of 24±1/2 hours (30min in practice).

4. Remove the aggregates from water & roll the same in a large piece of an absorbent cloth until all visible films of water are removed, although the surface of the particles will still appears to be damp.

5. Now, weigh 3kg of this sample in the in the saturated dry condition and note down the mass as W_1gm.

6. Place the weighed aggregate immediately in the wire basket & dip it water. Weigh this bucket with aggregates, keeping it in water with the help of a balance. Note down the mass as W_3 gm.

7. Note down the weight of suspended empty wire basket in water without aggregates and note down the mass as W_2 gm.

8. Dry the sample to the constant weight at the temperature of 100 to 110ºC for 24±1/2 hours.

9. Cool to room temperature and weigh it & note down the mass as W_4 gm.

10. Calculate specific gravity and repeat the procedure for fresh sample of aggregates.

Weight of oven dry aggregate (C) = W_4 gm.

Weight of saturated surface dry aggregate (B) = W_3 gm.

Weight of basket & aggregates in water (A_1) = W_2 gm.

Weight of empty basket submerged in water (A_2) = W_1gm.

Actual Specific gravity $= \frac{C}{B-A}$

Apparent specific gravity $= \frac{C}{C-A}$

Water absorption $= 100 \text{ X } \frac{B-C}{C}$

Where A = weight of saturated aggregate in water = $A_1 - A_2$.

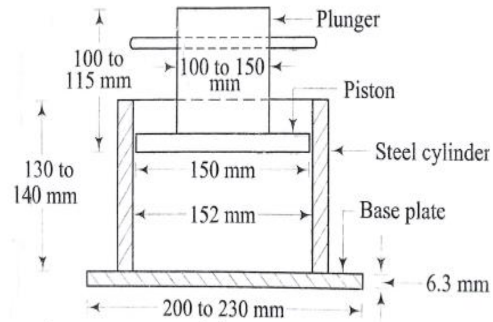
Testing of mechanical properties of aggregates

A. Test for determination of aggregate crushing value

The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load.

Apparatus required for this test are as follows

1. Steel cylinder (dia-15.2cm, height-14cm)
2. Cylindrical measure (dia-11.5cm, height-18cm)
3. Steel tamping rod (dia-1.6cm, height- 40 to 60cm)
4. Balance
5. Compression testing machine



Aggregate crushing test apparatus

Procedure

1. Oven dry aggregate passing 12.5mm IS sieve and retained on 10mm IS sieve is selected for the test.
2. The sample aggregates in filled three layers and each layer being tamped 25 blows by rounded end of the tamping rod.
3. After tamping the third layer, the top surface is leveled using the tamping rod as straight edge. The test sample weight is taken as W_1 gms.
4. The cylinder of the test apparatus is placed in position on the base plate and the test sample is transferred into the cylinder in three layers and each layer is tamped with 25blows.
5. The surface of the aggregate is leveled and the plunger inserted.
6. The cylinder with the test sample and plunger in position is placed on CTM.
7. Load is then applied through the plunger at a uniform rate of 4tones/min until the total load of 40tones and then the load is released.

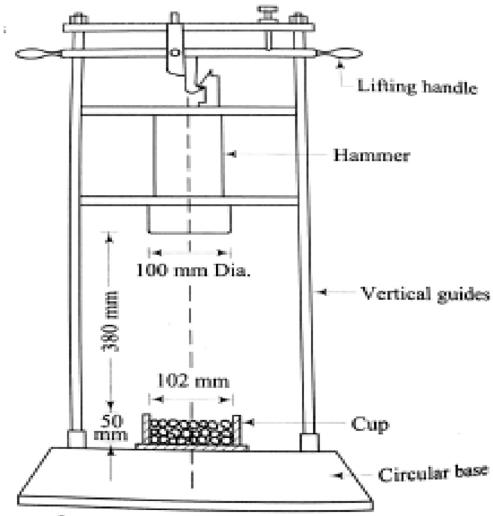
9. Aggregates including the crushed portion are removed from the cylinder and sieved on a 2.36mm IS sieve, the material which passes this sieve is collected and taken W_2 gms.

Aggregate crushing value $= \frac{W_2}{W_1} X100$

Note: According to Indian road congress & ISI has specified that aggregate crushing value of the coarse aggregate used for cement concrete pavements should not exceed 30% and used for concrete other than wearing surface should not exceed 45%.

B. To determine the aggregate impact value

The aggregate impact value gives the relative measure of the resistance of an aggregate to sudden shock or impact.



Impact testing machine

Apparatus required for the experiment are as follows

1. Impact testing machine
2. Cylindrical measure
3. Tamping rod
4. Balance

Procedure

1. Oven dry aggregate passing through 12.5mm IS sieve and retained in 10mm IS sieve are selected for the test.

2. The cylindrical measure is filled by the sample aggregates in three layers and each layer being tamped by 25blows with rounded end of the tamping rod.

3. After tamping the third layer, the top surface is leveled using the tamping rod as straight edge. The test sample weight is taken as W_1 gms.

4. The cup of the test apparatus is placed in position on the base plate and test sample is transferred to the cup in a single layer and being tamped 25 blows and top surface is leveled.

5. The hammer is raised until its lower face is 38cm above the upper surface of the aggregate in the cup, and allowed to fall freely on aggregate for 15 times at an interval not more than 2 seconds and not less than 1second.

6. The crushed aggregate is then removed from the cup and the whole sample is sieved on 2.36mm IS sieve, the material which passes this sieve is collected and taken W_2 gms.

Aggregate impact value $= \frac{W_2}{W_1} X100$

Note: According to IS specification, the aggregate impact value

< 10% → exceptionally strong
10 – 20% → strong
20 – 30% → satisfactory for road surfacing
> 30% → weak for road surfacing

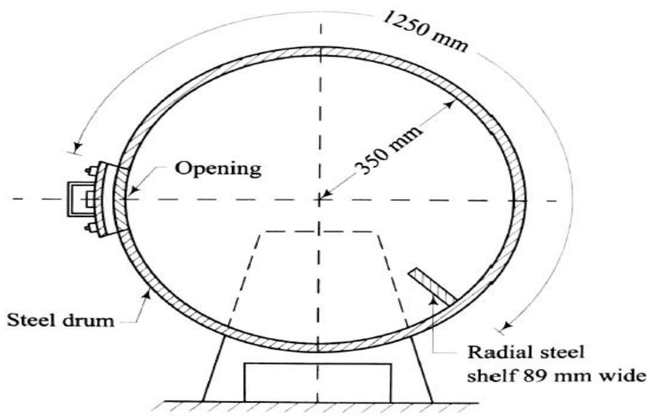
Recommended aggregate impact value for different types of pavements

No.	Type of pavement surfaces	Max. aggregate impact value (percentage)
1	Bituminous surface dressing; penetration macadam; cement concrete wearing course	30
2	Bitumen bound macadam	35
3	Cement concrete base course	45

C. Test for the determination of aggregate abrasion value

Apparatus required for the experiment are as follows

1. Los-Angeles machine
2. Steel balls (dia - 48cm, weight - 390 to 445g)
3. Balance
4. Sieves



Cross-section of Los Angeles testing machine

Procedure

1. Clean dry aggregate, confirming to any one of the grading A to G is used for the test. Aggregate weighing 5kg for grading A, B, C or D and 10kg for grading E and for G may be taken as test specimen and placed in the cylinder and is noted as W_1 gms.

2. The abrasive charge is also chosen depending upon the aggregate and is placed in the cylinder of the machine; the cover is then fixed dust tight.

3. The machine is rotated for 500 revolutions for grading A, B, C and D & for grading E, F and G it shall be rotated for 1000 revolutions.

4. After the desired number of revolutions, machine is stopped and the material is discharged from the machine taking care to take out entire stone dust.

5. Using 1.7mm IS sieve the material is sieved and the coarser material is retained on the sieve is taken as W_2 gms.

Percentage wear $= \frac{W_2}{W_1} X100$

Specifications for Los-Angeles test

No.	Sieve size		Weight (in gms) and grading of test samples						
	Passing on mm	Retained on mm	A	B	C	D	E	F	G
1	80	63	-	-	-	-	2500	-	-
2	63	50	-	-	-	-	2500	-	-
3	50	40	-	-	-	-	5000	5000	-
4	40	25	1250	-	-	-	-	5000	5000
5	25	20	1250	-	-	-	-	-	-
6	20	12.5	1250	2500	-	-	-	-	-
7	12.5	10	1250	2500	-	-	-	-	-
8	10	6.3	-	-	2500	-	-	-	-
9	6.3	4.75	-	-	2500	-	-	-	-
10	4.75	2.36	-	-	-	5000	-	-	--
Number of spheres to be used			12	11	8	6	12	12	12
Number of revolutions			500				1000		

Maximum allowable Los-Angeles abrasion values

No.	Type of surface	Maximum abrasion values
1	W.B.M subsurface course	60
2	W.B.M base course with bituminous surfacing	50
3	W.B.M surface course	40
4	Cement concrete surface course	35
5	Bituminous / Asphalt concrete surface course	30

1.3.3 Recycled Aggregates

- Aggregates which are obtained from demolished concrete structures are referred as Recycled aggregates.
- Used in road pavement construction and for non-structural works.
- ASTM (American Society for Testing and Materials) has classified these aggregates as Artificial aggregates.
- It has low strength, lower young's modulus, low density, high drying shrinkage, higher porosity and higher absorption capacity.
- It produces a concrete of low density than compared to conventional aggregates.
- It is an added advantage if it is saturated. Because it helps in internal curing.

1.3.4 Process of manufacturing Recycled aggregates

- Crushing
- Pre-sizing
- Sorting
- Screening
- Contaminant elimination

Aggregates which are obtained from demolished concrete structures are first crushed with the help of crushing equipment. Then with the help of Vertical Shaft Impact machine it is made into different sizes, sorted, screened and washed with water to remove the impurities which are present on the surface of aggregates.

Advantages of Recycled Aggregates

- Reduces the amount of virgin aggregates to be created, hence less evacuation of natural resources.
- While being crushed into smaller particles a large amount of carbon dioxide is absorbed. This reduces the amount of CO2 is the atmosphere.
- Cost saving – few research studies have shown a significant reduction in construction costs if RAC is used.
- Conserves landfill space, reduces the need for new landfills and hence saving more costs.
- Creates more employment opportunities is recycling industry.

Disadvantages of Recycled Aggregates

- Downgrading of quality of concrete.
- Increase in water absorption capacity ranging from 3% to 9%
- Decrease in compressive strength of concrete (10-30%)
- Reduces workability of concrete.
- Lack of specifications and guidelines.
- Less durability of RAC, however few papers have shown an improvement in the durability by mixing it with special materials like fly ash

Applications of Recycled Aggregates

- Can be used for constructing gutters, pavements etc.
- Large pieces of crushed aggregate can be used for building revetments which in turn is very useful in controlling soil erosion.
- Recycled concrete rubbles can be used as coarse aggregate in concrete.

1.3.5 Blending of Aggregates

Sometimes aggregates available at sites may not be of specified or desirable grading. In such cases two or more aggregates from different sources may be combined to get the desired grading. Often, mixing of available fine aggregate with available coarse aggregate in appropriate percentages may produce desirable grading. But sometimes two or more fractions of coarse aggregates is mixed first and then the combined coarse aggregate is mixed with fine aggregate to obtain desirable grading.

Water

1.4.1 Quality of mixing water

A popular yard stick to the suitability of water for mixing concrete and cement is that, if the water is fit for drinking is fit for mixing concrete. This statement may not be true for all conditions. Some water containing a small quantity of sugar is fit for drinking but it is not desirable for mixing concrete and conversely water suitable for mixing concrete may not be fit for drinking.

Some of the Qualities of water can used for mixing are

- The use of portable water is generally safe for mixing of concrete.
- Any water with a pH of 6 to 8 which does not taste saline is suitable for use to mix the concrete.
- Sea water contains large quantities of chlorides tends to cause persistent dampness and efflorescence.
- In RCC, sea water increases the risk of corrosion of the reinforcement.
- Water containing less than 2000ppm of dissolved salts can generally be used satisfactory for making concrete.
- Presence of zinc, copper, tin, manganese and lead reduce the concrete strength.
- Sodium phosphate, sodium borate etc., acts as retarders which results in loss of strength.
- Sugar up to 0.05% by weight of water is harmless.
- Sugar up to 0.05% by weight of cement retard the setting time, reduce the early strength and increases 28days strength.
- Sugar up to 0.2% causes quick setting of cement.
- Mineral oils in concentration greater than 2% by weight of cement may reduce the concrete strength by 20%.
- Algae present in water or on the surface of aggregates either reduce the bond by combining with cement or entraining large amount of air in concrete.
- Curing water should be free from impurities, oils etc.
- Water containing more than 0.08ppm of iron is not recommended for curing.
- When aggregates are washed with water containing impurities, they get coated with silts, salts etc., and reduces the bond strength between cement and aggregate.

1.4.2 Use of sea water for mixing concrete

Sea water has a salinity of about 3.5%. In that about 78% is NaCl and 15% is chlorides and sulphates of magnesium. Sea water also contains small quantities of sodium and potassium salts. This will react with aggregates and cement used for mixing. Hence sea water should not be used for mixing concrete. It is seen that use of sea water for mixing concrete does not appreciably reduce the strength of concrete but it may lead to corrosion of reinforcement. Sea water slightly accelerates the early strength of concrete but it reduces 28days strength of concrete by about 10-15%.

Admixtures

1.5.1 Introduction

- Admixtures are chemical or mineral substances other than fine aggregates, coarse aggregates, cement and water, which are added in small amount before or at the mixing stage to the concrete product.
- They can also be blended at the time of grinding of clinker in cement manufacturing process.
- Added only when properties of fresh or hardened concrete need to be modified.

Most commonly used Chemical admixtures are

- Plasticizers
- Super plasticizers
- Retarders and Retarding plasticizers
- Accelerators and Accelerating plasticizers
- Air-entraining Admixtures
- Damp proofing and Water Proofing Admixtures
- Gas forming Admixtures
- Air detraining Admixtures
- Workability Admixtures
- Bonding Admixtures
- Coloring Admixtures

How Chemical Admixtures act?

Reaction of chemical admixtures with cement takes place in three different stages

1. Physico Chemical reaction:-

In this stage, C_3S & C_3A are formed early when water is added to the cement and because of adhesive property of cement, an intermolecular force of attraction will be created between the cement grains as a result cement floc will be formed in the cement paste.

2. Chemical adsorption and interaction: -

When chemical admixtures are added to the cement, it gets adsorbed on cement compounds or cement grains and on the products of hydration (especially on C_3A), which stiffens the hydrated compounds. But sometimes it also initiates very early stiffening. They really combine and never slowdowns the setting but initiates long term hydration.

3. Deflocculation or Dispersion: -

Flocculated cement compounds consists of certain amount of water in it. But due to the attack of admixtures, it deflocculates or disperses the cement grains by creating an intermolecular repulsion between the cement grains which releases the water in the cement paste as a result, workability of concrete increases. The intermolecular repulsion between the cement grains is known as **"Zeta Potential"**.

1.5.1.1 Plasticizers (Water reducers):-

- Workability is the inherent property of concrete. High degree of workability is required in deep beams, thin walls, column- beam junctions and in RMC's.
- Plasticizer helps in providing high workability even in difficult situations.
- Addition of extra water will only improve the fluidity but not workability.
- Addition of plasticizers will improve the plastic properties of concrete.
- It reduces the water-cement ratio for a given workability, which increases strength and durability.
- Used to reduce the cement content and heat of hydration in mass concreting.
- Some of the chemical admixtures which are commonly adopted are,
  - Lignosulphonates
  - Hydroxylated Carboxylic acids

- Usually added in the range of 0.1 to 0.4% by weight of cement.
- When it is added, it entrains air as a result mechanical property of concrete is reduced.
- Therefore a good plasticizer should not entrain air more than 1-2%.

1.5.1.2 Super plasticizers: -

- These are chemically different form normal plasticizers.
- Reduces water content up to 30% without reducing the workability.
- Used for producing self-leveling, flowing, self-compacting and high performance concrete.
- Can produce high workability at same workability.
- Can reduce w/c ratio for a given workability.
- Can reduce cement content for given w/c ratio.
- Provides homogenous cohesive concrete but no tendency of segregation and bleeding.
- Commonly used as base for super plasticizer are

- Sulphonated Melanie – Formaldehyde condensates (SMF)
- Sulphonated Naphthalene – Formaldehyde condensates (SNF)
- Modified Ligno sulphonate (MLS)
- Poly Carboxylated Ether (PCE)

1.5.1.3 Retarders:-

- ➢ It is an admixture which slowdowns the hydration process and concrete remains plastic for long time.
- ➢ Use to overcome the accelerated effect of high temperature on setting in weather conditions.
- ➢ Calcium sulphates are the best retarding admixtures which retards setting of concrete
- ➢ Sometimes common sugar is also used to delay setting of concrete.

1.5.1.4 Retarding Plasticizers:-

- ➢ We know that plasticizers and super plasticizers show certain extent of retardation.
- ➢ Retarding plasticizers are used in
  - ✓ RMC's for retaining slump loss in case of long distance transportation,
  - ✓ when concrete is being placed or transported under conditions of high ambient temperature
  - ✓ In case of large concrete pours
  - ✓ Concrete construction involving sliding formwork

Mode of action

- It is thought that retarding admixtures are absorbed on to the C3A phase in cement forming a film around the cement grains and presenting or reducing the reaction with water.
- After a while thus film breaks down and normal hydration proceeds.

Commonly used chemicals

- ➢ Unrefined lignosulphonates containing sugar
- ➢ Hydroxyl carboxylic acid and their salts
- ➢ Carbohydrates including sugar
- ➢ Soluble zinc
- ➢ Soluble borates etc.

1.5.1.5 Accelerators: -

- Added to increase the early strength development in concrete.
- Allows earlier removal of formwork
- Reduce required period of curing
- Used in emergency repair works
- Commonly used chemicals are
  - Calcium chlorides
  - Sulphates
  - Aluminates

But $CaCl_2$ is not desirable for concrete because it leads to corrosion of reinforcement in RCC.

1.5.1.6 Accelerating Plasticizers: -

- When accelerated super plasticizers are added to the concrete, it increases the strength.
- Commonly used chemicals are
  - Tri-ethanolamine chlorides
  - Nitrates and fluorosilicates

1.5.1.7 Air entraining admixtures

- Mixing small quantity of air entraining agents will increase the voids or air bubbles in concrete which improves the plastic and hardened properties and have improved resistance against frost action and permeability.
- Air voids in concrete can be brought into two groups
  - Entrapped air is due to insufficient compaction of concrete
  - Entrained air is intentionally added and distributed uniformly.
- Some of the chemical air entraining agents are Natural wood resins, Animal and vegetable fats and oils

Mineral admixtures

Mineral admixtures are inorganic, finely grained materials having Pozzolanic properties added to the concrete mix in order to improve the properties of concrete.

Source of Mineral Admixtures

a) Raw or calcined natural minerals
b) Industrial by products

Classification of Mineral Admixture

ASIM specification C618 recognizes the following three classes of mineral admixtures.

a) Class N — Raw or calcined natural pozzolanic such as diatomaceous earths, clay and shales, tuffs and volcanic ashes.

b) Class F — Fly ash produced from burning anthracite or bituminous coal.

c) Class C — Ash normally produced from lignite or sub-bituminous coal which may contain analytical CaO higher than 10%.

Reasons for using mineral admixtures

a) In recent years' considerable efforts have been made by the cement industry world-wide to reduce energy consumption in the manufacture of Portland cement. Therefore, a partial replacement of Portland cement by mineral admixtures which can be of the order of 50 – 60% by weight of total cementitious material, represents considerable energy savings.

b) The ability of cement and concrete industries to consume mithions of tons of industrial byproducts containing toxic metal would qualify these industries to be classified as environmentally friendly.

c) Since natural Pozzolana and industrial by products are generally available substantially lower costs than Portland cement, the exploitation of the Pozzolanic and cementitious properties of mineral admixtures are used as a partial replacement of cement can lead to a considerable economic benefit.

d) Possible technological benefits from the use of mineral admixtures in concrete include entrancement of impermeability and chemical durability, improved resistance to thermal cracking and increase in ultimate strength.

Types of Mineral admixtures

- Fly Ash
- GGBS
- Silica Fume
- Metakaolin
- Rice Husk Ash

1.5.1.8 Fly ash:-

- A by-product of coal fired electric generation plant, used for partially replacing cement up to 60% by mass.
- It is obtained by Electro static precipitator.
- It is produced in large quantity in India.
- In India, Fly ash is classified as Class F because it contains less calcium.
- It contributes strength and durability and enhances workability due to spherical nature.
- There are two types of Fly ash

Low lime Fly ash → produces cementitious property because of lime or cement
High lime fly ash → Exhibit cementitious property by itself

Applications:- Building blocks, Fine aggregate, Blending cements, geotechnical applications etc.

Effects of Fly Ash on Fresh Concrete:

- ✓ Reduction of water demand for desired slump.
- ✓ With the reduction of unit water content, bleeding and drying shrinkage will also be reduced.

Effects of Fly Ash on Hardened Concrete:

- ✓ Contributes to the strength of concrete due to its pozzolanic reactivity.
- ✓ Continued pozzolanic reactivity concrete develops greater strength at later age not at initial stage.
- ✓ Resulting in decrease of water permeability

1.5.1.9 Ground Granulated Blast Furnace Slag (GGBFS/ GGBS):-

- It is a by-product of steel production
- Used to partially replace cement by 80% by mass.

Effects on fresh concrete:

- ✓ It reduces the unit water content necessary to obtain the same slump.
- ✓ Water used for mixing is not immediately lost, as the surface hydration of slag is slightly slower than that of cement.
- ✓ It reduction of bleeding.

Effects on hardened concrete:

- ✓ It Reduced heat of hydration.
- ✓ Refinement of pore structures greatly reduced permeability to the external agencies and increased resistance to chemical attack.

1.5.1.10 Silica Fume:-

- ➢ A by-product of production of silicon and Ferro-silicon alloys similar to Fly ash but particle size is 100 times smaller. This helps in more Pozzolanic reaction.
- ➢ It is used to increase the strength and durability of concrete and super plasticizer is necessary for obtaining workability.

Effect on fresh concrete:

- ✓ Fresh concrete sticky in nature and hard to handle.
- ✓ Causes large reduction in bleeding and concrete with micro silica could be handled and transported without segregation to plastic shrinkage cracking.

Effect on hardened concrete:

- ✓ Modulus of elasticity of micro silica concrete is less.
- ✓ It causes improvement in durability of concrete and Resistance against frost damage.

Application:

- ✓ Conserve cement
- ✓ Produce ultra high strength concrete of the order of 70 to 120 Mpa.
- ✓ Increase early strength of fly concrete.
- ✓ Control alkali-aggregate reaction.
- ✓ Reduce sulfate attack & chloride associated corrosion.

1.5.1.11 High reactive Metakaolin (HRM):-

- ➢ Similar to silica fume and it is also used to increase the strength and durability of concrete.
- ➢ Silica fume → dark grey or black where, Metakaolin → bright white
- ➢ Metakaolin is usually employed for providing architectural effects to concrete structures.

Effects of Metakaolin:

- ✓ High reactive Metakaolin shows high pozzolanic reactivity and reduction in Ca(OH)2 even as early as one day.
- ✓ The cement paste undergoes distinct densification.
- ✓ Densification includes an increase in strength and decrease in permeability.
- ✓ The high reactive Metakaolin is having the potential to compete with silica fume.

1.5.1.12 Rice Husk Ash:-

- Obtained by burning Rice husk.
- Exhibits Pozzolanic properties
- Contributes high strength, durability and highly impermeable concrete.
- Consists of more percentage of SiO_2 which can be used as admixture.

Effects:

- ✓ It reduces susceptible to acid attack and improves resistance to chloride penetration and reduces large pores and porosity resulting very low permeability and free lime present in the cement paste.
- ✓ It Decreases the permeability of the system and Improves overall
- ✓ resistance to CO2 attack Improves capillary suction and accelerated chloride diffusivity.
- ✓ It also Enhances resistance to corrosion of steel in concrete. Reducing micro cracking and improving freeze-thaw resistance.

1.6 Assignment questions

1. Define cement and explain the characteristics of cement.
2. Write a note on chemical composition of cement
3. Explain the methods for manufacturing of concrete with a neat flow chart.
4. What are the types of cement? Explain any five in brief.
5. What are the types for testing cement and explain in brief.
6. Write a note on classification of aggregates.
7. What is grading of aggregates and explain in brief.
8. What is the importance of grading of aggregates in the manufacture of concrete?
9. What are admixtures?
10. What are the types of admixtures?

11. What are chemical admixtures?
12. What are plasticizers? Explain the properties of plasticizers.
13. What are super plasticizers? Explain the properties of super plasticizers.
14. What are mineral admixtures?
15. Explain the properties of Fly ash, GGBS, silica fumes, RHA, Metakaolin

1.7 Outcome

- Gives knowledge about chemical composition of cement, different types of cement and its applications, field and laboratory tests conducted on cement.
- Gives an idea about the classification, functions, properties and tests performed on aggregates.
- Gives knowledge about admixtures

1.8 Future study

By knowing this one can able to use the particular type of cement, aggregates and admixtures for a particular application.

Module-2 Fresh concrete

Contents:-

2.1 Introduction
2.2 Objectives
2.3 Properties of good concrete
2.4 Fresh properties
2.4.1 Workability
2.4.2 Segregation
2.4.3 Bleeding
2.5 Process of manufacturing concrete
2.5.1 Batching
2.5.2 Mixing
2.5.3 Transporting
2.5.4 Pacing
2.5.5 Compaction
2.5.6 Curing
2.5.7 Finishing
2.6 Assignment questions
2.7 Outcome
2.8 Future study

2.1 Introduction

- ✓ The cement concrete is a mixture of cement, sand, pebbles or crushed stones and water. When this mixture is placed and allowed to cure, becomes hard like a stone.
- ✓ The potential strength and durability of concrete of a given mix proportion is very dependent on the degree of its compaction
- ✓ It is vital, therefore, that the consistency of the mix be such that the concrete can be transported, placed, and finished sufficiently early enough to attain the expected strength and durability.

Significance

- The first 48 hours are very important for the performance of the concrete structure.
- It controls the long-term behavior, influence f'c (ultimate strength), Ec (elastic modulus), creep, and durability.

2.2 Objective

- To determine the fresh properties of concrete
- To study different types of test to be performed on concrete
- To know the manufacturing process of concrete

2.3 Properties of good concrete

1. It has high compressive strength.

2. It is free from corrosion and less effected by atmospheric agents.

3. It hardens with age and process of hardening continues for a long period of time after concrete has attained sufficient strength.

4. It is proved to be more economical than steel. This is due to the fact that, the aggregates constitute about 80 – 90% of volume of concrete and is available at reasonable rates.

5. It binds rapidly with steel and as it is weak in tension, the steel reinforcement is placed in cement concrete structure at suitable places to take up tensile stresses. This is termed as **Reinforced Cement Concrete** (**RCC**).

6. Under the following two conditions, it has a tendency to shrink:

a) There is an initial shrinkage of cement concrete which is mainly due to the loss of water through forms, absorption by surfaces of forms.

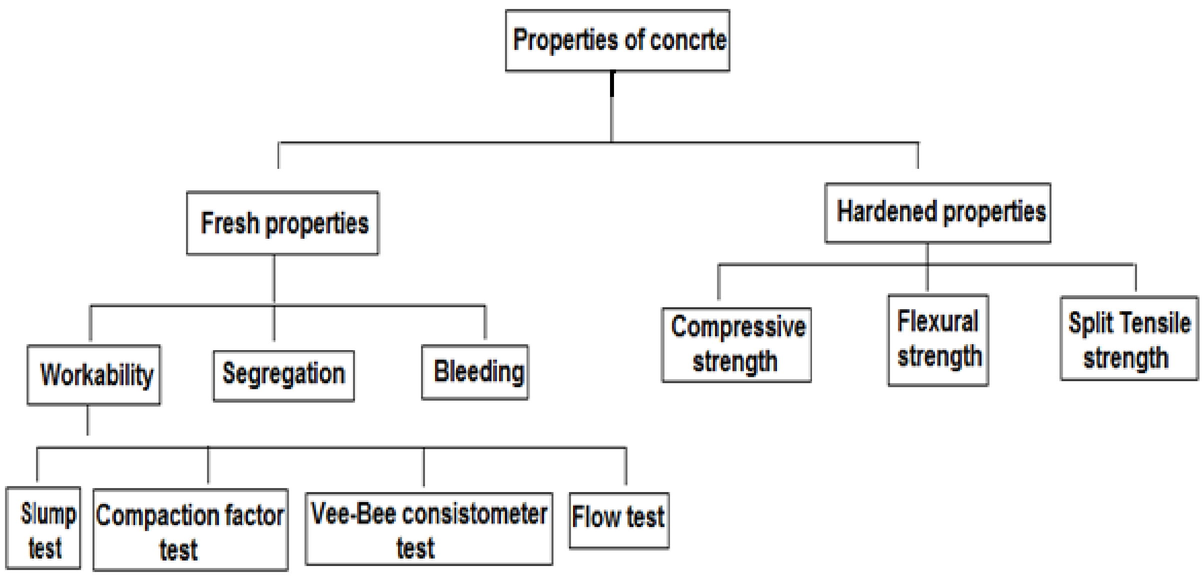
b) The shrinkage of cement concrete occurs as it hardens. This tendency of cement concrete can be minimized by proper curing of concrete.

7. It has a tendency to be porous in nature. This is due to the presence of voids which are formed during and after its placing. The two precautions necessary to avoid this tendency are as follows:

a) There should be proper grading and consolidation of aggregates.

b) The minimum water-cement ratio should be adopted.

8. It forms a hard surface and offers resistance to abrasion.



Fresh concrete: It is the freshly mixed materials which can be moulded into any desired shape. The properties of fresh concrete are workability, segregation and bleeding.

2.4 Fresh Properties

2.4.1 Workability

The property of concrete determines the amount of internal work required to produce full compaction.

Or

It is the ease with which the concrete can be compacted 100% and can be deposited / transported or placed in required position.

Factors affecting workability

1. **Water content:** The water content in a given volume of concrete will have significant influence on workability of concrete. Higher the water content per cubic meter of concrete, higher will be the fluidity. It should be noted that from the desirable point of view, increase in water content will be the last resource for improving the workability in case of uncontrolled concrete. But for controlled concrete we cannot increase the water content. If we want to increase the water content, simultaneously we have to increase the cement in order to maintain water-cement ratio as constant and strength of the concrete remains same.

2. **Mix proportion:** aggregate to cement ratio is an important ratio influencing workability. Higher the aggregate to cement ratio, leaner will be the concrete mix. In case of lean concrete less quantity of paste is available for lubricating the surface. Hence there is chance of mobility of aggregates. On the other hand in case of rich mix with lower aggregate to cement ratio, more paste is available to make the mix cohesive and also gives better workability.

3. **Size of aggregate:** Bigger the size of particles less will be the surface area and hence less amount of water is required and also less cement paste required for lubricating the surfaces of aggregates. So bigger the size, gives higher workability.

4. **Shape of aggregate:** Angular, elongated or flaky aggregates make the concrete very harsh when compared to rounded or cubical aggregates. Contribution to better workability of rounded aggregate will come from the fact that for a given volume or weight. It will have a less surface area and lesser voids. Not only is that being in rounded in shape, the frictional resistance between the aggregates also reduced. Hence the workability will be more in case of rounded than compared to flaky aggregates. Hence the strength will be more by using rounded or cubical aggregates.

5. **Surface texture:** The influence of surface texture on the workability is due to the fact that, total surface area of rough texture aggregate is more than that of surface area of smooth rounded aggregates of same volume. Rough textured aggregates will show poor workability and smooth textured aggregates will give better workability because of lesser frictional resistance of inner surface particle.

6. **Grading of aggregates:** This is one of the factor will have maximum influence on workability. A well graded aggregate will give least amount of voids for given volume of aggregates. When the voids are less, excess paste will be available to give better workability. Better the grading, lesser will b the voids and greater will be the workability.

7. **Use of admixtures:** Like plasticizers and super plasticizers greatly improves the workability of concrete.

Measurement of Workability:

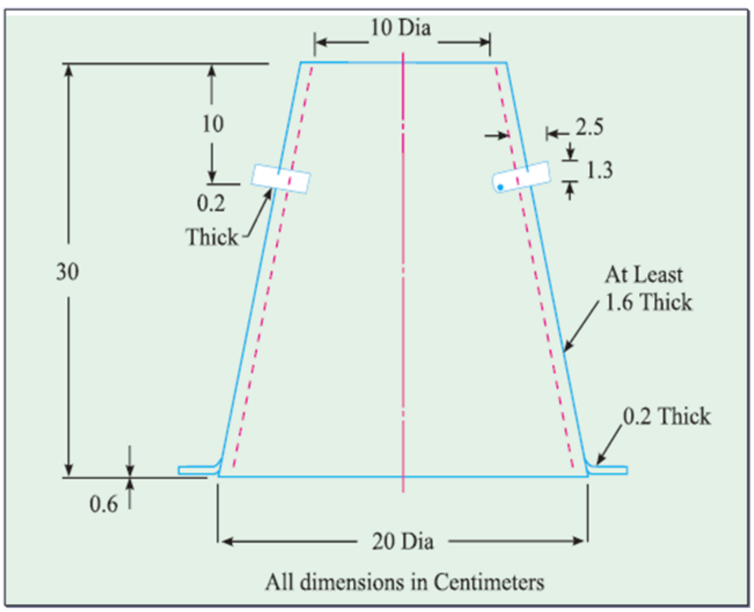
The following tests are commonly employed to measure workability.

- Slump Test
- Compacting Factor Test
- Vee-Bee Consistometer Test
- Flow Test

2.4.1.1 Slump test:

Unsupported fresh concrete flows to the sides and sinking in height takes palce. This vertical settlement is known as slump.

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete.

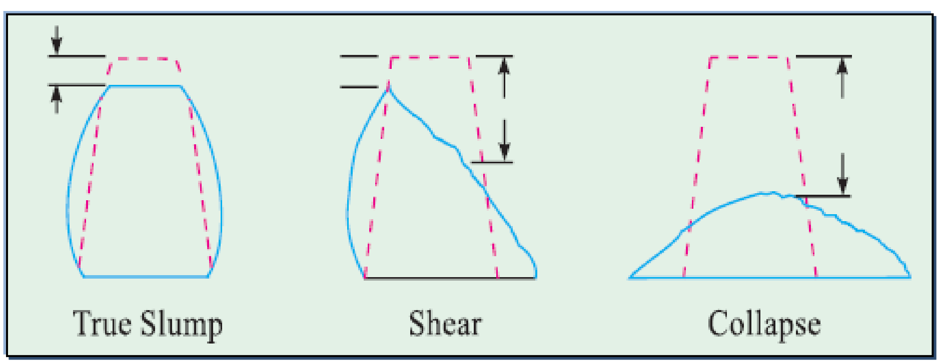


Procedure:

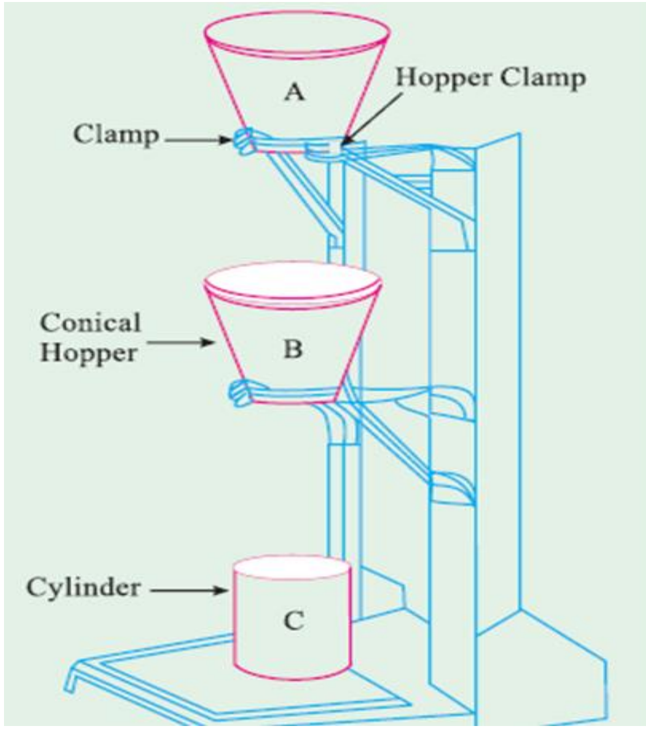
The apparatus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as under:

- ✓ Bottom diameter : 20 cm
- ✓ Top diameter : 10 cm
- ✓ Height : 30 cm

- For tamping the concrete, a steel tamping rod 16 mm dia, 0.6 meter along with bullet end is used.
- The mould is placed on a smooth, horizontal, rigid and non-absorbent surface.
- The mould is then filled in four layers, each approximately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping rod taking care to distribute the strokes evenly over the cross section.
- After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod.
- The mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction.
- This allows the concrete to subside. This subsidence is referred as SLUMP of concrete.
- The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm. is taken as Slump of Concrete.
- If the concrete slumps evenly it is called true slump.
- If one half of the cone slides down, it is called shear slump.
- Shear slump also indicates that the concrete is non-cohesive and shows the characteristic of segregation.



2.4.1.2 Compacting factor test:



- The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field.
- It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration.
- It is claimed that it is one of the most efficient tests for measuring the workability of concrete.
- This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height.
- The degree of compaction, called the compacting factor is measured by the density ratio *i.e.*, the ratio of the density actually achieved in the test to density of same concrete fully compacted.

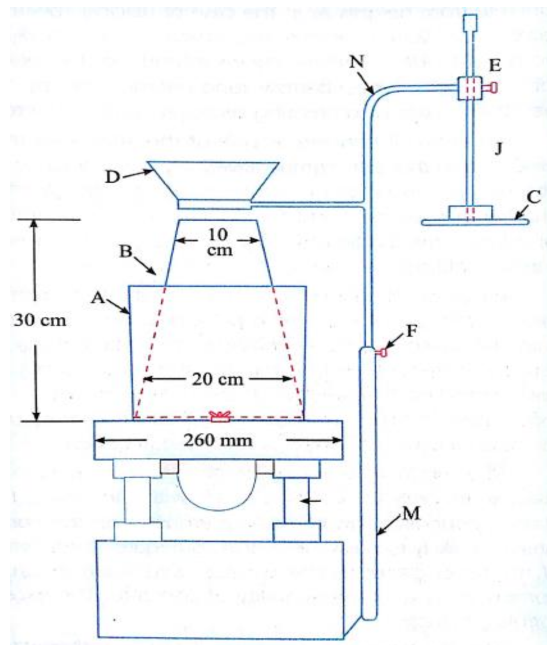
Procedure

- The sample of concrete to be tested is placed in the upper hopper upto the brim.
- The trap door is opened, so that concrete falls to the lower hopper bottom.
- The trap door of lower is opened, so that concrete falls into the cylinder.
- The excess concrete is removed and levelled off.
- This amount of concrete along with the cylinder is weighed and let it be W_1gms, where W_1 is the weight of partially compacted concrete.
- The cylinder is emptied and refill the same sample of concrete in 3 layers and each layer is being tamped by 25blows evenly on the sample.

- After compacting top layer, level the top surface and note down the weight of cylinder along with the compacted concrete and let it be W_2gms, where W_2 is the weight of fully compacted concrete.

$$\text{The Compacting Factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

2.4.1.3 Vee Bee Consistometer Test:



A – Cylindrical container
B – Metal sheet slump cone
C – Transparent disc
D – Funnel
E – Guide sleeve
N – Swivel arm
M – Swivel arm holder
J – Graduated rod

- This is a good laboratory test to measure indirectly the workability of concrete.
- This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod. The apparatus is shown in Figure.
- Slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer.
- The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot.
- The electrical vibrator is then switched on and simultaneously a stop watch started.
- The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape.
- Immediately when the concrete fully assumes a cylindrical shape, the stop watch is switched off.
- **The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as Vee Bee time.**
- This method is very suitable for very dry concrete whose slump value cannot be measured by Slump Test.

2.4.1.4 Flow test:

This is a laboratory test which gives the indication of quality of concrete with respect to consistency, cohesiveness and 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.

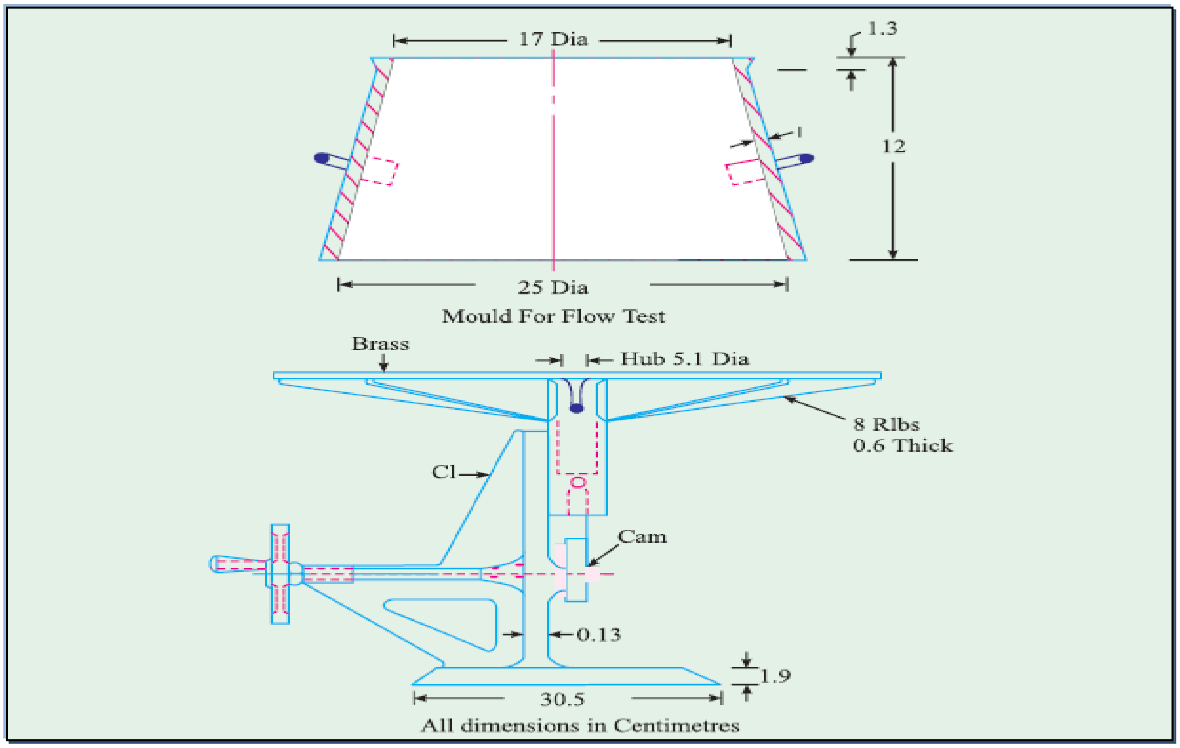


Fig. shows the details of apparatus used. It can be seen that the apparatus consists of flow table, about 76 cm. in diameter over which concentric circles are marked.

Procedure

- 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 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.

$$\text{Flow, per cent} = \frac{\text{Spread diameter in cm} - 25}{25} \times 100$$

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

The spread of concrete on the flow table indicates the characteristics of concrete like segregation.

2.4.2 Segregation:

- Segregation can be defined as the separation of the constituent materials of concrete.
- A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture.
- There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete.
- Segregation may be of three types firstly, the coarse aggregate separating out or settling down from the rest of the mixing
- Secondly, the paste or matrix separating away from coarse aggregate and thirdly, water separating out from the rest of the material being a material of lowest specific gravity.
- A well-made concrete, taking into consideration various parameters such as grading, size, shape and surface texture of aggregate with optimum quantity of waters makes a cohesive mix. Such concrete will not exhibit any tendency for segregation.
- The cohesive and fatty characteristics of mixing do not allow the aggregate to fall apart, at the same time.
- Segregation is difficult to measure quantitatively, but it can be easily observed at the time of concreting operation.
- The pattern of subsidence of concrete in slump test or the pattern of spread in the flow test gives a fair idea of the quality of concrete with respect to segregation.

2.4.3 Bleeding:

- Bleeding is sometimes referred as water gain or water rise. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete.
- Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete.

- In thin members like roof slab or road slabs and when concrete is placed in sunny weather show excessive bleeding.
- In case of water gain, water comes up and accumulate at the surface along with this sometimes a certain amount of cement content also rises up to the surface. When this surface is leveled by trowel, aggregates goes down and cement-water mixture comes to top surface. This formation of cement paste on the surface of concrete is known as **laitance**.

The effects of water gain:

- The water gain which causes voids and reduces the bond between the cement and aggregates.
- Water gain below the reinforcement especially at cranked portion reduces the bond between reinforcement and concrete.
- Water while traversing from bottom to top make a channel and if water-cement ratio greater than 0.7 is used, channel becomes continuous and responsible for permeability of concrete.

Water gain can be avoided by

1. Proper mix proportion

2. Proper mixing

3. By using finely divided pozzolanic material

4. By using finer cement or cement with less alkali content

5. By revibration of concrete

6. By using air entraining agents

2.5 Process of Manufacture of Concrete:

Production of quality concrete requires particulars 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 particulars care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality.

The various stages of manufacture of concrete are:

1. Batching

2. Mixing
3. Transporting
4. Placing
5. Compacting
6. Curing
7. Finishing.

2.5.1 Batching:

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

- Volume batching
- Weigh 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 meter is an indefinite quantity. Because of this, for quality concrete, material has to be measured by weight only. 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) liters. Gauge boxes are used for measuring the fine and coarse aggregates. The volume of the box is made equal to the volume of one bag of cement 35 liters or multiple thereof. Gauge boxes are generally called **farmas**. They can be made of timber or steel plates.

Weigh batching: this is the correct method of measuring the materials. Use of weight systems in batching gives accuracy, flexibility and simplicity. Cement is not weighed, but it is added in terms of bags. But this will lead to error because; on transporting some quantity of cement is lost.

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 liters will not be accurate for the reason of spillage of water. It is usual to have water measured in a horizontal or vertical tank filled to the mixture. These tanks are filled up often every batch.

2.5.2 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 color and consistency.

There are two methods adopted for mixing concrete:

- Hand mixing
- Machine mixing

Hand Mixing:

- Hand mixing is practiced 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 carried out on an impervious surface or brick layer of sufficient large capacity to take 1 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 color is achieved.
- This uniform mixture is spread out in thickness of about 20cm. Water is taken by means of water can fitted with sprinkling head. The water is sprinkled over the mixture and simultaneously turned over. This operation is continued till a good uniform homogenous mixture is obtained. It is to be observed that, water should not be poured, but it is has to be sprinkled.
- Water in small quantity should be added at the end of mixing in order to get required consistency.

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 Laboratory tilting drum mixer mixing concrete.
- They can be classified as batch-mixers and continuous mixers.
- Mixing of concrete is almost invariably carried out by 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. This type of mixers is used in mass concrete 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.

- Again drum type is classified into tilting, non-tilting, reversible and forced action type. Compared to non-tilting type, tilting type mixers are more efficient. Concrete while discharging from drum, first discharges the aggregates and then the matrix. So once again after discharging from drum the mixture has to be mixed properly before it is placed / transported.

How do we mix concrete in a mixer?

- Firstly about half the quantity of coarse aggregate is placed into the mixer.
- Over this about half quantity of fine aggregate is poured.
- On this mixture, 1 bag of cement is poured and over this remaining half quantity of coarse and fine aggregates is placed. This prevents the blowing away of cement in windy weather.
- Before the loading skip is placed into the drum, about 25% of water is added to the drum in order to avoid the sticking of cement to the surface / deposition at the bottom. After loading skip is placed, remaining 75% of water is added. If the mixer is having an independent feeding of water, it is desirable that remaining 75% of water is added simultaneously along with the loading skip.

Mixing Time:

- Concrete mixers are generally designed to run at a speed of 15 to 20 revolutions per minute.

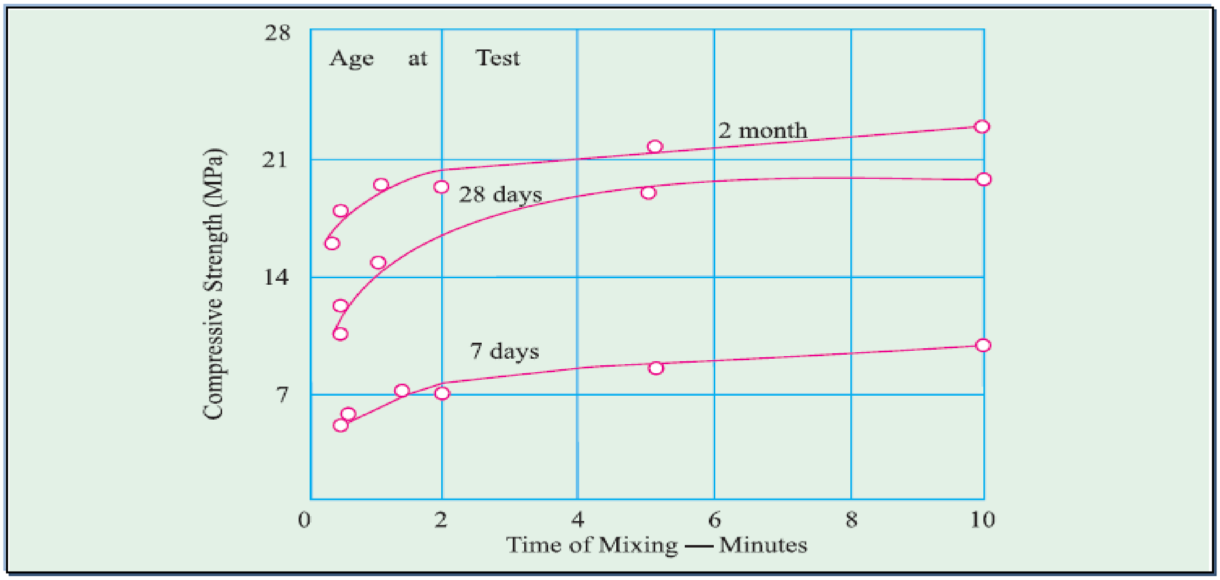
- For proper mixing, it is seen that about 25 to 30 revolutions are required in a well designed mixer.

- In the 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. Fig. shows the effect of mixing time on strength of concrete.



2.5.3 Transporting of Concrete:

Concrete can be transported by a 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
- Wheel Barrow, Hand Cart,
- Crane, Bucket and Rope way ,
- Truck Mixer and Dumpers,
- Chute,
- Skip and Hoist ,
- Tansit Mixer,
- Pump and Pipe Line,
- Helicoptor

Wheel Barrow, Hand Cart:

- 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.

Truck Mixer and Dumpers:

For large concrete works particularly for concrete to be placed at ground level, trucks and dumpers can be used.

Crane, Bucket and Rope way:

- A crane and bucket is one of the right equipment for transporting concrete above ground level.
- 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.
- Cranes are fast and versatile to move concrete horizontally as well as vertically along the placement of concrete at the exact point.

Chute:

- Chutes are generally provided for transporting concrete from ground level to a lower level.

Skip and Hoist:

- This is one of the widely adopted methods for transporting concrete vertically up for multistorey building construction.

Transit Mixer:

- Transit mixer is one of the most popular equipments for transporting concrete over a long distance particularly in Ready Mixed Concrete plant (RMC).
- 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.

2.5.4 Placing of Concrete:

It is enough that the concrete is properly mixed, correctly batched and transported, but also it has to be placed in a sequential manner to obtain better results.

- Placing concrete within earth mould (example foundation concrete for wall or a 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.

Placing concrete within earth mould:

- 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 and burnt 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.
- 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.

Placing concrete within large earth mould or timber plank formwork:

- 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, bottom portion of concrete becomes weak. Sometimes, in order to prevent the absorption of moisture from concrete,

a polyethylene film is placed between concrete and ground surface gives enough scope for the concrete to undergo sufficient shrinkage.

Placing concrete in layers within timber or steel shutters:

- 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.
- Before placing the concrete, the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush. Sometimes cement slurry or a very thin layer of rich mortar is placed on the old surface and then the fresh concrete is laid. This is done in order to avoid formation of cold joints. So it is better to leave the top surface as rough, which gives better binding between the two layers.

Placing of concrete within usual from work. (example: Columns, beams and floors):

Form work:

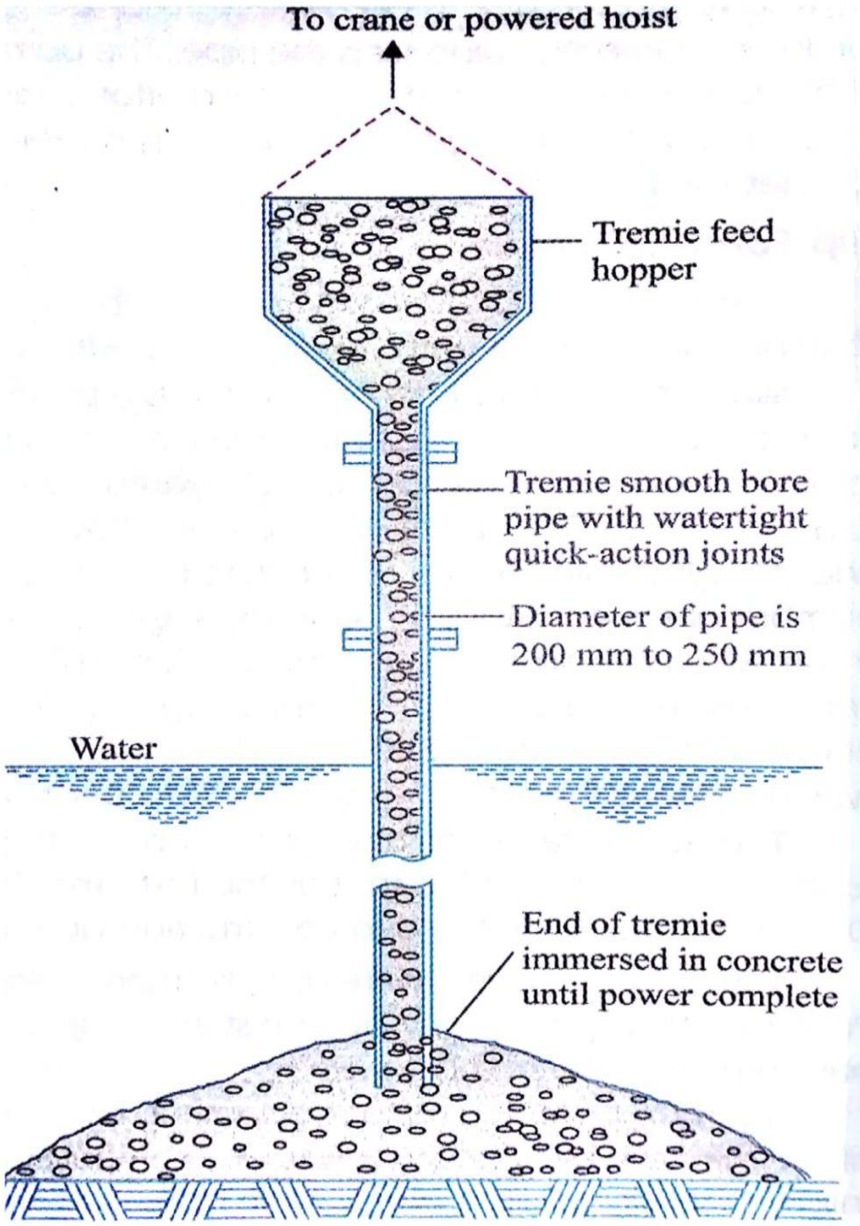
- Form work shall be designed and constructed so as to remain sufficiently rigid during placing and compaction of concrete.
- The joints are plugged to prevent the loss of slurry from concrete.
- Reinforcement should be cleaned and free from oils. When reinforcement is placed in congestion, concrete must be placed very carefully. While casting columns, dropping of concrete from greater height causes segregation. In order to avoid this, concrete is placed with tremie, drop chute or by any other means within the reinforcement and ties.
- When the formwork is narrow, a small opening is made on the sides of the formwork and concrete is placed.

Stripping Time:

- Formwork should not be removed until the concrete has developed strength of at least twice the stress to which concrete may be subjected at the time of removal of formwork.

Placing concrete under water:

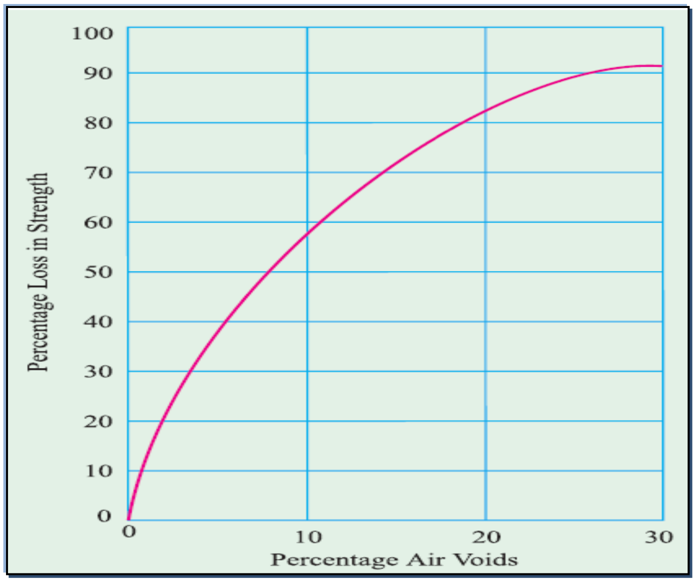
- In such cases, use of bottom dump bucket or tremie pipe is made use of.
- In the bottom dump bucket concrete is taken through the water in a water-tight box or bucket and on reaching the final place of deposition the bottom is made to open by some mechanism and the whole concrete is dumped slowly.
- A tremie pipe is a pipe having a diameter of about 20 cm capable of easy coupling for increase or decrease of length.
- A funnel is fitted to the top end to facilitate pouring of concrete.
- The bottom end is closed with a plug or thick polyethylene sheet or such other material and taken below the water and made to rest at the point where the concrete is going to be placed.
- Since the end is blocked, no water will enter from the bottom of the pipe.
- The concrete having a very high slump of about 15 to 20 cm is poured into the funnel. When the whole length of pipe is filled up with the concrete, the tremie pipe is lifted up and a slight jerk is given by a winch and pulley arrangement.
- When the pipe is raised and given a jerk, due to the weight of concrete, the bottom plug falls and the concrete gets discharged.
- Particular care must be taken at this stage to see that the end of the tremie pipe remains inside the concrete, so that no water enters into the pipe from the bottom.
- In this way, concrete work is progressed without stopping till the concrete level comes above the water level.



Under Water Concreting by Tremie Method.

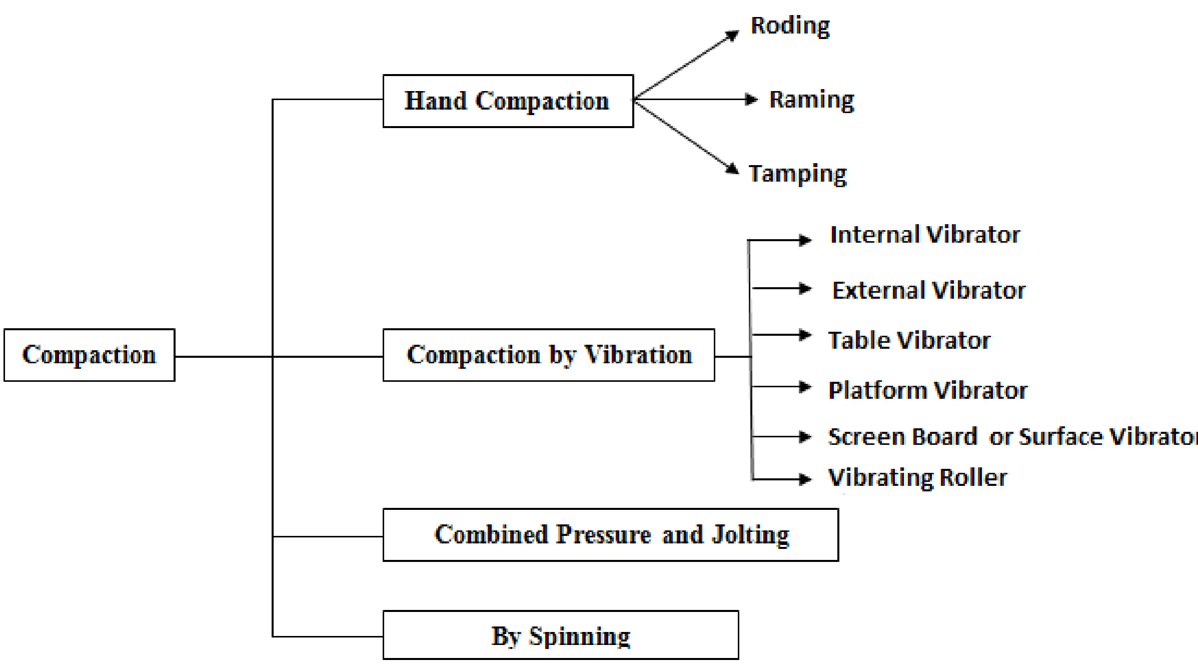
2.5.5 Compaction of concrete

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. If the air is not completely removed fully from the concrete, it loses its strength considerably. 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, 100% compaction is important not only from the point of strength but also durability.



From the above graph, it can be seen that a 5% voids reduce the strength about 30% and 10% of voids reduces about 50%.

Types of Compaction



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.

- **Roding:**
  Roding 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. Roding is done continuously over the complete area to effectively pack the concrete and drive away entrapped air. Sometimes, instead of iron rod, bamboos are also used for Roding purpose.
- **Ramming:**
  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.
- **Tamping:**
  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. 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.

- **Internal vibrator (Needle vibrator):**

The internal vibrator is most commonly used. This is also called, “Needle Vibrator”, “Immersion 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. The frequency of vibration varies up to 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.

- **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.

- **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.

- **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 (Screed 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.

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

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 spined at a very high speed gets well compacted because of centrifugal force.

2.5.6 Curing of Concrete:

It is the process of keeping the set concrete damp for some days in order to enable concrete to gain more strength. Strength of the concrete increases with age provided it is damped. During the process of curing, concrete absorbs water necessary for its completion of hydration process in order to gain its required strength.

Purpose of curing: In the field though enough water is used for mixing the concrete, some part of water gets evaporated and the water available for hydration process becomes insufficient. If the hydration has to be progressed, then extra water is added which replenishes the loss of water due to evaporation. Hydration process must continue to attain the desirable properties of concrete.

Curing Methods:

Curing methods may be divided broadly into four categories:

- Water curing
- Membrane curing
- Application of heat
- Self-Curing
- Accelerated Curing
- Miscellaneous

Water curing:

This is 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.

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 a 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, 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:

It is adopted in the following conditions

- When there is scarcity of water for curing
- When the building is located in remote areas
- When the curing of concrete cannot be properly supervised
- When the workman does not understand the importance of curing

Curing has to be done to promote hydration of concrete by not allowing the water present the concrete to get evaporated. This can be done by providing a membrane or sealant on the surface of concrete. This idea of sealing is to obtain a continuous over the top surface of concrete by means of impervious film to prevent the escape of moisture content due to evaporation and at the same time it is placed in between the ground and concrete to avoid the absorption of moisture from the concrete. For this purpose bituminous compounds like polyethylene or polyester, water proofing paper and rubber compounds are used.

Application of heat

The development of strength is a function of not only time 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 essential. Hence subjecting the concrete to higher temperature and maintaining the required moisture can be achieved by stream curing.

Advantages of faster attainment of strength

- Concrete member can be handled very quickly
- Less space will be sufficient during casting
- A small curing tank will be sufficient
- The prestressing bed can be released early for further casting

The exposure of concrete to higher temperature is done by following ways:

- Steam curing at ordinary pressure
- Steam curing at higher pressure
- Curing by infrared radiation
- Electrical curing

Steam curing at ordinary pressure

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

Steam curing at high pressure

This is similar to the above method but the only difference is that high pressure and temperature is applied on the concrete. This process is also called as **Autoclaving.**

Following are the advantages of this method

- High pressure steam cured concrete develops in one day, or less the strength as much as the 28days strength of normally cured concrete.
- High pressure steam cured concrete exhibits higher resistance to sulphate attack, freezing and thawing action. It also shows less efflorescence.
- High pressure steam cured concrete exhibits lesser shrinkage and less moisture movement
- Improvement in durability is more for the concrete made with higher water-cement ratio than for concrete made with low water-cement ratio.

Curing by infrared radiation

This method is practiced in very cold climate region. This system is adopted for curing of hallow concrete blocks. The normal operative temperature is around 90ºC.

Electric curing

This method is applied to very cold climate regions. Concrete can be cured electrically by passing alternative current through the concrete between the electrodes either burreid in concrete or applied to the surface of concrete. Care must be taken to prevent the moisture to evaporates which makes the concrete completely dry.

Accelerated Curing

- By adopting this method, concrete achieves high early strength.
- Adopted for prefabricated concrete elements.
- Formwork can be removed within 24hrs.
- It reduces the time interval between successive casting
- Cost saving benefits.

- Commonly used methods are steam curing, warm water curing, boiling water curing and autoclave method.

Self curing or internal curing

The ACI-308 Code states that "internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing Water." Conventionally, curing concrete means creating conditions such that water is not lost from the surface i.e., curing is taken to happen 'from the outside to inside'. In contrast, 'internal curing' is allowing for curing 'from the inside to outside' through the internal reservoirs (in the form of saturated lightweight fine aggregates, superabsorbent polymers, or saturated wood fibers) Created. 'Internal curing' is often also referred as 'Self–curing'.

Need for Self–curing

When the mineral admixtures react completely in a blended cement system, their demand for curing water (external or internal) can be much greater than that in a conventional ordinary Portland cement concrete. When this water is not readily available, due to de-percolation of the capillary porosity, for example, significant autogenous deformation and (early-age) cracking may result.

Potential Materials for IC

- Lightweight Aggregate (natural and synthetic, expanded shale),
- LWS Sand (Water absorption =17 %)
- LWA 19mm Coarse (Water absorption = 20%)
- Super-absorbent Polymers (SAP) (60-300 mm size)
- SRA (Shrinkage Reducing Admixture) (propylene glycol type i.e. polyethylene-glycol)
- Wood powder

Miscellaneous Methods:

Calcium chloride is used either as a surface coating or an admixture. It has been used satisfactory as 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.

2.5.7 Finishing

Finishing operation is the last operation in making concrete. Finishing in real sense does not apply to all concrete operations. For a beam concreting, finishing may not be applicable, whereas for the concrete road pavement, airfield pavement or for the flooring of a domestic building, careful finishing is of great importance. Particularly, many types of prefabricated concrete panels used as floor slab or wall unit are made in such a way as to give very attractive architectural affect.

Surface finishes may be grouped as under:

Formwork Finishes

Concrete obeys the shape of formwork. By judiciously assembling the formwork either in plane surface or in undulated fashion or having, a pleasing surface finish can be given to concrete. A pre-fabricated wall unit cast between steel formwork having very smooth surface using right proportioning of materials can give such a nice surface which can never be obtained by the best masons.

Surface treatment

This is one of the widely used methods for surface finishing. The concrete pavement slab is required to be plane but rough to exhibit skid resistance, so is the air-field pavements and road slabs. Concrete having been brought to the plane level surface, is raked lightly or broomed or textured or scratched to make the surface rough.

Applied finish

The term applied finish is used to denote the application of rendering to the exteriors of concrete structures. The concrete surface is cleaned and roughened and kept wet for sufficiently long time. Over this a mortar of proportion of about 1:3 is applied. This mortar rendering can be given by any required pleasant finish, such as cement stippling either fine or coarse, keying, renderings etc.

Special Surface Finishes

- Pattern and Textures
- Exposed Aggregate Concrete
- Colored Finishes
- Rough-form finishes
- Smooth off-the-form finish
- Sand-floated finish

- **Good and Bad Practices**

✓ Concrete is a complex construction material consisting of different ingredients, which have different functions.

✓ The properties of concrete depend on the particular mixture of constituents.

✓ The basic constituents used to make concrete are cement, lime, water, aggregates, and admixtures.

✓ Your concreting work can be successful if it involves a good planning and right practices.

✓ Most of the repair and maintenance problems may occur in the building due to bad practices in concrete construction.

- **Do's**

✓ Do hire an experienced Concrete contractor for successful concreting operation.

✓ Also, see that the main/general contractor hire good skilled sub/labour contractor for concreting.

✓ See that concreting is done under skilled supervision. Never leave it to labour on site.

✓ Always wear suitable PPE (Personal Protective Equipment) before casting concrete.

✓ Start placement of concrete with adequate manpower, proper equipment and tools.

✓ Always choose right cement for the particular job.

✓ If you have confusion, ask the technical person.

✓ Always pour the concrete when the weather conditions are favourable.

✓ Suitable mix design should be used for particular specifications (i.e. M25, M30 etc.).

✓ Choose right concrete mix as per specifications.

✓ First mix the dry concrete uniformly i.e. cement, coarse aggregates, fine aggregates (either manually or in transit mixture) as per predetermined quantity (i.e. batching of concrete materials).

✓ A good concrete contractor will always mix the dry concrete first.

✓ Add water as per predetermined quantity only.

✓ Always measure the water with measuring container before adding in concrete.

- ✓ Mix the wet concrete thoroughly for around 2 minutes to get the consistent concrete.
- ✓ Do slump test before placing the concrete.
- ✓ Concrete must be placed within 15 to 20 minutes of pouring water. If delayed add fresh cement or concern the consultant.
- ✓ Do the proper compaction to the concrete with a vibrator or wooden tamp to remove air from the concrete.
- ✓ If compaction is not well, it will create voids/honeycomb in concrete resulting in leakages from the concrete structure, thereby causing corrosion and also reducing the strength. This also affects the life of the structure.
- ✓ Pour the concrete throughout in an even thickness.
- ✓ Always keep on checking the stability of props/ supports of formwork below.
- ✓ See that the covers insert doesn't get displaced.
- ✓ Do proper finishing at joints during concrete construction.
- ✓ Give attention towards the bleeding in concrete. Water should not evaporate rapidly.
- ✓ Calculate the number of cement bags concreted per hour. If more than 25 to 30 bags are used per hour, then mixing time allowed is less and it should not be permitted (For 1 bag mixture machine).
- ✓ See that no one walks on the concrete surface till the concrete gets hardened.
- ✓ Do proper curing when the concrete has hardened initially.
- ✓ Start curing after 6 to 10 hours.

- **Don'ts**

- ✓ Don't use damaged formwork. It affects the concrete resulting in the honeycomb.
- ✓ Don't use unwashed aggregates in concrete; it may result in a weak concrete and substantial cost of maintenance.
- ✓ Don't start concreting before casting of a concrete cube. The Strength of the concrete should be as per predetermined mix design.
- ✓ Don't go for volumetric batching. Never allow the use of gamellas.
- ✓ Don't use high concrete slump, excessively high air content, or excessive fines.

- ✓ Don't run concrete mixer more than two minutes resulting in segregation of concrete constituents.
- ✓ Don't add more water for ease of placement during the making of concrete.
- ✓ Don't use semi-dry concrete in pouring. There will be chances of honeycomb inside the concrete.
- ✓ Don't drop concrete form greater height as this will cause segregation.
- ✓ Don't allow heaping of concrete at one place during pouring.
- ✓ Don't vibrate the concrete after the initial setting has taken place. (i.e. after 30 minutes)
- ✓ Don't finish the concrete while bleeding is present on the surface of the concrete.
- ✓ Unless must and unavoidable, never do concreting at night.
- ✓ The lighting arrangements are never adequate at all work places and hence some errors can always happen somewhere.
- ✓ Don't remove formwork until the concrete has gained sufficient strength.
- ✓ When finishing of the concrete is carried out, never throw or sprinkle the water on to the concrete surface.
- ✓ Don't try to finish the dried concrete.
- ✓ Don't do concreting if it is raining heavily
- ✓ Never allow child labour on site. You will land in jail for violence of law.

- **Effect of Heat of hydration in case of mass concreting works**

- ✓ Mass concrete is defined by ACI "Any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking.
- ✓ Mass concrete is defined by some agencies as "any concrete element having a least dimension greater than 3 ft (0.9 m).

Examples:

- ➢ Dam
- ➢ Raft Foundation
- ➢ Pile Cap.

- Thick Wall.
- Thick column.
- Deep Slap.

Why is temperature control necessary?

- Concrete is thermally very poor conductor.
- Heat transfer (heat of hydration) results in unequal thermal expansion
- Tensile stress at the free surface due to expansion of core exceeds the tensile strength
- Then surface cracking will develop
- Temp. difference between interior & outer surface of more than 20^0 C cause cracks.

Cracks may cause

- Cracks generated due to thermal gradients may cause
- loss of structural integrity
- loss in monolithic action
- excessive shrinkage
- loss in durability
- aesthetically objectionable

Methods of temperature control

- Methods of controlling mass concrete temperatures range from relatively simple to complex, and from inexpensive to costly.
- Depending on a particular situation, it may be advantageous to use one or more methods over another.
- Low-heat material - GGBFS, Fly ash, Silica fume, large size aggregates
- Pre cooling of concrete – Use chilled mix water, Liquid nitrogen
- Post-cooling of concrete
- Surface insulation – Insulating formwork

2.6 Assignment Questions

1. Define concrete.
2. What are the properties of good concrete and how are they classified?
3. Define fresh concrete.
4. Define workability and what are the factors affecting workability of concrete?
5. Name the tests conducted for measurement of workability of fresh concrete.
6. Write a brief note on segregation.
7. Write a brief note on Bleeding.
8. Define compaction of concrete.
9. Explain different methods adopted for compacting concrete.
10. Explain the significance of setting time of concrete.

2.7 Outcome

- Gives knowledge about the fresh properties of concrete
- Gives information about different types of tests performed on concrete
- Gives idea about the manufacturing process of concrete

2.8 Future study

By understanding the fresh properties of concrete one able to design a concrete mix.

Module – 3 Hardened concrete

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3.1 Introduction

Compressive strength of concrete is one of the most important and useful property of concrete. For a given cement, an acceptable aggregate size, the strength of the concrete developed by a workable concrete which is properly placed and influenced by the following factors.

The factors on which the strength of concrete depends are

- Ratio of cement to the water
- Ratio of cement to the aggregate
- Grading, surface texture, shape, strength and stiffness of the aggregate
- Maximum size of aggregate

3.2 Objective

- To study the mechanical properties of concrete
- To study different Non-destructive tests of hardened concrete

3.3 Water Cement ratio

Strength of concrete primarily depends on strength of cement paste. The strength of cement paste depends on dilution of paste or in other words, the strength of the paste increases with cement content and decreases with air and water content.

Abram's water-cement ratio law states that the **"strength of concrete only depends on water-cement ratio provided the mix is workable".**

$$S = \frac{A}{B^x}$$

Where x = water- cement ratio & A, B are constants and the values of these constants are given below

A = 1400 lbs/sq.in
B = 7000 Pounds/sq.in

3.4 Gel space ratio

It is defined as the ratio of volume of the hydrated cement paste to the sum of volume of hydrated cement paste and of capillary pores.

Calculation of gel space ratio

Case 1:- For Complete hydration

Let C be the weight of cement in grams.
V_c be the specific volume of cement = 0.319ml/gm
W_o be the weight of mixing water in vol
Assuming that 1gm of cement on hydration will produce 2.06ml of gels
Therefore Volume of gel = C * V_c * 2.06
= C * 0.319 * 2.06
= **0.657 C**
The space available = (C * V_c) + W_o
= **(C * 0.319) + W_o**

$$\text{Gel space ratio (x)} = \frac{\text{Volume of gel}}{\text{Space available}}$$

$$x = \frac{\mathbf{0.657\ C}}{(\mathbf{C} * \mathbf{0.319}) + \mathbf{Wo}}$$

Case 2:- For partial Hydration

Let α be the fraction of cement that has hydrated.
Volume of gel becomes = C * V_c * 2.06 * α
= C * 0.319 * 2.06 * α
= **0.657 C α**
Therefore total space available = (C * V_c * α) + W_o
= **(C * 0.319 * α) +W_o**

$$\text{Gel space ratio (x)} = \frac{\mathbf{0.657\ C\ \alpha}}{(\mathbf{C} * \mathbf{0.319} * \boldsymbol{\alpha}) + \mathbf{Wo}}$$

The factors that effects the strength of concrete depends on any w/c ratio are

- Degree of hydration of cement
- Chemical and physical properties of cement
- The temperature at which the hydration takes place
- Air content in case of air entrained concrete
- Change in effective w/c ratio
- Formation of fissures and cracks due to bleeding and segregation

3.5 Maturity of concrete

Strength development of concrete depends on both time and temperature. It can be said that, strength of concrete is a function of summation of product of time and temperature. This summation is called as maturity of concrete.

Maturity of concrete = $\sum(\text{time} * \text{temperature})$

The temperature is lying between -12°C to -10°C. it was experimentally found that the hydration of the concrete continues to take place till it reaches to -11°C. Hence -11°C is taken as the datum line for calculating the maturity value.

A sample of concrete cured at 18°C for 28 days it is treated as fully matured concrete, then its maturity value is given by

Maturity = $\sum(\text{time} * \text{temperature})$

= [(28 * 24) * {18-(-11)}]

= 19488°Ch

Maturity concept is useful for determining the strength of concrete at any other maturity as a percentage of strength of concrete of known maturity.

Maturity equation:-

The strength at any maturity has percentage of strength at maturity of 19800°Ch is given by

19800°Ch = A +B $\log_{10}\left(\frac{\text{Maturity}}{1000}\right)$

Where A and B are Plowman's co-efficient

Strength of concrete after 28days @18°C maturity of 19800°Ch	**A**	**B**
< 17.5	10	68
17.5-35	21	61
35-52.5	32	54
52.5-70	42	46.5

3.6 Testing of hardened concrete

3.6.1 Compressive strength

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.

Objective:

To determine the Compressive strength of concrete cubes.

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 mm thick machined plate and of dimensions greater than 17.5 mm, 100 ton compression testing machine.

Procedure

- A cube specimen of size 15cm x 15cm x 15cm is taken and the inner surface is oiled.
- The concrete of specified designed mix is prepared and is placed inside the mould in 3 layers and each layer is tamped with 25 numbers of blows and after tamping the last layer, top layer is leveled by skimming off the extra material.
- The concrete along with mould is allowed to dry for a day and then concrete cube is placed in the curing tank and cubes are tested in compressive testing machine of 100 ton capacity after specified days of curing. Usually concrete cubes are test for 3, 7, 14 and 28 days of curing.
- Before testing the concrete cubes, the surface should be in saturated dry condition. The load at which concrete specimen fails is noted as Maximum compressive force and then compressive strength of concrete is calculated.

ID	Length (mm)	Breadth (mm)	Height (mm)	Area (mm^2)	Compressive strength P (MPa)

Compressive strength of concrete = $\frac{\text{Maximum load}}{\text{Cross section area of specimen}} = \frac{P}{A}$ N/mm^2

3.6.2 Split tensile strength test

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack.

The test is carried out by placing concrete cylindrical specimen horizontally between the loading surfaces of a compressive testing machine & the load is applied until the failure of the concrete specimen takes place along vertical dia.

When the load is applied, the vertical dia of the cylindrical specimen will be subjected to a

- Vertical compressive stress $= \frac{2P}{\pi DL}\left[\frac{D2}{r(D-r)} - 1\right]$ &
- Horizontal stress = $\frac{2P}{\pi DL}$

Apparatus:-

Concrete cylinder 15 cm diameter & 30cm long. The tamping bar is a steel bar of 16 mm diameter, 60 cm long and bullet pointed at the lower end.

Procedure:-

- A cylindrical specimen of size 15cm dia and 30c length is taken and the inner surface is oiled.
- The concrete of specified designed mix is prepared and is placed inside the mould in 4 layers and each layer is tamped with 25 numbers of blows and after tamping the last layer, top layer is leveled by skimming off the extra material.

- The concrete along with mould is allowed to dry for a day and then concrete cylinder is placed in the curing tank and concrete cylinders are tested in compressive testing machine of 100 ton capacity after specified days of curing. Usually concrete cylinders are test for 3, 7, 14 and 28 days of curing.
- Before testing the concrete cylinders, the surface should be in saturated dry condition. The load at which concrete specimen fails is noted as Maximum compressive force and then split tensile strength of concrete is calculated.

D = dia of cylinder in mm

L = Length of the cylinder in mm

P = Maximum load in KN

Split tensile strength of concrete = $\frac{2P}{\pi DL}$ N/mm^2

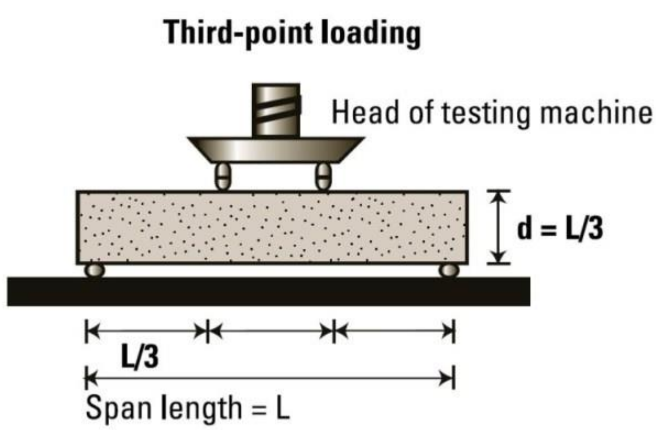
3.6.3 Flexural Strength test

Objective:-

To determine the Flexural Strength of Concrete, which comes into play when a road slab with inadequate sub-grade support is subjected to wheel loads and / or there are volume changes due to temperature / shrinking.

EQUIPMENT & APPARATUS

1. **Beam mould** of size 15 x 15x 70 cm (when size of aggregate is less than 38 mm) or of size 10 x 10 x 50 cm (when size of aggregate is less than 19 mm)
2. **Tamping bar** (40 cm long, weighing 2 kg and tamping section having size of 25 mm x 25 mm)
3. **Flexural test machine**



Procedure

1. Prepare the test specimen by filling the concrete into the mould in 3 layers of approximately equal thickness. Tamp each layer 35 times using the tamping bar as specified above. Tamping should be distributed uniformly over the entire cross-section of the beam mould and throughout the depth of each layer.
2. Clean the bearing surfaces of the supporting and loading rollers, and remove any loose sand or other material from the surfaces of the specimen where they are to make contact with the rollers.
3. Circular rollers manufactured out of steel having cross section with diameter 38 mm will be used for providing support and loading points to the specimens. The length of the rollers shall be at least 10 mm more than the width of the test specimen. A total of four rollers shall be used, three out of which shall be capable of rotating along their own axes. The distance between the outer rollers (i.e. span) shall be **3d** and the distance between the inner rollers shall be **d**. The inner rollers shall be equally spaced between the outer rollers, such that the entire system is systematic.
4. The specimen stored in water shall be tested immediately on removal from water; whilst they are still wet. The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the rollers. For moulded specimens, the mould filling direction shall be normal to the direction of loading.

5. The load shall be applied at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens.

CALCULATION

The Flexural Strength or modulus of rupture (f_b) is given by

$f_b = pl/bd^2$ (when **a** > 20.0cm for 15.0cm specimen or > 13.0cm for 10cm specimen) or

$f_b = 3pa/bd^2$ (when **a** < 20.0cm but > 17.0 for 15.0cm specimen or < 13.3 cm but > 11.0cm for 10.0cm specimen.)

Where, a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, b = width of specimen (cm), d = failure point depth (cm), l = supported length (cm), p = max. Load (kg)

3.7 Creep

- Creep can be defined as the "time dependent" part of strain resulting due to stress.
- We know that, stress-strain relationship of concrete is not a straight line relationship but a curved one.
- The degree of curvature of stress-strain relationship mainly depends on
  - Intensity of stress
  - time for which load is acting
- Therefore relation between stress and strain is a function of time.
- **The gradual increase in strain without increase in stress with respect to time is called creep of concrete.**
- **Creep can also be defined as the increase in strain under sustained stress.**
- All materials undergo creep under some loading conditions to a greater or smaller extent.
- Concrete creeps significantly at all stresses for a long period.
- Creep is approximately linear function of stress upto 30 to 40% of its strength.

Mechanism of creep

- Cement paste consists of unhydrated cement grains surrounded by the products of hydration in the form of gels (C-S-H gels).
- These gels are interpenetrated by gel pores which can absorb water and interspersed by capillary cavities.
- The process of hydration generates more no. of hydrated compounds and there will be reduction of unhydrated cement and capillary cavities.
- In young concrete, gel pores are filled with water and capillary cavities may or may not be filled with water.
- The movement of water held in gel and paste structure takes place under the influence of internal and external water vapour pressure.
- The movement of water may also takes place due to sustained load on concrete.
- The conglomerate of very fine colloidal particles with enclosed with water-filled voids behave under the action of external forces.

- Mechanism of creep mainly based on the theory that, the colloidal particles slides against each other to re-adjust their position displacing the water held in gel pores and capillary cavities.
- This flow of gel and consequent displacement of water is responsible for complex deformation behavior and is known as creep of concrete.

Factors affecting creep

1. **Influence of aggregate**

- Aggregates undergo very little creep.
- It is really the paste which is responsible for creep
- The paste which is creeping under load is restrained by aggregates which do not creep.
- Stronger the aggregate, more is the restraining effect hence lesser is the magnitude of creep.
- Higher the modulus of elasticity of aggregates, lesser is the creep.
- Light weight aggregate shows higher creep than normal weight because having low modulus of elasticity.

2. **Influence of mix proportion**

- The amount of paste and its quality is one of the most important factor influencing creep.
- A poorer paste structure undergoes higher creep.
- Therefore creep increases with increase in water / cement ratio.
- Creep is inversely proportion to strength of concrete.

3. **Influence of age**

- Quality of gel improves with time. Such gel will have less creep.
- The young gel under the load creeps more because of its elastic property
- The moisture content of concrete being different at diff ages also influences creep

Effects of creep

- In RCC beams creep increases the deflection with time and may be critical consideration for the design of RCC beam.
- In RCC columns when loaded eccentrically, the creep increases the deflection and it will lead to buckling
- In mass concrete structure such as dams on account of differential temperature condition at the interior and surface, creep is harmful and by itself may be cause of cracking at the interior portion of dams.

3.8 Shrinkage

It is the most objectionable defect in concrete due to the presence of cracks particularly in floors and pavements. The term shrinkage is used to describe the various aspects of volume change in concrete due to the loss of moisture at different stages due to different reasons.

Classification of shrinkage

- Plastic shrinkage
- Drying shrinkage
- Autogeneous shrinkage
- Carbonation shrinkage

Plastic shrinkage

- The shrinkage of this type occurs when concrete is placed in formwork. When concrete is still in plastic stage, the loss of water by evaporation from surface of concrete or by absorption of water by aggregates are the reasons of plastic shrinkage. The loss of water results in reduction of volume. Thereby aggregates or reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.
- In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage.

- Sometimes even if the concrete is not subjected to severe drying, but poorly made with a high water/cement ratio. Large quantity of water bleeds and accumulates at the surface. When this water at the surface dries out, the surface concrete collapse causing cracks.
- Plastic concrete is sometimes subjected to unintended vibrations or yielding of formwork support which again causes plastic shrinkage cracks as the concrete at this stage has not developed enough strength.

Causes of plastic shrinkage

- High water/cement ratio
- Bad proportion concrete
- Rapid drying
- Greater bleeding
- Unintended vibration

Preventionary measures

- Plastic shrinkage can be reduced mainly by preventing rapid loss of water from surface. This can be done by covering the surface with polythene sheets immediately after placing concrete,
- By monomolecular coatings by fog spray that keeps the surface moist or
- By working at night
- Revibrate the concrete in controlled manner
- Use of small quantity of aluminium powder during mixing of concrete
- Use of expensive cement or shrinkage reducing cement.

Drying shrinkage

- Just like hydration of cement which is everlasting process, shrinkage is also the same.
- The cement shrinks more than the mortar and mortar shrinks more than concrete.
- Concrete made with smaller size aggregate shrinks more than the concrete made with big size aggregates.
- The magnitude of drying shrinkage is a function of fineness of gel. Finer the gel more will be shrinkage

- High pressure steam cured concrete with low specific surface of gel shrinks much less than that of normally cured concrete.

Factors affecting shrinkage

1. **Relative humidity:** the relative humidity of atmosphere at which the concrete specimen is kept. If concrete is placed at 100% relative humidity for a length of time, there will be no shrinkage instead there will be a slight swelling.
2. **Water/cement ratio:** when w/c ratio adopted is less, a drier mix is formed and when this mix is exposed to hot atmospheric condition shrinkage will be developed. If concrete mix is prepared with high w/c ratio, because of higher water content, swelling takes place.
3. **Aggregate:** the grading of aggregate by itself may not directly make any significant influence. But since it affects the quantum of paste and water/cement, it definitely influences the drying shrinkage indirectly. The aggregate particles restrain the shrinkage of the paste. It can be observed that harder aggregate with higher modulus of elasticity like quartz shrinks much less than softer aggregate such as sandstone.
4. **Moisture movement**

Concrete shrinks when allowed to dry in air at lower humidity and swells when kept at 100% relative humidity or when placed in water.

Just as drying shrinkage is a everlasting / continuous process. Concrete swells continuously when placed in water. If a concrete sample subjected to drying condition, at some stage it is subjected to wetting condition, it starts swelling. Initial drying shrinkage is not at all recovered even after prolong storage in water which shows that the phenomenon of shrinkage is irreversible.

The property of swelling when placed in water and shrinks when placed in dry condition is referred as moisture movement in concrete.

The moisture movement in concrete induces alternatively compressive stress and tensile stress which may cause fatigue in concrete which reduces durability of concrete to reversal the stresses.

Autogeneous shrinkage:

In a conservative system, where no moisture movement to or from the paste is permitted when temperature is constant some shrinkage may occur. The shrinkage of such conservative system is referred as Autogeneous shrinkage.

Carbonation shrinkage:

Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide gets converted into calcium carbonate and also some other cement compounds are decomposed. Carbonation penetrates beyond the exposed surface of concrete only very slowly. Carbonation shrinkage is caused by dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product formed is less in volume than the replaced product shrinkage takes place. Carbonation reduces the alkalinity of concrete which gives a protective coating to the reinforcement against rusting. If depth of carbonation reaches up to steel reinforcement it is liable to corrosion.

Durability

3.9 Introduction

For long time it was assumed that concrete is one of the most durable material and requires less maintenance but it is not true because, it will be subjected to severe or abrasive environment.

Reasons for loss of durability

- Concrete structures which are constructed in largely polluted urban areas,
- Effected by subsoil water in case of coastal regions &
- No other material is available in nature which is more suitable or durable.

"Durability is ability of concrete to resist chemical attack, weathering, abrasion actions or any other process of deterioration".

Durable concrete is one which should maintain its original form and serviceability even though when it is subjected or exposed to severe environment.

3.10 Significance of durability / strength durability relationship

While designing a concrete mix or designing a concrete structure, the exposure condition at which concrete is supposed to withstand should be judge first. Since environment pollution is increasing day by day and it is reported that, in industrially developed countries about 40% of the total resources will be spent on repairs and maintenance. This indicates that, we are not giving much importance for durability aspects.

Construction industries require faster development of strength in concrete so that they can complete the projects within estimated time. This demand leads to the use of **high early strength cement and lower water-cement ratios.** This intern results higher drying shrinkage, thermal shrinkage, lower modulus of elasticity and lower creep coefficients.

High early strength cements are prone to cracking than moderate or low strength cements. If durability is the main criteria, then a proper balance between high and low cement content should be considered.

Structural cracks in high early cement can be controlled by introducing reinforcement but it does not help the concrete durability. By providing more reinforcement, it will only results in conversion of bigger cracks to smaller cracks and these smaller cracks are sufficient to allow oxygen, carbon dioxide and moisture into the concrete which affects the long-term durability.

It is very difficult to conclude that, formation of micro cracks in high early strength cement is responsible for the loss of long-term durability. These cracks promote permeability and concrete structure undergoes deterioration, degradation, disruption and eventual failure.

Durability of concrete depends on external and internal factors

External factors

- **Physical factors**: Loss of durability may be due to frost actions, variation in thermal properties of cement paste and aggregates.
- **Chemical factors**: Due to chemical action b/w seepage of water through cracks or voids of concrete and cement paste.
- **Mechanical factors**: Due to abrasion, erosion or impact
- **Environmental factors**: Due to extreme temperature, attack of natural or industrial liquids & gases.

Internal factors

- **Alkali Aggregate Reaction**
- **Volume change due to difference in thermal properties of aggregate and cement paste**
- **Permeability of concrete**

3.11 Factors affecting durability of concrete

- **Cement content**

Mix should be designed to ensure cohesion and prevent segregation and bleeding. If cement is reduced, then at fixed w/c ratio the workability of concrete will be reduced leading to inadequate compaction. However, if water is added to improve workability, w/c ratio increases and resulting permeable material.

- **Compaction**

The concrete as a whole contain voids can be caused by inadequate compaction. Usually it is being governed by the compaction equipments used, types of formworks, and density of the steelwork.

- **Curing**

It is very important to permit proper strength development and moisture retention and to ensure hydration process occur completely.

- **Cover to the reinforcement:-** Thickness of concrete cover must follow the limits set in codes.
- **Permeability:-** It is considered the most important factor for durability. It can be noticed that higher permeability is usually caused by higher porosity. Therefore, a proper curing, sufficient cement, proper compaction and suitable concrete cover could provide a low permeability concrete.

3.12 Chemical actions

The durability of concrete is affected by

- Physical
- Chemical and
- Mechanical causes.

Durability of concrete is most affected by chemical causes which results in volume change, cracking and leads to deterioration of concrete structures.

3.12.1 Sulphate attack

- They occur in soils or ground water.
- Soils contain some sulphates in the form of $CaSO_4$, Na_2SO_4, KSO_4 and $MgSO_4$.
- $CaSO_4$ is less soluble in water. Therefore ground water may contain other salts except $CaSO_4$.
- Solid sulphates do not attack the concrete severely, but when chemicals are in solution state, they find the entry into porous concrete and react with the hydrated cement products.

- Among all the sulphates, $MgSO_4$ causes maximum damage to concrete.
- **A characteristic whitish appearance is the clear indication of sulphate attack**.
- It denotes an increase in the volume of cement paste due to chemical action between the products of hydration of cement and solutions containing sulphates.
- **In the hardened concrete, Calcium aluminate hydrate (C-A-H) reacts with Sulphate salts from outside results in the formation of Calcium - sulpho- aluminate known as Ettrignite**
- The rate of sulphate attack increases with increase in the strength of solution.
- $MgSO_4$ can cause serious damage to concrete with higher water-cement ratio in a short time.
- However if concrete is made with low w/c ratio it can withstand the action of magnesium sulphate for 2 to 3 yrs.
- **The concentration of sulphates is expressed as the number of parts by weight of SO_3 per million parts (ppm).**

$Na_2SO_4 10\ H_2O + Ca(OH)_2 \rightarrow CaSO_4 2H_2O + 2NaOH + 8\ H_2O$
(Gypsum)

Reaction of sodium sulphate solution with calcium aluminate hydrate.

$2\ [3CaO.\ Al_2O_3.\ 12H_2O] + 3[Na_2SO_3 10\ H_2O] \longrightarrow$

$3CaO.Al_2O_3.3CaSO_4 + 8H_2O + 2Al\ (OH)_2 + 6NaOH + 17H_2O$

Methods of controlling sulphate attack

a) Use of Sulphate resisting cement :- by using low calcium aluminates (C_3A) cements.

b) Quality of concrete :- well designed, dense and impermeable concrete

c) Use of air entrainment cement :- upto an extent of 6% it has beneficiary affect on sulphate resisting cement.

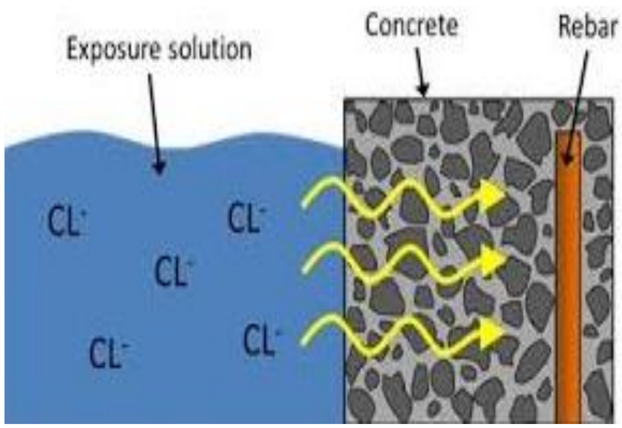
d) Use of Puzzolana :- replaces a part of cement by Puzzolanic materials which reduces sulphate attack, improves impermeability.

e) High pressure steam curing :- a part of cement is replaced by Puzzolanic materials which reacts with $Ca(OH)_2$ improves the resistance of concrete to sulphate attack.

f) High alumina cement :- resists sulphate attack by the formation of a thin film which checks the diffusion of sulphate ions into the interior of concrete

3.12.2 Chloride attack

- It primarily causes corrosion of reinforcement.
- About of 40% of failure of structures is due to the corrosion of reinforcement.



Due to high alkality of concrete, a protective oxide film is present on the surface of steel reinforcement

This protective layer can be lost due to **Carbonation**

- ➢ Reaction of CO_2 with the hydrated cement paste or
- ➢ Presence of chloride in the water.

Sulphates attack the concrete but chlorides attacks the steel reinforcement.

- Chlorides enter the concrete from cement, water, aggregates and sometimes from admixtures.
- Chlorides enter the concrete by diffusion from environment.
- According to Bureau of IS, permissible chloride content in cement should be 0.1%.
- The amount of chloride required for initializing corrosion is partly depend on the p^H value of pore water in concrete.
- As the p^H value is less than 11.5, corrosion may occur even without the presence of chloride and greater than 11.5 requires chloride.
- Total amount of chloride present in concrete partly as insoluble chloride-aluminates and partly as soluble chlorides.
- Soluble chlorides are responsible for corrosion of steel reinforcement.

Corrosion control

- ❑ Good quality of concrete → good construction practices
- ❑ Proper mix design → use of right quality , quantity of cement for different exposure condition
- ❑ Less water-cement ratio → associated with lower permeability
- ❑ Use of supplementary cementicious materials → such as flyash, GGBS, silica fumes etc. required to be used along with lower w/c ratio in order to obtain dense concrete.
- ❖ Silica fumes → improves the quality of concrete which reduces corrosion of steel reinforcement
- ❖ GGBS → reduces the water permeability upto 100% and reduces the diffusion of chlorides ions into the concrete.

3.12.3 Freezing and thawing

- Concrete exposed to atmosphere are subjected to cycles of freezing and thawing and suffer from the damaging action of frost.
- Frost action is one of the most important weathering action on the durability of concrete.

Durability of concrete is affected by

- ➢ Alternative wetting and drying
- ➢ Alternative heating and cooling
- ➢ Penetration and deposition of salts and other aggressive chemicals

- Leaching of $Ca(OH)_2$
- Action of certain acids
- Alkali Aggregate Reaction
- Mechanical wear and tear
- Abrasion and cavitation

- Concrete should not be subjected to freezing temperature.
- Fresh concrete contains a considerable quantity of free water. If the free water is subjected to freezing temperature discrete ice lenses are formed.
- Water expands about 9% in volume during freezing.
- Formation of ice lenses causes permanent damage to concrete and it will not recover the structural integrity.
- Hardened concrete should not be subjected to extremely low temperature. It is estimated that free water present in the hardened concrete exerts a pressure of 14MPa.
- The resistance to freezing and thawing is measured by the durability factor

$$\text{Durability factor} = \frac{\text{No of cycles at the end of test} * \text{\% of original modulus}}{300}$$

- If D.F. < 40 → concrete is not satisfactory to resist freezing and thawing
- If D.F. in between 40 to 60 → range for doubtful performance
- If D.F. > 60 → concrete is probably satisfactory
- If D.F. = 100 → concrete is satisfactory

3.12.4 Carbonation

- CO_2 gas present in the atmosphere may vary from rural, urban and highly industrialized area.
- In case of rural areas the atmospheric CO_2 is found out to be 0.03% by volume, 0.1% or more in case of urban areas, and 0.3% in case of highly industrialized areas.

- In the presence of moisture CO_2 forms **carbonic acid,** which reacts with $Ca(OH)_2$, forming calcium carbonate.
- The reaction between CO_2 with hydrated cement is called **Carbonation**
- Carbonation causes contraction in the concrete resulting in a small shrinkage known as **Carbonation Shrinkage**
- In actual practices , CO_2 present in the atmosphere is smaller or greater concentration diffuses or penetrates into the concrete and reacts with $Ca(OH)_2$ forming carbonates and reduces the P^H value of hole water from (13-9) . When all the $Ca(OH)_2$ is carbonated the P^H reduces to about 8.3
- In such low P^H values , the protective layer gets dissolved or destroyed and the steel exposed to corrosion.

Factors affecting the corrosion

- Permeability of concrete
- Moisture content
- Grade of concrete
- Relative humidity of ambient medium
- Depth of cover

Concrete with higher w/c ratio and inadequate curing will have more carbonation effect ie, depth of carbonation is more.

Measurement of Carbonation

- A freshly broken concrete surface is treated with a solution of phenolphthalein in dilute alcohol.
- If there is no reaction of $Ca(OH)_2$ with CO_2 the color of concrete will turn **pink**
- If the color of the concrete changes → no carbonation

If the color of the concrete does not changes → carbonation

- The color pink will show even upto a P^H value of 9.5

Rate of Carbonation depends on

- **The level of pore water ie, relative humidity :-**

- If pore is filled with water the diffusion of CO_2 is very slow. But whatever CO_2 is diffused into the concrete , is readily formed into dilute carbonic acid reduces the alkalinity .
- If the pores are dry, at low relative humidity the CO_2 remains in the gaseous form and does not react with hydrated cement. The moisture penetration from external source is necessary to carbonate the concrete.
- The highest rate of carbonation occurs at a relative humidity of between 50 and 70%.

- Grade of concrete
- Permeability of concrete
- Whether the concrete is protected or not
- Depth of cover
- Time of exposure

The rate of carbonation depth will be slower in case of stronger concrete because it is much denser with lower w/c ratio.

3.13 Non Destructive Testing

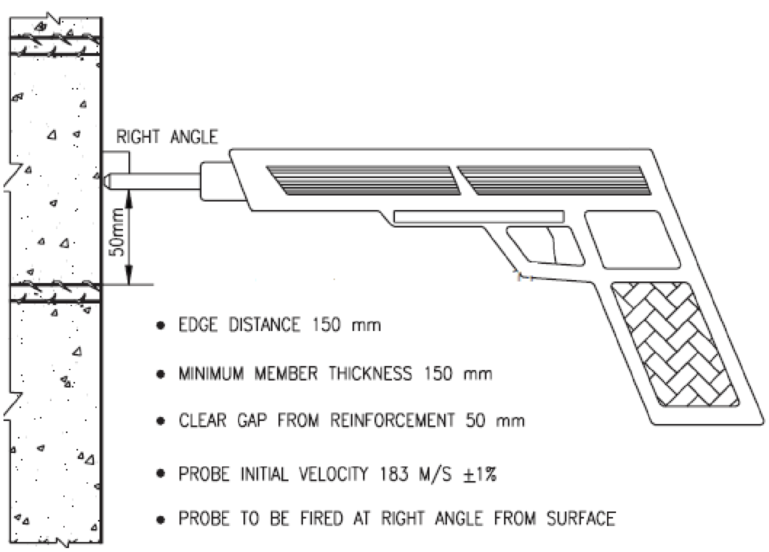
3.13.1 Penetration Resistance Test

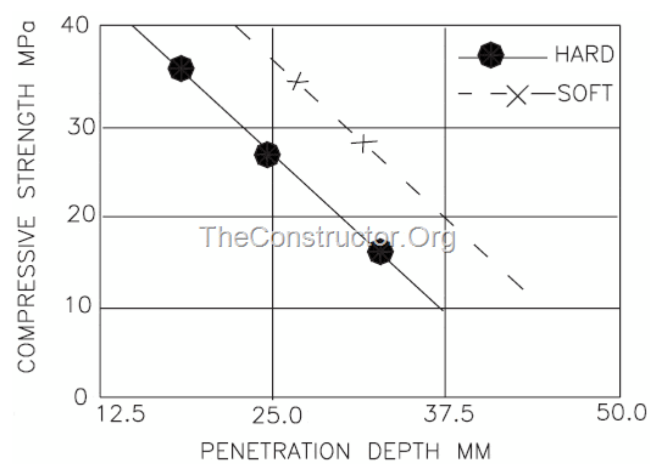
Penetration resistance tests on concrete offers a means of determining relative strengths of concrete in the same structure or relative strength of different structures. Because of nature of equipments, it cannot and should not be expected to yield absolute values of strength. ASTM C-803 gives this standard test method titled “Penetration Resistance of Hardened Concrete”.

Windsor Probe is penetration resistance measurement equipment, which consists of a gun powder actuated driver, hardened alloy of probe, loaded cartridges, a depth gauge and other accessories. In this technique a gunpowder actuated driver is used to fire a hardened alloy probe into the concrete. During testing, it is the exposed length of probe which is measured by a calibration depth gauge. But it is preferable to express the coefficient of variation in terms of depth of penetration as the fundamental relation is between concrete strength and penetration depth.

The probe shown in fig.1 has a diameter of 6.3mm, length of 73mm and conical point at the tip. The rear of the probe is threaded and screwed into a probe-driving head, which is 12.6mm in diameter and fits snugly along with a rubber washer into the bore of the driver. As the probe penetrates into the concrete, test results are actually not affected by local surface conditions such as texture and moisture content. However damage in the form of cracking may be cause to slender members. A minimum edge distance and member thickness of 150mm is required. It is important to leave 50mm distance from the reinforcement present in the member since the presence of reinforcing bars within the zone of influence of penetrating probe affects the penetration depth.

A pin penetration test device (PNR Tester) which requires less energy than the Windsor Probe system is given in fig.2





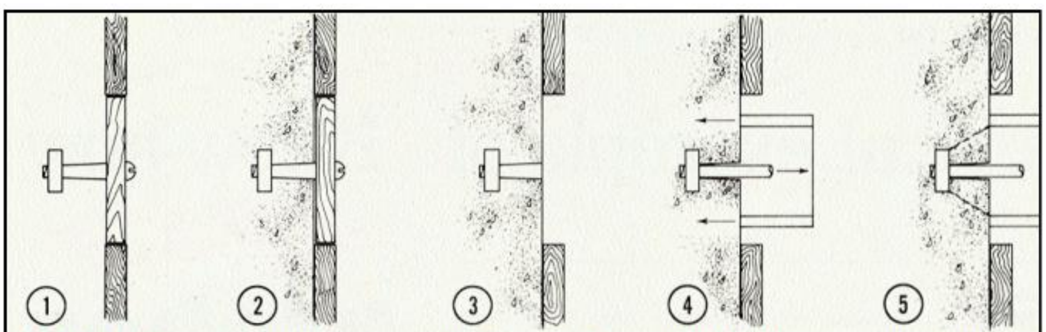
Being a low energy device, sensitivity is reduced at higher strengths. Hence it is not recommended for testing concrete having strength above 28 N/sq.mm. in this a spring-loaded device, having energy of about 1.3% of that of Windsor probe, us used to drive 3.56mm diameter, a pointed hardened steel pin into the concrete. The penetration of pin creates a small indentation (or hole) on the surface of concrete. The pin is removed from the hole, the hole is cleaned with an air jet and the hole depth is measured with a suitable depth gauge. Each time a new pin is required as the pin gets blunted after use.

The strength properties of both mortar and stone aggregate influence the penetration depth of the probe in a concrete, which is contrastingly different than cube crushing strength, wherein the mortar strength predominantly governs the strength. Thus the type of stone aggregate has a strong effect on the relation of concrete strength versus depth of penetration

3.13.2 Pull out test

This test method covers determination of the pull out strength of hardened concrete by measuring the force required to pull a specially shaped steel rod or disc out of the fresh or hardened concrete into which it has been cast. Because of its shape, the steel rod is pulled out with a cone of concrete whose surface slope is approximately 45 degrees to the vertical. A hollow tension ram bearing on the concrete surface exerts the necessary pull on the steel rod, with power supplied by a hand-operated hydraulic pump. The force required for pullout is then related to the compressive strength of the concrete.

The principal parts — ram and pump—are commercially available and peripheral parts such as the rods, washers and sleeves can be manufactured locally, or all of the components may be purchased as one proprietary system.

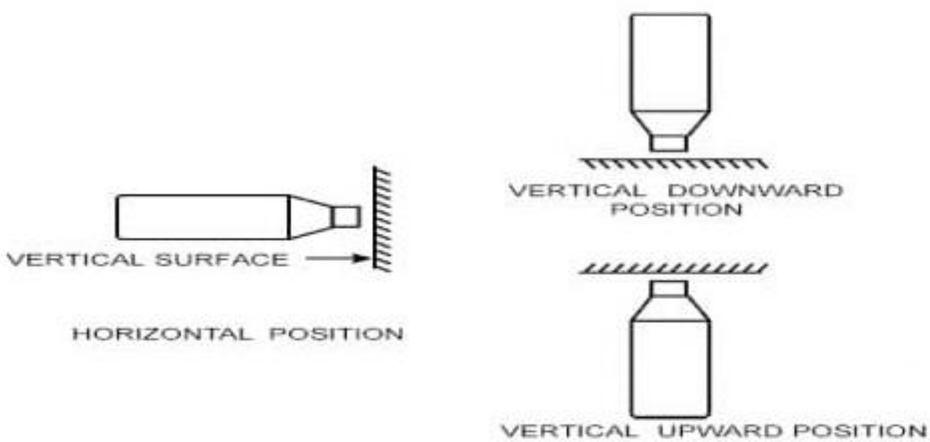


1. The test bolt including disc and stem is mounted on the inside of the form prior to placing concrete.
2. Concrete is placed.
3. The form (or part of the form) and the stem of the test bolt are removed.
4. A pull bolt is screwed into the disc, and the instrument is mounted on the surface of the concrete.
5. By applying a force with the instrument a small piece of the concrete is dislodged.

3.13.3 Rebound hammer test

Procedure for rebound hammer test on concrete structure starts with calibration of the rebound hammer. For this, the rebound hammer is tested against the test anvil made of steel having Brinell hardness number of about 5000.

After the rebound hammer is tested for accuracy on the test anvil, the rebound hammer is held at right angles to the surface of the concrete structure for taking the readings. The test thus can be conducted horizontally on vertical surface and vertically upwards or downwards on horizontal surfaces as shown in figure below:



If the rebound hammer is held at intermediate angle, the rebound number will be different for the same concrete.

It consists of a spring controlled mass that slides on a plunger within a tubular housing.

Principle

When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale.

This measured value is designated as Rebound Number (rebound index). A concrete with low strength and low stiffness will absorb more energy to yield in a lower rebound value

The following points should be observed during testing.

(a) The concrete surface should be smooth, clean and dry.

(b) Ant loose particles should be rubbed off from the concrete surface with a grinding wheel or stone, before hammer testing.

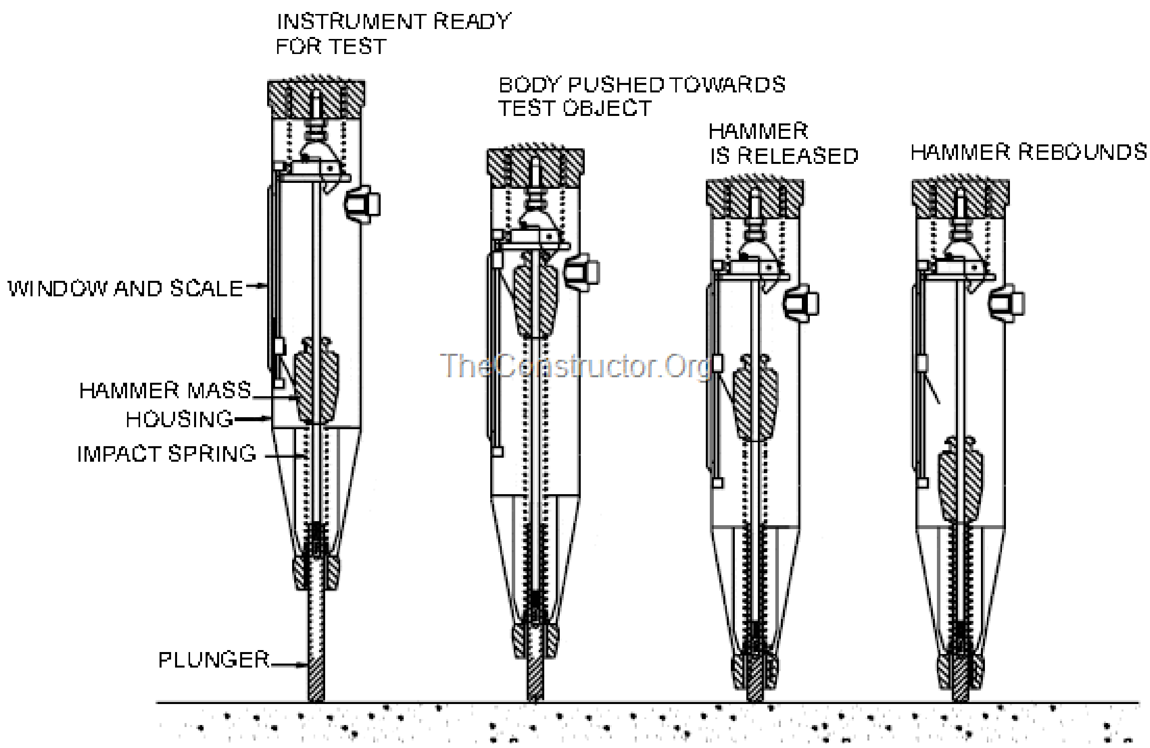
(c) Rebound hammer test should not be conducted on rough surfaces as a result of incomplete compaction, loss of grout, spalled or tooled concrete surface.

(d) The point of impact of rebound hammer on concrete surface should be at least 20mm away from edge or shape discontinuity.

Six readings of rebound number is taken at each point of testing and an average of value of the readings is taken as rebound index for the corresponding point of observation on concrete surface.

Interpretation of Rebound Hammer Test Results:

After obtaining the correlation between compressive strength and rebound number, the strength of structure can be assessed. In general, the rebound number increases as the strength increases and is also affected by a number of parameters i.e. type of cement, type of aggregate, surface condition and moisture content of the concrete, curing and age of concrete, carbonation of concrete surface etc. Moreover the rebound index is indicative of compressive strength of concrete up to a limited depth from the surface. The internal cracks, flaws etc. or heterogeneity across the cross section will not be indicated by rebound numbers.



3.13.4 Core extraction tests

Core extraction and testing of concrete covers obtaining, preparing, and testing cores drilled from concrete for compressive strength test of casted concrete structures.

Apparatus for Core Extraction of concrete:

- Core drill, for obtaining cylindrical core specimens with diamond impregnated bits attached to the core barrel.
- Saw for trimming the ends of the core. The saw shall have a diamond or silicon carbide cutting edge and shall be capable of cutting specimens that confirm to the prescribed dimensions without excessive heating or shock

Samples for core testing:

- Samples of hardened concrete for use in the preparation of strength test specimens shall not be taken until the concrete is strong enough to permit sample removal without disturbing the bond between the mortar and the coarse aggregates.
- Also samples that have been damaged during removal shall not be used unless the damaged portions are removed and the resulting test specimen is having the required length.
- Samples containing embedded reinforcement cannot be used for the test

Core drilling:

- Core specimen shall be drilled perpendicular to the surface and not the formed joints or edges.
- Record and report the approximate angle between the longitudinal axis of the core drilled and horizontal plane of the concrete as placed.
- A specimen drilled perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit when possible

3.13.5 Ultrasonic pulse velocity test

Ultrasonic test on concrete is a recognized non-destructive test to assess the homogeneity and integrity of concrete.

1. Qualitative assessment of strength of concrete, its gradation in different locations of structural members and plotting the same.

2. Any discontinuity in cross section like cracks, cover concrete delamination etc.

3. Depth of surface cracks

This test essentially consists of measuring travel time, T of ultrasonic pulse of 50 to 54 kHz, produced by an electro-acoustical transducer, held in contact with one surface of the concrete member under test and receiving the same by a similar transducer in contact with the surface at the other end. With the path length L, (i.e. the distance between the two probes) and time of travel T, the pulse velocity (V=L/T) is calculated (fig.2). Higher the elastic modulus, density and integrity of the concrete, higher is the pulse velocity. The ultrasonic pulse velocity depends on the density and elastic properties of the material being tested.

The pulse velocity in concrete may be influenced by:

a) Path length

b) Lateral dimension of the specimen tested

c) Presence of reinforcement steel

d) Moisture content of the concrete

In general, the velocity is increased with increased moisture content, the influence being more marked for lower quality concrete.

PULSE VELOCITY	CONCRETE QUALITY
>4.0 km/s	Very good to excellent
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and los of integrity exist.

Procedure for Ultrasonic Pulse Velocity

i) **Preparing for use**: Before switching on the ‘V’ meter, the transducers should be connected to the sockets marked “TRAN” and “REC”. The ‘V’ meter may be operated with either:

a) The internal battery,

b) An external battery

c) The A.C line.

ii) **Set reference**: A reference bar is provided to check the instrument zero. The pulse time for the bar is engraved on it. Apply a smear of grease to the transducer faces before placing it on the opposite ends of the bar. Adjust the ‘SET REF’ control until the reference bar transit time is obtained on the instrument read-out.

iii) **Range selection**: For maximum accuracy, it is recommended that the 0.1 microsecond range be selected for path length upto 400mm.

iv) **Pulse velocity**: Having determined the most suitable test points on the material to be tested, make careful measurement of the path length ‘L’. Apply couplant to the surfaces of the transducers and press it hard onto the surface of the material. Do not move the transducers while a reading is being taken, as this can generate noise signals and errors in measurements. Continue holding the transducers onto the surface of the material until a consistent reading appears on the display, which is the time in microsecond for the ultrasonic pulse to travel the distance ‘L’. The mean value of the display readings should be taken when the units digit hunts between two values.

Pulse velocity = (Path length/Travel time)

v) Separation of transducer leads: It is advisable to prevent the two transducer leads from coming into close contact with each other when the transit time measurements are being taken. If this is not done, the receiver lead might pick-up unwanted signals from the transmitter lead and this would result in an incorrect display of the transit time.

Questions

1. What is hardened concrete?
2. Define Abram's water cement ratio law.
3. What is gel space ratio?
4. What is maturity of concrete?
5. Explain the test for finding out the mechanical strength of concrete.
6. Define creep and what are the factors affecting creep of concrete?
7. Define shrinkage and what are the factors affecting shrinkage of concrete?
8. Define durability? Explain the significance of durability of concrete in its life time.
9. Define durability? Explain the significance of durability of concrete in its life time.
10. What are the factors affecting durability of concrete.
11. Write a note on effect of water-cement ratio on durability of concrete
12. On which factors durability of concrete depends?
13. Write a note on permeability of concrete
14. Explain the procedure for determining permeability of concrete.
15. What are the measures to be taken for controlling permeability of concrete
16. Why permeability of mortar and concrete is more than corresponding cement paste?
17. Write a brief note on following effects on concrete

    i) Sulphate attack, ii) Chloride attack, iii) Freezing and Thawing effect and

    iv) Carbonation.
18. Write a note on Non destructive testing of concrete.

Outcome

- Gives knowledge about the mechanical properties of concrete
- Gives information about different Non-destructive tests of hardened concrete

Future study

By studying the tests one can adopt to know the strength of concrete

Module – 4 Concrete Mix Design

Contents:-

4.1 Introduction
4.2 Objective
4.3 Concept of concrete mix design
4.4 Requirements of concrete mix design
4.5 Types of mixes
4.6 Factors affecting the choice of mix proportion
4.7 Variables in proportion of concrete mix
4.8 Factors to be considered for mix design
4.9 Mix proportion designation
4.10 Flow chart of mix proportioning
4.11 Procedure for mix proportion
4.12 Problems
4.13 Assignment questions
4.14 Outcome
4.15 Future study

4.1 Introduction

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of required strength, durability and workability as economical as possible is termed as Concrete Mix Design.

4.2 Objective

- To know the importance and concept of mix design.
- To know different variables of mix design.

4.3 Concept of concrete mix design

It will be worthwhile to recall all this stage the relationships between aggregate and paste, which are the two essential ingredients of concrete. Workability of the mass is provided by the lubricating effect of the paste and is influenced by the amount and dilution of the paste. The more dilute the paste, the greater the spacing between cement particles, and thus weaker will be the ultimate paste structure.

The strength of concrete varies as the inverse function of the water-cement ratio. Since the quantity of water required also depends upon the amount of paste, it is important that as little paste as possible should be used and hence the importance of the grading.

4.4 Requirements of concrete mix design

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

a) The minimum compressive strength required from structural consideration.

b) The adequate workability necessary for full compaction with compacting equipment available.

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

4.5 Types of Mixes

1. Nominal Mixes:

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

Nominal mix concrete is used for concrete of M20 or lower. For e.g., M5, M7.5, M10, M15 and M20.

2. Standard Mixes:

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under or over-rich mix. 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, M40. In this designation the letter M refers to the mix and number represents the specified 28day 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), (1:1.5:2) and (1:1:2) respectively.

3. Design 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 proportion 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 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 $30N/mm^2$. No control testing is necessary reliance being placed on the masses of the ingredients.

4.6 Factors affecting the choice of mix proportions.

1. 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.

2. 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 implies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

3. 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.

4. 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 increases in maximum size of aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate.

IS 456:2000 and IS 10262:2009 recommend that nominal size of aggregate should be as large as possible.

5. Grading and type of aggregate

The grading of aggregate influences the mix proportion 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.

6. Quality control

The degree of control can be estimated statistically by the variations in the 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, cuing 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.

4.7 Variables in proportion of concrete mix

The four variables to be considered in connection with specified concrete mix are,

1) **Water-cement ratio** → water/cement ratio expresses as dilution of the paste.

2) **Cement content or Cement-aggregate ratio** → Cement content varies directly with the amount of paste.

3) Gradation of aggregates → grading of aggregate is controlled by varying the amount of given fine and coarse aggregate.

4) Consistency → consistency is established by practical requirements of placing. In brief, the effort in proportioning is to use a minimum amount of paste that will lubricate the mass while fresh and after hardening will bind the aggregate particles together and fill the space between them.

Any excess of paste involves greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering action. This is achieved by minimizing the voids by good gradation.

Various method of proportion

a) Arbitrary proportion

b) Fineness modulus method

c) Maximum density method

d) Surface area method

e) Indian Road Congress, IRC 44 method

f) High strength concrete mix design

g) Mix design based on flexural strength

h) Road note no.4 (grading curve method)

i) ACI Committee 211 method

j) DOE method

k) Mix design for pump able concrete

l) Indian Standard Recommended method IS 10262-82

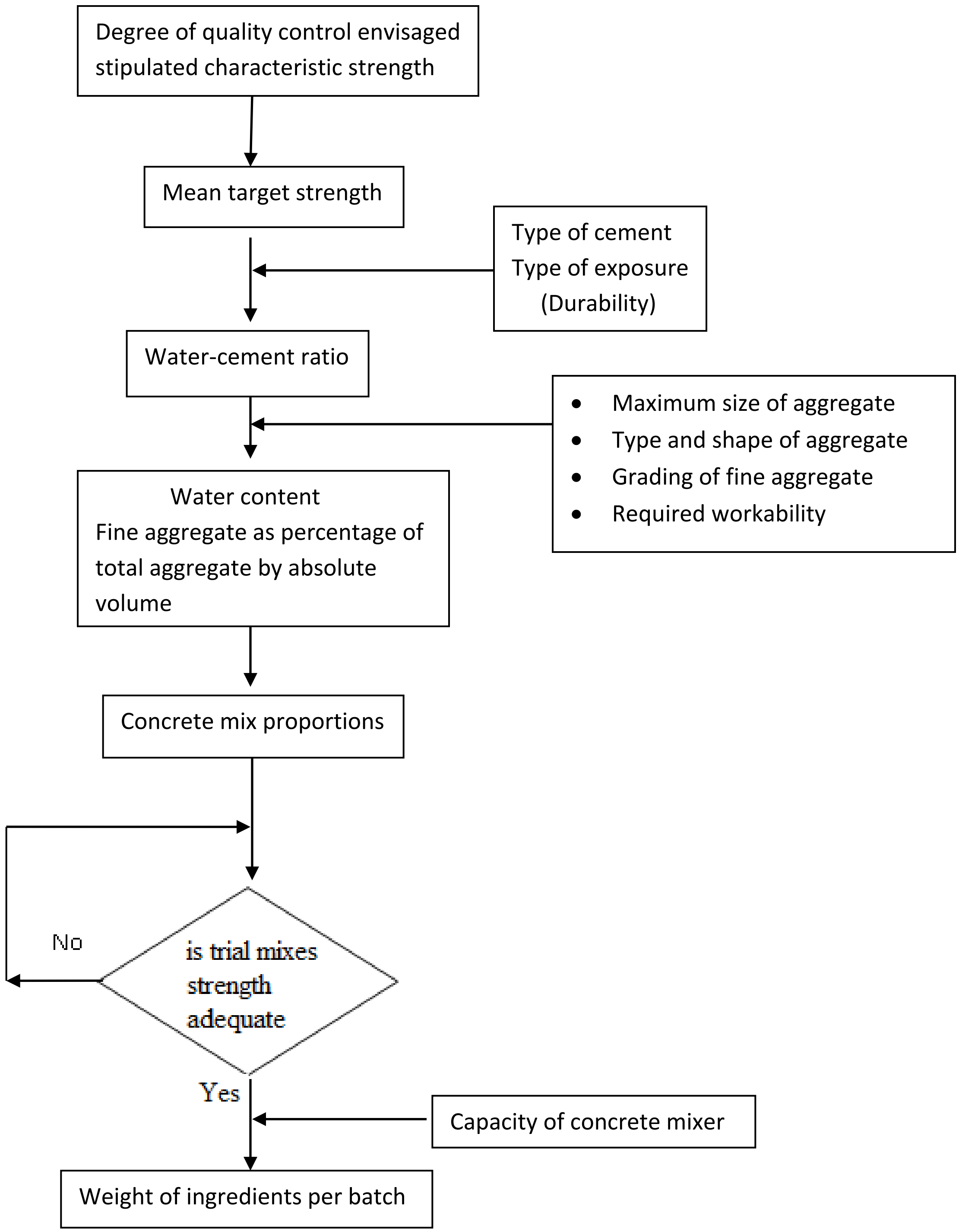
4.8 Factors to be considered for mix design

- 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 456:200.
- The cement content for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transporting, placing and compaction.

4.9 Mix Proportion designation

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

4.10 Flow chart of mix proportioning



4.11 Problems

Design stipulations for proportioning

Grade designation:	M20
Type of cement:	OPC 43 grade confirming to IS 8112
Maximum nominal size of aggregates:	20 mm
Minimum cement content:	Refer table 5 of IS456:2000
Maximum water cement ratio:	0.55
Workability:	75 mm (slump)
Exposure condition:	Mild
Degree of supervision:	Good
Type of aggregate:	Crushed angular aggregate
Maximum cement content:	450 kg/m3
Chemical admixture:	Not recommended

TEST DATA FOR MATERIALS

Specific gravity of cement:	3.15
Specific gravity: Coarse aggregate:	2.68
Fine aggregate:	2.65
Water absorption: Coarse aggregate:	0.6 percent
Fine aggregate:	1.0 percent
Free (surface) moisture: Coarse aggregate:	Nil (absorbed moisture full)
Fine aggregate:	Nil
Sieve analysis: Coarse aggregate:	Conforming to Table 2 of IS: 383
Fine aggregate:	Conforming to Zone I of IS: 383

STEP 1: TARGET STRENGTH FOR MIX PROPORTIONING

$f'_{ck} = f_{ck} + 1.65\ s$ or $f'_{ck} = f_{ck} + X$ (whichever is higher)

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

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

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

s= Standard deviation

From Table 2 standard deviation, s = 4 N/mm^2

Therefore target strength = 20 + 1.65 x 4

= **26.60 N/mm^2**

$f'_{ck} = f_{ck} + X$

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

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

X = factor based on grade of concrete

From Table 1 standard deviation, X = 5.5 N/mm^2

Therefore target strength = 20 + 5.5

= **25.5 N/mm^2**

Therefore target strength = 26.60N/mm^2

STEP 2: APPROXIMATE AIR CONTENT

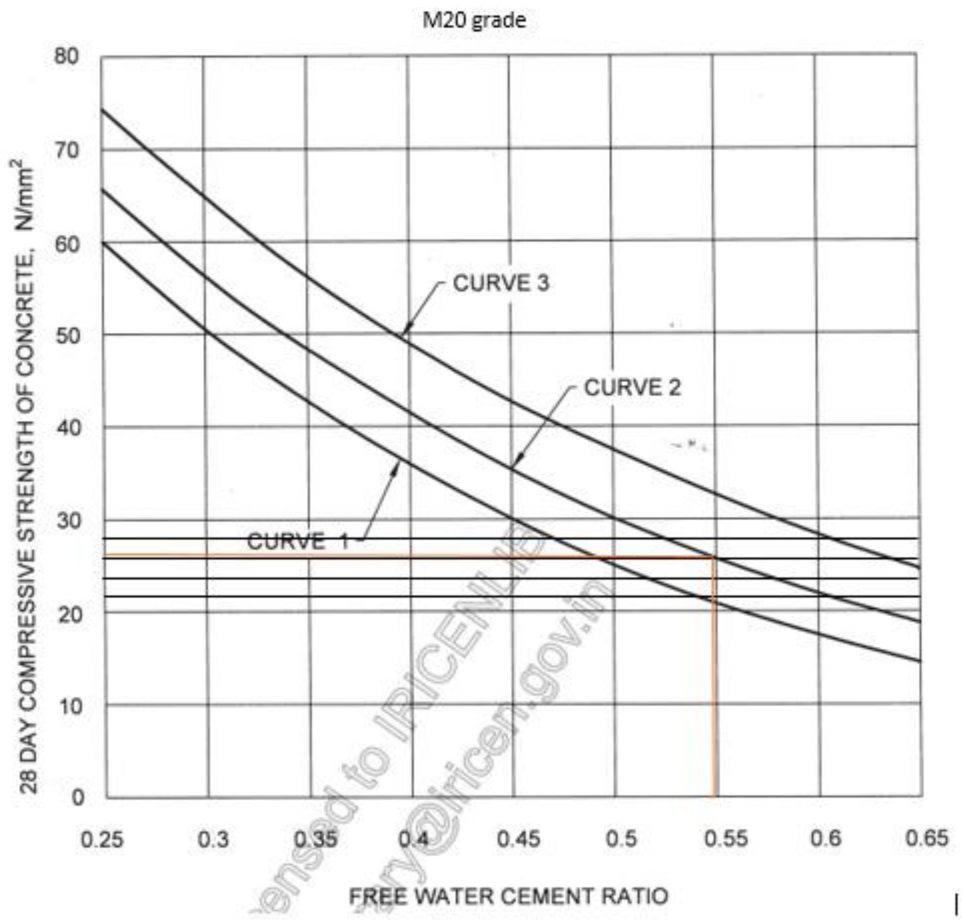
From Table 3, the approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is 1.0 percent for 20 mm nominal maximum size of aggregate.

Table 3 Approximate Air Content
(*Clause* 5.2)

Sl No.	Nominal Maximum Size of Aggregate mm	Entrapped Air, as Percentage of Volume of Concrete
(1)	(2)	(3)
i)	10	1.5
ii)	20	1.0
iii)	40	0.8

STEP 3: SELECTION OF WATER CEMENT RATIO

- From Fig. 1, the free water-cement ratio required for the target strength of 26.60 N/mm2 is 0.55 for OPC 43 grade curve.
- This is equal to maximum value of 0.55 prescribed for 'mild' exposure for reinforced concrete as per Table 5 of IS 456.
- Hence adopt w/c = 0.55



STEP 4: SELECTION OF WATER CONTENT

From Table-4,

- maximum water content = 186 liters (for 25mm – 50mm slump range and for20 mm aggregates)
- For every increase of 25mm slump, increase the water content by 3%
- Estimated water content for 75 mm slump

$= 186 + \frac{3}{100} * 186 = 191.6$ liters.

Table 4 Water Content per Cubic Metre of Concrete For Nominal Maximum Size of Aggregate

(*Clause* 5.3)

Sl No.	Nominal Maximum Size of Aggregate mm	Water Content[1)] kg
(1)	(2)	(3)
i)	10	208
ii)	20	186
iii)	40	165

STEP 5: CALCULATION OF CEMENT CONTENT

Water cement ratio = 0.55

$\frac{W}{C} = 0.55$

Cement content = $\frac{191.6}{0.55}$ = 348.36kg/m^3 < 450 kg/m^3 (Max cement content given)

From Table 5 of IS: 456, minimum cement content for mild exposure condition = 300 kg/m^3

Hence OK.

STEP 6: PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINEAGGREGATE CONTENT

From Table 5, the proportionate volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 = 0.60.

Table 5 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate for Water-Cement/Water-Cementitious Materials Ratio of 0.50

(*Clause* 5.5)

Sl No.	Nominal Maximum Size of Aggregate mm	Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
		Zone IV	Zone III	Zone II	Zone I
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	0.54	0.52	0.50	0.48
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.73	0.72	0.71	0.69

In the present case water-cement ratio is 0.55.

Compare the present w/c ration and std w/c ratio

Standard value is 0.5

The present value is greater by 0.05 than compared to std value 0.5

For every ↑ 0.05, ↓ the volume of coarse aggregate by 0.01 or

For every ↓ 0.05, ↑ the volume of coarse aggregate by 0.01

Therefore for the present case, 0.55 – 0.5 = + 0.05

Therefore vol of CA = 0.60 – 0.01 = 0.59

Then vol of FA = 1 – 0.59 = 0.41

STEP 6: MIX CALCULATIONS

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

a) Volume of concrete = 1 m^3

b) Volume of entrapped air in wet concrete = 0.01 m3

c) Volume of cement = $\frac{mass\ of\ cement}{specific\ gravity\ of\ cement} \text{ x } \frac{1}{1000}$

$= \frac{348.36}{3.15} \text{ x } \frac{1}{1000}$

= 0.110 m^3

d) Volume of water = $\frac{mass\ of\ water}{specific\ gravity\ of\ water} \text{ x } \frac{1}{1000}$

$= \frac{191.6}{1} \text{ x } \frac{1}{1000}$ = 0.196 m^3

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

= (1+0.01) – (0.110 + 0.196)

= 0.704 m^3

f) Mass of coarse aggregates = e x Volume of CA x specific gravity of CA

= 0.704 x 0.59 x 2.68 x 1000

= 1113.16 kg

g) Mass of fine aggregates = e x Volume of FA x specific gravity of FA

= 0.704 x 0.41 x 2.65 x 1000

= 764.89 kg

Step 7: MIX PROPORTIONS FOR TRIAL NUMBER 1

- Cement = 348.36 kg/m^3
- Water = 191.6 kg/m^3
- Fine aggregate = 764.89 kg/m^3
- Coarse aggregates = 1113.16 kg/m^3
- Water cement ratio = 0.55

STEP 8: ADJUSTMENT ON WATER, FINE AGGREGATE AND COARSE AGGREGATE

Fine Aggregate = $\frac{\textit{Mass of fine aggregate in SSD condition}}{1+\frac{\textit{water absorption}}{100}}$

$= \frac{764.89}{1+\frac{1}{100}}$

= 757.31kg/m^3

Coarse Aggregate = $\frac{\textit{Mass of coarse aggregate in SSD condition}}{1+\frac{\textit{water absorption}}{100}}$

$= \frac{1113.16}{1+\frac{0.6}{100}}$

= 1106.52kg/m^3

The extra water to be added for absorption by coarse and fine aggregate,

For fine aggregate = Mass of fine aggregate in SSD condition – mass of fine aggregate in dry condition

= 764.89 – 757.31 = 7.58kg

For coarse aggregate = Mass of coarse aggregate in SSD condition – mass of coarse aggregate in dry condition

= 1113.16 – 1106.52 = 6.64 kg

The estimated requirement for added water, therefore, becomes

= 191.16 + 7.58 + 6.64 = 205.38 kg/m3

STEP 9: FINAL MIX PROPORTION of dry sample

- Cement = 348.36 kg/m^3
- Water = 205.38 kg/m^3
- Fine aggregate = 757.31kg/m^3
- Coarse aggregates = 1106.52 kg/m^3
- Water cement ratio = 0.58

FINAL PROPORTION

CEMENT : FINE AGGREGATE : COARSE AGGREGATE

$$1 : \frac{757.31}{348.36} : \frac{1106.52}{348.36}$$

1 : 2.17 : 3.17

4.12 Assignment Questions

1. Define the term concrete mix design.
2. Explain the concept of concrete mix design.
3. What are the requirements of concrete mix design?
4. Explain different types of mixes adopted in design.
5. Explain the factors affecting choice of mix proportioning.
6. Explain different variables in concrete mix proportioning.
7. Explain mix proportion designation.
8. Write step by step procedure of IS method of mix design.
9. Write a flow chart for concrete mix proportion.
10. Explain the importance of design mix in design of RCC structural members.

4.13 Outcome

Gives knowledge about the variables involved in designing a concrete mix

4.14 Future Study

By studying this, one can design various mixes for various grades by altering the mix constituents

Module – 5 Special Concrete

Contents: -

5.1 Ready mix concrete
- 5.1.1 Introduction
- 5.1.2 Advantages
- 5.1.3 Disadvantages

Special concrete

5.2 Light weight concrete
- 5.2.1 Introduction
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- 5.2.4 Properties of light weight aggregate
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5.5 High Strength Concrete

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5.7 Questions

5.8 Outcome

5.9 Future Study

Ready mixed concrete

5.1.1 Introduction

A concrete whose constituents are weighed according to the proportion at a central batching plant, mixed either at the plant itself or in truck mixers and then transported to the construction site and delivered in a condition ready to use, is termed as **Ready Mixed Concrete.**

The concrete delivered at site or into purchaser vehicle in plastic condition. It requires no further treatments before being in position in which it as to set and harden is called **Ready Mixed Concrete.**

Objective

To know about RMC (Ready Mix Concrete)

Problems involved in site mixed concrete are

- It requires large space to stack materials.
- It requires large labour force.
- Work output is low.
- Quality is not uniform.
- No control on water –cement ratio.
- Variation of mixing time.
- Dust pollution and noise etc

These problems can be rectified by RMC because of the following reasons

- Production by weigh batch.
- Controlled mixing.
- Water cement can be controlled easily.
- Lower labour force and less maintenance cost.
- No need of ordering cement and aggregate.
- Reduces inventory expenses.
- Multi transporting of materials is eliminated.
- Assured uniform quality of concrete.

- Pollution free environment.

Scope for Ready Mix Concrete

- Major concerting projects like dams, roads, bridges, tunnels, canals etc.
- For concreting in congested areas where storage of materials is not possible.
- Sites where intensity of traffic makes problems.
- When supervisor and labour staff is less.
- To reduce the time required for construction etc.
- Huge industrial and residential projects.

5.1.2 Advantages of RMC (Merits)

- Production is by weigh batching: In this type of batching the properties can be controlled same for successive mixing.
- Controlled mixing: In plant we can control the mixing without leading it to segregation.
- Water/cement ratio can be controlled easily.
- Lower labour force and less supervisory cost.
- No need of ordering cement and aggregate: since concrete is directly available for the placing where it is necessary.
- Reduces inventory expenses.
- Multi transporting of material is eliminated
- Assured uniform quality of concrete.
- Pollution free environment.
- Time is very much saved than other modes of concreting.

5.1.3 Disadvantages of RMC (Demerits)

1. Need huge initial investment.

2. Not affordable for small projects (small quantity of concrete)

3. Needs effective transportation system from R.M.C to site.

4. Traffic jam or failure of vehicle creates problem if proper dose of admixture is not given.

5. Labors should be ready on site to cast the concrete in position to vibrate it and compact it.

6. Concrete's limited time span between mixing and going-off means that ready-mix should be placed within 90 minutes of batching at the plant

Light weight concrete

5.2.1 Introduction

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as durability and lessened the dead weight.

It is lighter than the conventional concrete with a dry density of 300 kg/m3 up to 1840 kg/m3 and 87 to 23% lighter. It was first introduced by the Romans in the second century where 'The Pantheon' has been constructed using pumice, the most common type of aggregate used in that particular year. From there on, the use of lightweight concrete has been widely spread across other countries such as USA, United Kingdom and Sweden.

The main specialties of lightweight concrete are its low density and thermal conductivity. Its advantages are that there is a reduction of dead load, faster building rates in construction and lower haulage and handling costs. The building of 'The Pantheon' of lightweight concrete material is still standing eminently in Rome until now for about 18 centuries. It shows that the lighter materials can be used in concrete construction and has an economical advantage.

Lightweight concrete performance after producing of artificial lightweight aggregates in early 20^{th} century moved to a new phase, so that the use of lightweight concrete in deck slabs of High Rise Buildings, bridge decks and other similar cases such as special application of lightweight concrete in oil extraction deck and oil-drilling basements.

Wide range of lightweight aggregates is used for producing concrete. Using appropriate materials and methods lead to achieve concrete unit weigh of 300 to 1850 kg/m^3 and its corresponding strength about 3 MPa and in some cases upon to 60 MPa.

Lightweight concrete may be made by using lightweight aggregates, or by using of foaming agents, such as aluminum powder, which generates gas while the concrete is still plastic. Natural lightweight aggregates include pumice, scoria, volcanic cinders, tuff, and diatomite. Lightweight aggregate can also be produced by heating clay, shale, slate, diatomaceous shale, perlite, obsidian, and vermiculite. Industrial cinders and blast-furnace slag that has been specially cooled can also be used.

Pumice and scoria are the most widely used of the natural lightweight aggregates. They are porous, froth-like volcanic glass which come in various colors and are found in the Western United States. Concrete made with pumice and scoria aggregate weighs from 90 to 100 pounds per cubic foot.

Objective
To know about lightweight concrete.

5.2.2 Classification of Light Weight Concrete

The RILEM classification of light weight concrete is as given below

1. Lightweight aggregate concrete
    a. Fully compacted concrete
    b. Partially compacted concrete
2. No fines concrete
3. Aerated concrete
    a. Aerated concrete by chemical processes [gas concrete]
    b. Aerated concrete by physical processes [foam concrete]
4. Micro cellular concrete

The other modes of classification is based on either **type of binder** [cement, lime, Gypsum etc] or **type of aggregates** [natural, processed natural by products, Unprocessed].

Classification based on density and strength

1] Light weight concrete of low strength and exceptionally good thermal Insulating properties having densities in the range of 250 to 800 kg/m^3.

2] Light weight concrete of medium strength and adequate thermal insulating Properties having density range of 800 to 1400 kg/m^3.

3] Light weight concrete of structural strength and limited thermal insulating properties having density in the range of 1400 to 2100 kg/m^3.

5.2.3 Types of lightweight concrete

Lightweight concrete can be prepared either by injecting air in its composition or it can be achieved by omitting the finer sizes of the aggregate or even replacing them by a hollow, cellular or porous aggregate.

Particularly, lightweight concrete can be categorized into **three groups**
i) No-fines concrete
ii) Lightweight aggregate concrete
iii) Aerated/Foamed concrete

i) <u>No-fines concrete</u>

It is a kind of concrete in which the fine aggregate fraction has been omitted. This concrete is made up of only coarse aggregate, cement and water. Very often only single sized coarse aggregate of size passing through 20mm and retained on 10mm is used.

No-fines concrete can be defined as a lightweight concrete composed of cement and coarse aggregate. Uniformly distributed voids are formed throughout its mass. The main characteristics of this type of lightweight concrete is it maintains its large voids and not forming laitance layers or cement film when placed on the wall.

No-fines concrete usually used for both load bearing and non-load bearing for external walls and partitions. The strength of no-fines concrete increases as the cement content is increased. However, it is sensitive to the water composition. Insufficient water can cause lack of cohesion between the particles and therefore, subsequent loss in strength of the concrete. Likewise, too much water can cause cement film to run off the aggregate to form laitance layers, leaving the bulk of the concrete deficient in cement and thus weakens the strength.

Properties of No fines concrete

I. **Density:** The density of no fines concrete may be around 360kg per cubic meter.
II. **Compressive strength:** The compressive strength of no fines concrete may vary from 1.4 MPa to 14 MPa.
III. **Bond Strength**: The bond strength of no fines concrete is very low.
IV. **Drying Shrinkage:** The drying shrinkage of no fines concrete is considerably lower than that of conventional concrete.
V. **Thermal conductivity:** The value of coefficient of thermal conductivity of no fines concrete is much less than that of conventional concrete.

ii) Lightweight aggregate concrete

Porous lightweight aggregate of low specific gravity is used in this light weight concrete instead of ordinary concrete. The lightweight aggregate can be natural aggregate such as pumice, scoria and all of those of volcanic origin and the artificial aggregate such as expanded blast-furnace slag, vermiculite and clinker aggregate. The main characteristic of this lightweight aggregate is its high porosity which results in a low specific gravity.

The lightweight aggregate concrete can be divided into two types according to its application. One is partially compacted lightweight aggregate concrete and the other is the structural lightweight aggregate concrete. The partially compacted lightweight aggregate concrete is mainly used for two purposes that is for precast concrete blocks or panels and cast in-situ roofs and walls. The main requirement for this type of concrete is that it should have adequate strength and a low density to obtain the best thermal insulation and a low drying shrinkage to avoid cracking.

Structurally lightweight aggregate concrete is fully compacted similar to that of the normal reinforced concrete of dense aggregate. It can be used with steel reinforcement as to have a good bond between the steel and the concrete. The concrete should provide adequate protection against the corrosion of the steel. The shape and the texture of the aggregate particles and the coarse nature of the fine aggregate tend to produce harsh concrete mixes. Only the denser varieties of lightweight aggregate are suitable for use in structural concrete.

Lightweight aggregate concrete can be produced using a variety of lightweight aggregates. Lightweight aggregates originate from either:

- Natural materials, like volcanic pumice.
- The thermal treatment of natural raw materials like clay, slate or shale i.e. Leca.
- Manufacture from industrial by-products such as fly ash, i.e. Lytag.
- Processing of industrial by-products like FBA or slag.

iii) Aerated concrete

Aerated concrete does not contain coarse aggregate, and can be regarded as an aerated mortar. Typically, aerated concrete is made by introducing air or other gas into a cement slurry and fine sand. In commercial practice, the sand is replaced by pulverized fuel ash or other siliceous material, and lime maybe used instead of cement.

There are two methods to prepare the aerated concrete. The first method is to inject the gas into the mixing during its plastic condition by means of a chemical reaction.

The second method, air is introduced either by mixing-in stable foam or by whipping-inair, using an air-entraining agent. The first method is usually used in precast concrete factories where the precast units are subsequently autoclaved in order to produce concrete with a reasonable high strength and low drying shrinkage. The second method is mainly used for in-situ concrete, suitable for insulation roof screeds or pipe lagging.

5.2.4 properties of light weight concrete

The properties of light weight concrete can be categorized into two types

i. *Functional properties.*
ii. *Structural properties*

Functional properties

Thermal Insulation

Lightweight aggregate concrete has excellent insulating properties. The Co-efficient of thermal expansion of light aggregate concrete is less than that of normal weight concrete and is primarily a function of the component materials. Thermal Conductivity is a measure of the rate at which heat energy passes through a unit area of material of unit thickness per degree temperature gradient.

Density and Strength

The most obvious characteristic of light weight concrete is its density, which at times could be only be a fraction of that of ordinary concrete. Light weight concrete brings in a distinct advantage of having appreciable reduction of dead loads, lo9wer haulage and handling costs. Based on density and strength following are types of light weight concrete;

- Light weight concrete of low strength and exceptionally good thermal insulation having densities in the range of 250 to 800 kg / m^3
- Light weight concrete of medium strength and adequate thermal insulating properties having densities range of 800 to 1400 kg / m^3
- Light weight concrete of structural strength (not less than 17.5 M pa) and limited thermal insulating property having density in the range of 1400 to 2100 kg / m^3

Acoustic Properties

Noise nuisance may be avoided by suppression of the sound as its source or by isolating it from the zone where it is generated. Light weight concrete have not been considered to have any special sound insulating value. Compared to slightly higher sound insulation than might be expected from mass law, light weight concretes show moderately good built in sound absorption coefficients of value ranging from 0.2 to 125 cps to 0.5 at 4000 cps frequencies.

Water Absorption

Light weight concretes particularly those used in blocks, being porous in nature, have a higher tendency to absorb water than dense concrete. Since light weight concretes in practice are not generally used without water proofing to prevent rain penetration, this is not considered to be of significance in practice.

Fire protection

More effective fire protection than compared to conventional concrete.

Durability

It posses good resistance to exposed environmental pollutants.

Structural property

Tensile strength

It increases with the aging of concrete

Modulus of elasticity

It is usually one half to three fourth that of the reference concrete.

Fatigue strength

It is similar to that of normal concrete.

Creep

Creep is higher than that of normal aggregate concrete.

Shrinkage

The shrinkage is assumed to be twice that of conventional concrete

Bond strength

The bond strength of structurally light weight concrete is normally high and as such at equal compressive strengths, comparable bond strength can be expected although the bond strength for horizontal bars are lower.

Shear strength

Shear strength is lower compared to that of conventional concrete

5.2.5 Structural applications of light weight concrete

- Structural light weight concretes have come of age as an important and versatile material in modern construction.
- It has many and varied applications such as multistory buildings frames and floors, curtain walls, shell roofs, folded plates bridges, priestesses or precast elements of all types.
- High quality structural light weight concrete can safely be used in reinforced concrete columns, including ultra high rise buildings.

- The low density of cellular concrete makes it suitable for precast floor and roofing units which are easy to handle and transport from the factory to the sites.
- As load bearing masonry walls using cellular concrete blocks.
- As precast floor and roof panels in all types of buildings.
- As a filler wall in the form of precast reinforced wall panels in multistoried buildings
- As partition wall in the residential, institutional and industrial buildings
- As in situ composite roof and floor slabs with reinforced concrete grid beams.
- As precast composite wall or floor panels
- An insulation cladding to exterior walls of all types of buildings particularly in office and industrial buildings.

5.2.6 Advantages of Light Weight Concrete

- ➢ In high rise building can save money and manpower considerably. In addition to the reduced dead weight the lower modulus of elasticity and adequate ductility of light weight concrete may be advantageous in the seismic design of structures.
- ➢ Other inherent advantages of the material are its greater fire resistance, low thermal conductivity, low co-efficient of thermal expansion, and lower erection and transport costs for pre-fabrication members.
- ➢ For pre-fabricated structures a smaller crane is required or the same crane can handle large unit due to reduction in dead weight.
- ➢ For cast in-situ structures, its smaller dead weight makes foundation less expensive.

5.2.7 Disadvantages of Light Weight Concrete

- Very sensitive with water content in the mixtures
- Difficult to place and finish because of the porosity and angularity of the aggregate. In some mixes the cement mortar may separate the aggregate and float towards the surface
- Mixing time is longer than conventional concrete to assure proper mixing

Discuss the suitability of (a) pumice (b) scoria (c)saw dust as light aggregates for making light weight concrete?

pumice

These are rocks of volcanic origin which occur in many parts of the world. They are light enough and yet strong enough to be used as light weight aggregate. Their lightness is due to the escaping of gas from the molten lava when erupted from deep beneath the earth's crest. Pumice is usually light colored or nearly white and has a fairly even texture of interconnected cells.

Scoria

Scoria is also lightweight aggregate of volcanic origin which is usually dark in color and contains large and irregularly shaped cells unconnected with each other. there fore ,it is slightly weaker than pumice.

Saw dust

Sometimes saw dust is used as a light weight aggregate in flooring and in the manufacture of precast products. A few difficulties have been experienced for its wide-spread use. Saw dust affect adversely the setting and hardening of Portland cement owing to the content of tannins and soluble carbohydrates. With saw dust manufactured from soft wood, the addition of lime to the mix in an amount equal to about 1/3 to ½ the volume of cement will counteract this.

What are the situations under which light weight concrete is used?

Light weight aggregate is relatively new material. For the same crushing strength, the density of concrete made with such an aggregate can be as much as 35% lower than the normal weight concrete. In addition to the reduced dead weight, the lower modules of elasticity and adequate ductility of light weight concrete may be advantageous in the seismic design of structure. Other inherent advantages of material are its greater fire resistance, low thermal conductivity, low co-efficient of thermal expansions, and low eructation and transport cause for pre-fabricated member.

The light weight concrete is used as

(i) Load bearing masonry walls using cellular concrete blocks.

(ii) Pre-cast floor and roof panels in all types of building.
(iii) A filler wall in the form of pre cast reinforced wall panels in multistoried building.
(iv) Partition walls in residential, institutional and industrial buildings.
(v) In-situ composite roof and floor slabs with reinforced concrete grid beams.
(vi) Pre- cast composite wall or floor panel.
(vii) Insulation cladding to exterior walls of all types of building, particularly in Office and industrial buildings.

Fiber reinforced concrete

5.3.1 Introduction

Fiber reinforced concrete can be defined as a composite material consisting of cement mortar or concrete and discontinuous, discrete, uniformly dispersed fibers. The continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers.**(or)**

Addition of small closely spaced and uniformly dispersed fibers to concrete would act as crack arrester which improves its static and dynamic properties. This type of concrete is known as Fiber reinforced concrete.

A fiber is a small discrete reinforcing material produced from steel, plastic, glass, carbon and natural materials in various shapes and sizes. A numerical parameter describing a fiber as its **Aspect ratio** which is defined as the fiber length divided by an equivalent fiber diameter. Typical aspect ratio range from 30 to 150 for length dimensions of 0.1 to 7.62 cm. Typical fiber diameters are 0.25 to 0.76 mm for steel and 0.02 to 0.5 mm for plastic.

Objective

To know about Fibre reinforced concrete

Role of Fibers

When the loads imposed on concrete approach that for failure, cracks will propagate, sometimes rapidly; fibers in concrete provide a means of arresting the crack growth. Reinforcing steel bars in concrete have: the same beneficial effect because they act as long continuous fibers. Short discontinuous fibers have the advantage, however, of being uniformly mixed and dispersed throughout the concrete. Fibers are added to a concrete mix which normally contains cement, water and fine and coarse aggregate. Among the more common fibers used are steel, glass, asbestos and polypropylene.

5.3.2 Types of Fibers

Steel Fibers

It is one of the most commonly used fibre. Generally, round fibres in cross-sections are used. The diameter may vary from 0.25mm to 0.75mm. The steel fibre is likely to get rusted and loose some of its strength. But investigations have shown that the rusting of the fibres takes place only at the surface. Use of steel fibres makes significant improvements in flexural, impact and fatigue strength of conrete.

Steel fibers have been extensively used in overlays of roads, pavements, airfields, bridge decks and floorings subjected to wear and tear and chemical attack. The main problem encountered in the use of steel fibers is the tendency of the fibers to ball or cling together during mixing. This leads to non-uniform dispersion of fibers. Incorporation of steel fibers also decreases workability of concrete.

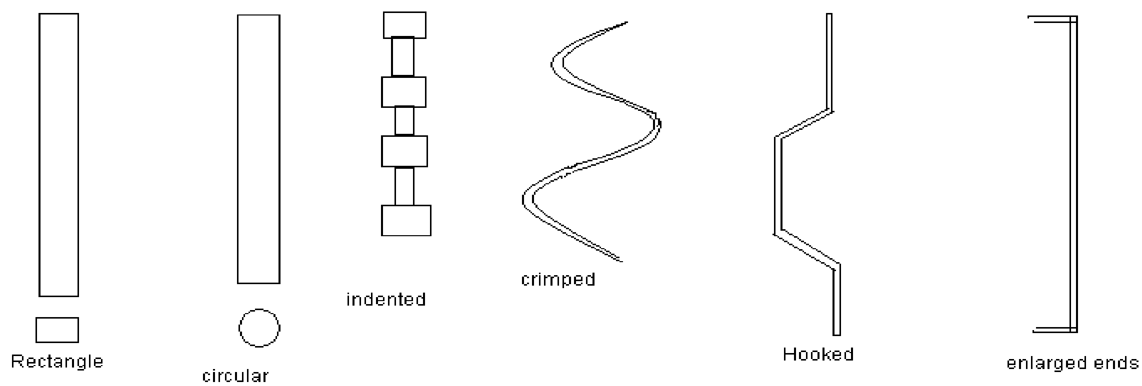


Fig 1 : Different shapes of steel fibers

Advantages

The following advantages can be obtained for SFRC Structural Components:

Increased flexural, shear, torsion strength and freezing-thawing resistances, Increased durability, fatigue strength, cracking and thermal resistance and reduce shrinkage.

Uses

SFRC elements are suitable to use in the following areas:

1. Slabs and Bridge Decks, Airport Pavements, Parking areas, Fence Posts.

2. Embankment protection, Machine foundation, Manhole covers and Dams.

3. Storage tanks, Precast Concrete Members, Slab- Column connections, shotcrete

4. Repair of cavitation’s.

Glass Fibers

It is a recent introduction in making fibre concrete. It has very high tensile strength 1020 to 4080 N/mm2. Glass fibres which is originally used in conjunction with cement was found to be effected by alkaline condition of cement. Therefore, alkali-resistant glass gibre by trade name 'CEM-FIL' has been developed and used. The use of this fibre results in improvements of impact and flexural strength of concrete.

These are produced in three basic forms (a) rovings (b) strands (c) woven or chopped strand mats. Major problem in their use are breakage of fibers and the surface degradation of glass by high alkalinity of the hydrated cement paste. However, alkali resistant glass fibers have been developed now. Glass fiber reinforced concrete (GFRC) is mostly used for decorative applications rather than structural purposes.

They are classified as

- A-glass (soda lime silica glass)
- E-glass (borosilicate glass)
- A-R glass (alkaline resistant glass, ph>12.5)

Property	A-Glass	E-Glass	AR-Glass
Specific Gravity	2.46	2.54	2.7
Tensile strength (MPa)	3030	3450	2480
Modulus of Elasticity (MPa)	64800	71700	80000
Strain at ultimate (%)	4.7	4.8	3.6

Plastic Fibres or Polymeric fibers

Fibers such an Acrylic, Aramid, Nylon, Polypropylene and Polyethylene have high tensile strength but low Young's Modulus thus sharing inability to produce reinforcing effect. However, due to their high ultimate elongation, their addition to concrete have shown better resistance to cracking, reduced crack size and higher impact strength. Their use in concrete is gaining popularity due to numerous advantages.

Fiber Type	Effective Diameter x10^3	Specific gravity	Tensile Strength(MPa)	Elastic Modulus(GPa)	Ultimate Elongation(%)
Acrylic	13-104	1.17	207-1000	14.6-19.6	7.5-50.0

Aramid	10	1.44	3620	117	2.5
Nylon	-	1.16	9.65	5.17	20
Polyester	-	1.34-1.39	896-1100	17.5	-
Polyethylene	25-1020	0.96	200-300	5.0	3.0
Polypropylene	-	0.9-0.91	310-760	3.5-4.9	15

Carbon Fibers

Carbon fibers perhaps possess very high tensile strength 2110 to 2815 N/mm^2. It has been reported that cement composite made with carbon fiber as reinforcement will have high modulus of elasticity and flexural strength. The use of carbon fibers for structures like cladding, panels and shells will have promising future. The most important characteristic of the carbon fibre is that it is stable at high temperature.

These fibers possess high Young's Modulus. The modulus of rupture of an aligned carbon fiber reinforced cement composite with 8 % fiber volume can be as high as 1623 kg/cm^2. The composite also possesses high fatigue resistance. The use of carbon fibers in concrete is promising but it is costly and availability of carbon fibers in India is very limited.

Advantages

- High strength lightweight concrete can be achieved.
- More durable in hot weather & less shrinkage value.
- Increased freezing - thawing resistances.

Uses

- The uses of CFRC are in different fields where the lightweight concreting is required.
- Precast thin sections with lightweight concreting (up to Specific Gravity 1.0).
- Suitable for high temperature and low humidity areas

Asbestos fibre

It is mineral fibre and has proved to be most successful of all fibres as it can be fixed with Portland cement. Tensile strength of asbestos varies between 560 N/mm^2 to 980 N/mm^2. The composite product called asbestos cement has considerably higher flexural strength than the Portland cement paste.The maximum length of asbestos fiber is 10 mm but generally fibers are shorter than this.

Natural fibers

These are naturally obtaining fibers extracted from plants in cement based composites. The unique aspect of these fibers is low energy needed for their extraction.

Types of natural fibers

1. Wood fibre Ex: bamboo

2. Leaf fiber Ex: sisal

3. Fruit fiber Ex: coir

4. Stem fiber Ex: jute

Aspect ratio

It is the ratio of length of the fibre and equivalent diameter. In case of non circular cross sections of the fibre equivalent diameter is found by equating area of the fibre to equivalent circle.

5.3.3 Factors affecting properties of fiber reinforced concrete

➢ **Relative fiber matrix stiffness.**

- Modulus of elasticity of matrix must be less than of fibers for efficient stress transfer.
- Low modulus of fibers imparts more energy absorption while high modulus fibers imparts strength and stiffness.
- Low modulus fibers e.g. Nylons and Polypropylene fibers.
- High modulus fibers e.g. Steel, Glass, and Carbon fibers

➢ **Volume of fiber.**

Strength of composite largely depends on the quantity of fiber. It is found that increase in the volume of fiber, increases approximately linearly, the tensile strength and toughness of the composite.

Classification

Low volume fraction (less than 1%)

- Used in slab and pavement that have large exposed surface leading to high shrinkage cracking.

Moderate volume fraction (between 1 and 2 percent)

- Used in Construction method such as Shotcrete & in
- Structures which requires improved capacity against delamination, spalling & fatigue.

High volume fraction (greater than 2%)

- Used in making high performance fiber reinforced composites.

➢ **Aspect ratio of fiber.**

It has been reported that up to aspect ratio of 75, increase in the aspect ratio increase the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness reduced.

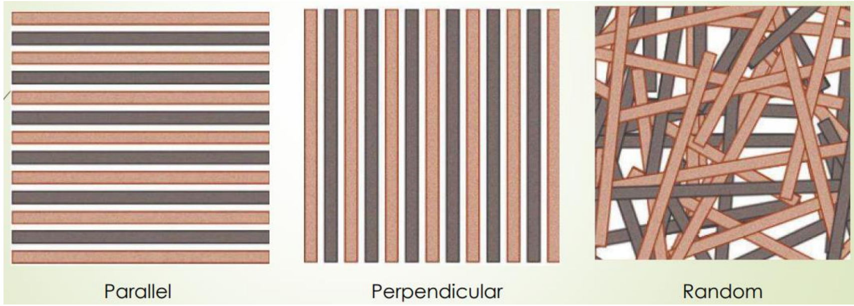
➢ **Orientation of fiber.**

One of the important factor which influence the properties and behaviour of the composite is the orientation of fiber.

Fibers can be

- Aligned in the direction of load
- Aligned in the direction perpendicular to load
- Randomly distribution of fibers

It was observed that the fiber aligned parallel to applied load offered more tensile strength and toughness than randomly distributed or perpendicular fiber.



- **Workability and compaction of concrete.**

- Incorporation of fiber decreases the workability considerably.
- Even prolonged vibration fails to compact the concrete.
- The fiber volume at which this situation reached depends on the length and diameter of the fiber.
- Another consequence of poor workability is non uniform distribution of the fibers.

- **Size of coarse aggregate.**

Maximum size of aggregate restricted to 10mm, to avoid appreciable reduction in the strength.

- **Mixing**

Mixing of FRC needs careful condition to avoid balling of fibers and Segregation. Increase in the aspect ratio and volume of fiber intensify the difficulties and balling tendencies. A steel fiber content in excess of 2% by volume and aspect ratio of more than 100 are difficult to mix.

5.3.4 Mechanical Properties of FRC

Addition of fibers to concrete influences its mechanical properties which significantly depend on the type and percentage of fiber. Fibers with end anchorage and high aspect ratio were found to have improved effectiveness. It was shown that for the same length and diameter, crimped-end fibers can achieve the same properties as straight fibers using 40 percent less fibers. In determining the mechanical properties of FRC, the same equipment and procedure as used for conventional concrete can also be used.

Compressive Strength

The presence of fibers may alter the failure mode of cylinders, but the fiber effect will be minor on the improvement of compressive strength values (0 to 15 percent).

Modulus of Elasticity

Modulus of elasticity of FRC increases slightly with an increase in the fibers content. It was found that for each 1 percent increase in fiber content by volume there is an increase of 3 percent in the modulus of elasticity.

Flexure

The flexural strength was reported to be increased by 2.5 times using 4 percent fibers.

Toughness

For FRC, toughness is about 10 to 40 times that of plain concrete.

Splitting Tensile Strength

The presence of 3 percent fiber by volume was reported to increase the splitting tensile strength of mortar about 2.5 times that of the unreinforced one.

Fatigue Strength

The addition of fibers increases fatigue strength of about 90 percent and 70 percent of the static strength at 2 x 106 cycles for non-reverse and full reversal of loading, respectively.

Impact Resistance

The impact strength for fibrous concrete is generally 5 to 10 times that of plain concrete depending on the volume of fiber used.

Corrosion of Steel Fibers

A 10 year exposure of steel fibrous mortar to outdoor weathering in an industrial atmosphere showed no adverse effect on the strength properties. Corrosion was found to be confined only to fibers actually exposed on the surface. Steel fibrous mortar continuously immerse in seawater for10 years exhibited a 15 percent less compared to 40 percent strength decrease of plain mortar.

5.3.5 Advantages of Fibre Reinforced Concrete

- **Reduction in shrinkage and cracking**

  Research has shown that high fiber count (number of fibers per unit volume), reduces the effects of restrained and drying shrinkage cracking. The addition of polypropylene fiber also reduces crack width significantly. After cracking, the fibers transfer tensile stress across cracks and act to confine crack tip extension so that many fine (hair line) cracks occur instead of fewer larger cracks.

- **Improved Bond Strength**

The fibers exhibit improved mechanical bonding as a direct result of cement matrix penetrating the fibers network. This feature is called pegging. Mechanical bond or adhesion of fibers with calcium silicate hydrate has also been reported.

- **Fatigue strength and endurance limit**

  One of the important attributes of FRC is the enhancement of fatigue strength as compared to plain concrete. The addition of polypropylene fibers, even in small amount has increased the flexural fatigue strength. An increase of 15 % to 18 % has been reported.

- **Better Toughness**

  Addition of fibers improve post-crack behavior and energy absorbing capacity of concrete. The ability to absorb elastic and plastic strain energy and to conduct tensile stresses across cracks is an important performance factor for serviceability of concrete. Fibers have significant influence on post-crack load carrying capacity of concrete.

5.3.6 Applications

The uniform dispersion of fibers throughout the concrete mix provides isotropic properties not common to conventionally reinforced concrete. The applications of fibers in concrete industries depend on the designer and builder in taking advantage of the static and dynamic characteristics of this new material. The main area of FRC applications are:

Runway, Aircraft Parking, and Pavements
For the same wheel load FRC slabs could be about one half the thickness of plain concrete slab. Compared to a 375mm thickness' of conventionally reinforced concrete slab, a 150mm thick crimped-end FRC slab was used to overlay an existing as Properties and Applications of Fiber Reinforced Concrete 53phaltic-paved aircraft parking area. FRC pavements are now in service in severe and mild environments.

Tunnel Lining and Slope Stabilization
Steel fiber reinforced shotcrete (SFRS) are being used to line underground opening sand rock slope stabilization. It eliminates the need for mesh reinforcement and scaffolding.

Blast Resistant Structures
When plain concrete slabs are reinforced conventionally, tests showed that there is no reduction of fragment velocities or number of fragments under blast and shock waves. Similarly, reinforced slabs of fibrous concrete, however, showed 20percent reduction in velocities, and over 80 percent in fragmentations.

Thin Shell, Walls, Pipes, and Manholes

Fibrous concrete permits the use of thinner flat and curved structural elements. Steel fibrous shotcrete is used in the construction of hemispherical domes using the inflated membrane process. Glass fiber reinforced cement or concrete (GFRC) made by the spray-up process, have been used to construct wall panels. Steel and glass fibers addition in concrete pipes and manholes improves strength, reduces thickness, and diminishes handling damages.

Dams and Hydraulic Structure

FRC is being used for the construction and repair of dams and other hydraulic structures to provide resistance to cavitation and severe erosion caused by the impact of large Waterboro debris.

Fiber shot Crete:

- Fiber short Crete has been used in rock stabilization, tunnel lining and bridge repair.
- Fiber short Crete can be used in the protection of structural steel work particularly in the support structure.

Other Applications

These include machine tool frames, lighting poles, water and oil tanks and concrete repairs.

Merits

- There is an increase in tensile and flexural strength.
- There is an improvement in ductility and toughness.
- Improvement in blast resistance and impact resistance
- Fibres act as crack arrestors, thus control cracking and mode of failure by means of post cracking ductility.
- One major draw-back of high strength concrete is that it is brittle. The failure will be sudden and catastrophic, particularly in structures subjected to earthquake, blasts or suddenly applied loads. This serious disadvantage of high strength concrete is overcome by addition of fibres which makes it ductile.

De-merits

- If there is non-uniform distribution of fibres it leads to poor workability.

- ❖ Conventional mixing techniques and mix proportions usually lead to fibre balling, improper dispersion and hence quality control should be maintained.
- ❖ While mixing small quantities of fibre reinforced concrete by hand, there is a possibility of steel fibers shooting up and hitting the eyes of worker or even pricking the hand.

SELF COMPACTING CONCRETE

5.4.1 Introduction

"Self -Compacting Concrete is defined as a concrete mixture that can be placed purely by means of its own weight with little or no vibration". **Or**

"Concrete that is able to flow and consolidate under its own weight, completely fill the formwork of any shape, even in the presence of dense reinforcement, while maintaining homogeneity and without the need for any additional compaction"

Objective

To know about fiber reinforced concrete.

5.4.2 Materials

• SCC has more powder content and less coarse aggregate

• Fillers used can be fly ash, ground granulated blast furnace slag, condensed silica fume, rice husk ash, lime powder, chalk powder & quarry dust

• SCC incorporates high range water reducers (HRWR, Super plasticizers) & frequently, viscosity modifying agent in small amount.

These are some general **parameters** of mixes that our experience shows are required to produce **trial mixes** for quality SCC:

Coarse aggregate content: For normal-density aggregates this typically results in a specific volume that is 28%–32% of the concrete volume, with the balance (68–72%) being mortar.

Paste fraction: Approximately 35%–37% of the mix. For rounded well-graded fine aggregate this will be lower, for poor grades or manufactured fine aggregate this will be higher

Powder (cement, supplementary cementitious materials and inert powder materials with particle sizes passing the 150 mm sieve: Powder contents will generally be in the 295–365 kg/m^3 range.

Fine aggregate: Some people track fine aggregate to total aggregate ratio – which usually turns out to be approximately 45%–55%, with 50% being typical.

Water content: For first mix, as needed to get 25–75 mm slump in concrete without SCC admixtures. This would include water-reducing admixture or retarders for set control.

W/C ratio: As needed for durability. Generally, powder content requirements for SCC properties will mean that W/C is low enough, and resultant strength high enough for most applications; however this must be confirmed.

Air: Air content should be as needed for durability. Air can improve the viscosity of a mix and increase the paste volume, but may adversely affect paste density. There are many industry organizations at work developing specifications, test methods, and practices for SCC. As new information becomes available, this document will be updated accordingly.

5.4.3 Advantages of SCC:

- Reduction of labor cost (as much as 50% - 80%), machinery, energy
- Increases in early (initial set) and ultimate (in-place) strength
- Improved surface finish (virtually eliminates bug holes)
- Less efflorescence
- Covers reinforcement effectively
- Reduction of repairs due to inadequate compaction
- Saving in initial cost of form work and more usage
- Reduction of energy costs and noise levels (little or no vibration required)
- Suitable for slim and complicated moulds.

Some of the important points to be noted are

- SCC can improve product quality.
- SCC can reduce the product cost.
- SCC can be disaster if your quality control is lacking, but a success if your standards are good.

An SCC mix has the following characteristics:

- Non-Segregating: The aggregate will stay in suspension in the mix as it flows into the form,
- Non-Bleeding: Water will not rise to the top of the mix or be observed on the outer edges of a flow test.
- Vibration: No vibration is required during placement. SCC will flow around rebar and other inclusions in the form under its own weight,
- Flow spreads: Flow spreads of 18-inch diameter or greater are obtainable.
- Set time: The initial set time in many SCC mixes will increase upwards of 90 minutes, depending on the admixtures used and water content of the mix. This may be a desirable trait for many concreting operations in the drilled shaft industry.
- Cement cannot be the only finer/filler material.
- Mineral admixtures are used to enhance the deformability & stability of concrete.
- Chemical admixtures are a must for achieving excellent flow at low water content. VMA reduces bleeding & improves the stability of the concrete mixture

5.4.4 Fresh SCC Properties

Filling ability

“The ability of SCC to flow into and fill completely all spaces within the formwork, under its own weight.”

Passing ability

“The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking.”

Segregation resistance

“The ability of SCC to remain homogeneous in composition during transport and placing.”

5.4.5 Test methods for determining fresh SCC properties

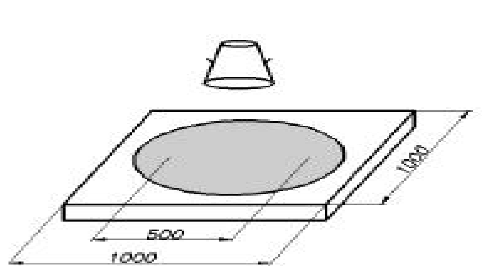
Filling ability: Slump flow & T50CM slump flow and V- Funnel test

Passing ability: L-Box, U-box, J-ring, Fill Box

Segregation resistance: V-Funnel at T5 Minutes, GTM Screen stability test

1. Slump flow test and T50cm test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions.



Equipment:

The apparatus is shown in figure

- mould in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm, conforming to EN 12350-2
- base plate of a stiff non absorbing material, at least 700mm square, marked with a circle marking the central location for the slump cone, and a further concentric circle of 500mm diameter
- trowel, scoop, ruler and stopwatch (optional)

Procedure:

1. About 6 litre of concrete is needed to perform the test, sampled normally. Moisten the base plate and inside of slump cone,
2. Place base plate on level stable ground and the slump cone centrally on the base plate and hold down firmly.
3. Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.
4. Remove any surplus concrete from around the base of the cone.
5. Raise the cone vertically and allow the concrete to flow out freely.
6. Simultaneously, start the stopwatch and record the time taken for the concrete to reach the 500mm spread circle. (This is the T50 time).
7. Measure the final diameter of the concrete in two perpendicular directions.
8. Calculate the average of the two measured diameters. (This is the slump flow in mm). Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

2. J Ring test

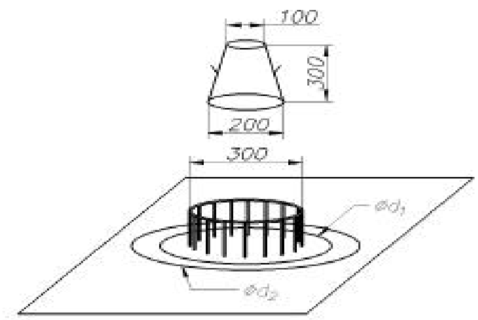


Fig: J-Ring test

Equipment

- Mould, WITHOUT foot pieces, in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm.
- base plate of a stiff non absorbing material, at least 700mm square, marked with a circle showing the central location for the slump cone, and a further concentric circle of 500mm diameter
- trowel, scoop and ruler
- J-Ring a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes. In the holes can be screwed threaded sections of reinforcement bar (length 100mm, diameter 10mm, spacing 48 +/- 2mm)

Procedure:

1. About 6 litre of concrete is needed to perform the test, sampled normally.
2. Moisten the base plate and inside of slump cone,
3. Place base-plate on level stable ground.
4. Place the JRing centrally on the base-plate and the and the slump-cone centrally inside it and hold down firmly.
5. Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.
6. Remove any surplus concrete from around the base of the cone.
7. Raise the cone vertically and allow the concrete to flow out freely.
8. Measure the final diameter of the concrete in two perpendicular directions.
9. Calculate the average of the two measured diameters. (In mm).

10. Measure the difference in height between the concrete just inside the bars and that just outside the bars.
11. Calculate the average of the difference in height at four locations (in mm).
12. Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

3. V funnel test and V funnel test at T 5minutes

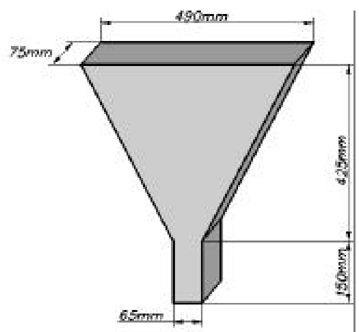


Fig: V-Funnel

Equipment:

- V-funnel, bucket (±12 litre), trowel, scoop and stopwatch

Procedure flow time:

1. About 12 litre of concrete is needed to perform the test, sampled normally.
2. Set the V-funnel on firm ground.
3. Moisten the inside surfaces of the funnel.
4. Keep the trap door open to allow any surplus water to drain.
5. Close the trap door and place a bucket underneath.
6. Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concrete
7. Level with the top with the trowel.
8. Open within 10 sec after filling the trap door and allow the concrete to flow out under gravity.
9. Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time**). This is taken to be when light is seen from above through the funnel.

10. The whole test has to be performed within 5 minutes.

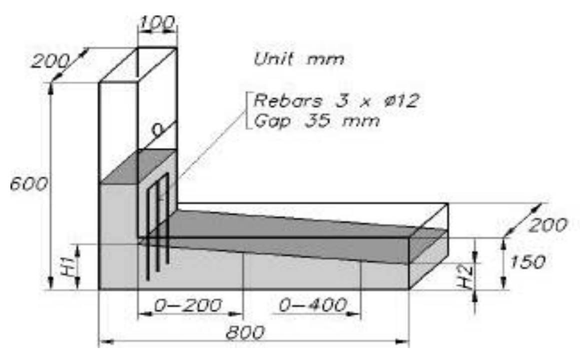
Procedure flow time at T 5 minutes:

1. Do NOT clean or moisten the inside surfaces of the funnel again.
2. Close the trap door and refill the V-funnel immediately after measuring the flow time.
3. Place a bucket underneath.
4. Fill the apparatus completely with concrete without compacting or tapping, simply strike off the concrete
5. Level with the top with the trowel.
6. Open the trap door 5 minutes after the second fill of the funnel and allow the concrete to flow out under gravity.
7. Simultaneously start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time at T 5 minutes**). This is taken to be when light is seen from above through the funnel.

4. L-box test method

Equipment:

- L box of a stiff non absorbing material see figure
- Trowel, scoop and stopwatch



Procedure:

1. About 14 litre of concrete is needed to perform the test, sampled normally.
2. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.
3. Moisten the inside surfaces of the apparatus, remove any surplus water

4. Fill the vertical section of the apparatus with the concrete sample.
5. Leave it to stand for 1 minute.
6. Lift the sliding gate and allow the concrete to flow out into the horizontal section.
7. Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400 mm marks.
8. When the concrete stops flowing, the distances "H1" and "H2" are measured.
9. Calculate H2/H1, **the blocking ratio.**
10. The whole test has to be performed within 5 minutes.

5. U box test method

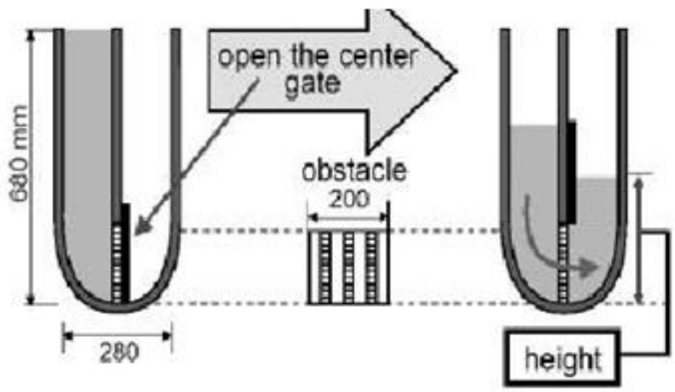


Fig: U-Box

Equipment

- U box of a stiff non absorbing material see figure D.7.1.
- Trowel, scoop and stopwatch

Procedure:

1. About 20 litre of concrete is needed to perform the test, sampled normally.
2. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.
3. Moisten the inside surfaces of the apparatus, remove any surplus water.
4. Fill the one compartment of the apparatus with the concrete sample.
5. Leave it to stand for 1 minute.
6. Lift the sliding gate and allow the concrete to flow out into the other compartment.

7. After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (H1). Measure also the height in the other compartment (H2).
8. Calculate H1 - H2, **the filling height.**
9. The whole test has to be performed within 5 minutes.

5.4.6 Applications of self -compacting concrete

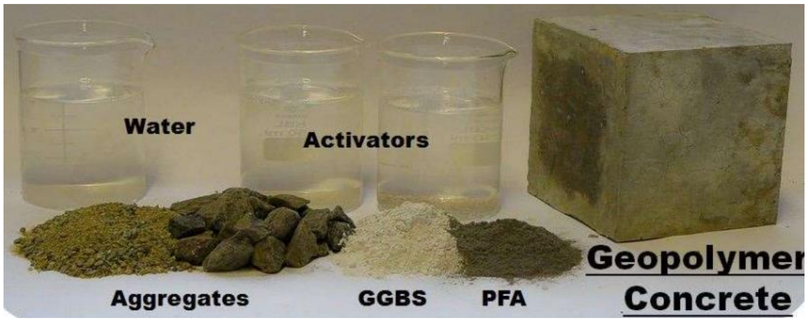
- Osaka Gas Station: First Application of SCC (1997-1998)
- Akashi-Kaikyo (Straits) Bridge: Longest suspension bridge Length 3911m and central span of 1991m, 240,000 m3 of SCC
- RCC girders
- Bangalore International Airport

How is SCC different from conventional slump concrete?

SCC must be highly workable so that it can move under the force of gravity without vibration, during mixing, transportation, handling, and placement. It is so highly flowable that the conventional slump test cannot distinguish between different levels of SCC flowability – all would be 280 mm+ (11 in. +) in slump. However, SCC must also be viscous enough so that the mortar suspends and carries coarse aggregate, maintaining a homogenous, stable mixture, resistant to segregation, bleeding, excessive air migration, or paste separation. It must have dynamic stability during mixing, transportation, handling and placement, and static stability during protection and curing. SCC's workability is a function of its rheology. Conventional concrete brought to 280 mm+ (11 in. +) slump does not have this stability.

Geo-polymer Concrete

- Geo-polymer concrete is an innovative, eco-friendly construction material.
- It is used as replacement of cement concrete.
- In geo-polymer concrete cement is not used as a binding material.
- Fly ash, silica-fume, or GGBS, along with alkali solution are used as binders



WHY NOT OPC?

- It is the most consumed commodity in the world after water.
- It is also the most energy intensive material
- Cement production leads to high carbon-dioxide emission. - 1 ton of CO_2 is produced for every 1 ton of cement. -It is produced by calcination of limestone and burning of fossil fuels

WHY GEOPOLYMER CONCRETE?

- Reduces the demand of OPC which leads CO_2 emission.
- Utilize waste materials from industries such as fly ash, silica-fume, GGBS.
- Protect water bodies from contamination due to fly ash disposal.
- Conserve acres of land that would have been used for coal combustion products disposal.
- Produce a more durable infrastructure

Constituents

- Coarse aggregate
- Fine aggregate - sand or bottom ash can be used
- Admixture – superplasticizers (naphthalene based or naphthalene sulphonate based)
- Alkaline activators
- -Alkaline activation is a process of mixing powdery alumina-silicate with an alkaline activator
- -It produce a paste which sets and hardens within short duration
- Alkaline activators commonly used are sodium or potassium hydroxide.

- -They are used in combination with sodium silicate (water glass) or potassium silicate solution.
- -NaOH and Na2SiO3 are more commonly used as it leads to higher geo-polymerization rate.
- -K2SiO3 solution rarely used because of high cost and lack of easy availability.
- -Alkali hydroxide is used for dissolution and sodium-silicate solution as binder.

TYPES OF GEOPOLYMER

Slag based geo-polymer

- Slag is a mixture of metal oxides and silicon dioxide
- a transparent by-product material formed in the processing of melting iron ore.
- OPC replacement with slag improve workability and reduce lifecycle costs
- it also increase its compressive strength
- corex slag, steel slag, iron blast furnace slag are examples

Rock based geo-polymer

- MK-750 in the slag based geo-polymer replaced by natural rock forming minerals forms this geo-polymer
- feldspar and quartz are natural rock forming minerals

Fly ash based geo-polymer

- improves workability and increase compressive strength
- reduce cost of OPC along with CO2 emission
- reduce drying shrinkage
- class F fly ash used commonly

Alkali activated geo-polymer:

Heat curing at 60 to 80 C is done. Into 1:2 alumina-silicate gel fly ash particles are embedded.

Slag based geo-polymer:

It contains silicate, blast furnace slag and fly ash

Ferro-silicate based geo-polymer

- same properties as that of rock based geo-polymers
- has a red color
- high iron oxide content
- poly type geo-polymer formed by substituting some of the aluminum atoms in the matrix

TEST ON GPC

CREEP TEST

- three 150x300 mm cylinders prepared
- placed on creep testing frame with hydraulic loading system
- before loading 7th day compressive strength determined
- load corresponding to 40% of mean compressive strength applied
- strain values measured and recorded
- test conducted at 23C and relative humidity 40-60%
- creep of GPC smaller than that of OPC
- smaller creep due to block polymerization concept
- presence of micro-aggregates increase creep resisting

DRYING SHRINKAGE TEST

- 75x75x285 mm prisms with gauge studs used
- specimens kept in a controlled temperature environment
- temperature at 23C and relative humidity 40-60%
- shrinkage strain measurements taken on third day of casting concrete
- specimen demoulded and st measurement taken
- horizontal length comparator used for measurement
- next measurement taken on 4th day
- further measurements taken till one year

Compressive Strength

- compressive strength of GPC decreased with increasing fly ash content
- it increased with higher aggregate content
- higher strength at lower alkali content
- compressive strength increased with age
- Poly-condensation of silica and alumina contribute to high strength

Modulus of Elasticity & Poisson's ratio

- modulus of elasticity increased with compressive strength in OPC similar trend in GPC but values lower than OPC
- GPC cured at elevated temperature yields higher value of E than cured at ambient temperature
- Poisson's ratio of GPC similar to that of OPC and increased with compressive strength

APPLICATIONS

PAVEMENTS

- light pavements can be cast using GPC
- no bleed water rise to the surface
- aliphatic alcohol based spray used to provide protection against drying

WATER TANKS

- two water tanks were constructed, one with 32MPa concrete with blended cement and other with GPC
- autogenous healing occurred in OPC due to calcium hydroxide deposition
- in GPC tank there is little calcium hydroxide
- nominal leaking in tank healed rapidly due to gel swelling mechanism

BOAT RAMP

- approach slab on ground to ramp was made using geo-polymer reinforced with FFRP
- entire constituents remained dormant until activator chemicals were added

PRECAST BEAM

- GPC beams formed three suspended floor levels of GCI building
- beams had arched curved soffit
- water pipes were placed inside them for temperature controlled hydronic heating of building spaces above and below

ADVANTAGES

- high compressive strength
- high tensile strength
- low creep
- low drying shrinkage
- resistant to heat and cold
- chemically resistant
- highly durable
- fire proof

DISADVANTAGES

- difficult to create
- requires special handling
- chemicals like sodium hydroxide are harmful to humans
- high cost of alkaline solution

5.5 High Strength Concrete

Introduction

- Concrete is defined as High Strength Concrete (HSC) only on the basis of Compressive strength and at given age
- High-strength concrete has a compressive strength greater than 40 MPa.
- High strength concrete is made by lowering the water cement (W/C) ratio to 0.35 or lower.
- Due to low w/c ratio it causes problem of placing, to overcome from this superplasticizer used

Ingredients of HSC

- Cement
- Sand
- Water (Low Water -Cement Ratio)
- Optimum sized aggregates (10mm to 20mm)
- Admixtures

Materials for High-Strength Concrete:

Cement:

- Almost any ASTM Portland cement type can be used to obtain concrete with compressive strength up to 60 MPa.
- In order to obtain higher strength mixtures while maintaining good workability, it is necessary to study carefully the cement composition and fineness.

Aggregate:

- In high-strength concrete, the aggregate plays an important role on the strength of concrete.
- The low-water to cement ratio used in high strength concrete causes densification in both the matrix and interfacial transition zone, and the aggregate may become the weak link in the development of the mechanical strength

Admixtures

- Silica fume (To prevent $Ca(OH)_2$ crystals in cement matrix)
- Water reducing agents (Super plasticizers)
- Dosage rate 5% to 20% or higher by mass of cementing material

Advantages of High strength concrete (HSC) are:

- It reduces the cross-section of structural elements and therefore increases available space,
- It improves aesthetics due to slimmer cross-section,
- It reduces self-weight of the structure,
- It increases the modulus of elasticity of concrete and reduces creep (deformation under continuous loading) that controls short-term and long-term deflections, and

- It improves the long-term durability of structures which is a key concern toward sustainable use of construction materials.
- High strength concrete is a useful material for high-rise buildings, long-span bridges, heavy-duty industrial floors, pre-stressed concrete, etc.

Methods for making HSC

1. Seeding
2. Re-vibration
3. High Speed Slurry
4. Use of admixtures
5. Inhibition of Cracks
6. Sulphur Impregnation
7. Use of Cementitious aggregates

1. Use Admixture

- The addition of admixture is one of the broad methods for the production of high-strength concrete by reducing water content; the act decreases pores in concrete.
- Admixtures reduce the water content in concrete and thus increase the strength in comparison to plasticizer and superplasticizer.
- Superplasticizer leads to the reduction of water content by up to 30%, and maintain the required workability.
- Not only does it increase concrete strength to a maximum possible value but also accelerate strength achievement.
- Water content reduction of up to 15% can be obtained with the use of a plasticizer.
- Pozzolanic materials like fly ash and silica fume are mineral admixtures that are usually added to the concrete mix.
- The pozzolanic materials react with Portland cement hydration product and generate extra C-S-H, extra strength added to concrete.
- The C-S-H gel is responsible for the strength of concrete

Re-Vibration

- The mixing water in concrete may bleed, accumulate at certain places, create continuous channels, and cause shrinkage that declines the strength of concrete.
- In this case, a controlled re-vibration of concrete would decrease the detrimental influences of these factors and consequently increase concrete

. High-speed Slurry Mixing

- High-speed slurry mixing involves the preparation of cement and water mixture in advance, and then the aggregate is added to the mix to produce high-strength concrete.
- The achievement of higher compressive strength is associated with the efficiency of cement particles, and water saved in the accurate mixing of cement paste

Inhibition or Prevention of Cracks

- Prevention of cracks is another technique by which high-strength concrete is produced.
- Crack development in concrete is inevitable and may cause concrete failure if it propagates.
- The replacement of 2-3% aggregate by polythene or polystyrene pieces of 0.025mm thick results into increased compressive strength.
- The polythene pieces stop the progression of cracks without the need for extra water for the workability of fresh concrete.
- In the laboratory, concrete samples produced by this method gained strength of 105 MPa

Sulfur Filling or Impregnation

- The impregnation of Sulphur into low-strength porous concrete is another method of producing high strength concrete.
- The impregnation process of concrete in the laboratory involves moist cured fresh concrete for 24hours, dry specimens at 120C for 24hours, the immersion of the specimens in molten Sulphur under vacuum for two hours, and then a release of the vacuum after two hours.
- The samples are then kept in molten Sulphur for half an hour. Finally, the specimens can be tested.
- A concrete compressive strength of 58MPa can be produced in the laboratory using the Sulphur impregnation technique.

Use of Cementitious Aggregates

- The use of cementitious aggregates, such as fondu, can produce high-strength concrete.
- The fondu aggregate is a glassy slag clinker cementitious material.
- It can give strength up to 125 MPa with a water/cement ratio of 0.32.

Seeding

- Seeding is a less practical method of producing high-strength concrete.
- It includes adding a small percentage of finely ground, fully hydrated Portland cement to the fresh concrete mix.
- The mechanism of developing high-strength concrete is difficult to explain

5.6 High Performance Concrete

Introduction

- High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete.
- This concrete contains one or more of cementitious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer.
- The use of some mineral and chemical admixtures like Silica fume and Super plasticizer enhance the strength, durability and workability qualities to a very high extent
- Any concrete which satisfies certain criteria proposed to overcome limitations of conventional concrete may be called as high performance concrete.
- It may include concrete which provides either substantially improved resistance to environmental influences OR substantially increased structural capacity while maintaining adequate durability.

Concrete may be regarded as high performance for several reasons

- High strength
- High workability
- High durability
- Also improve visual appearance

Properties of HPC

- Ease of placement
- Compaction without segregation
- Early age strength
- Long term mechanical properties
- Permeability
- Density
- Heat of hydration
- Toughness
- Volume stability
- Long life in severe environments

TYPES OF HPC

1. Toproc CR – Chemical Resistant concrete
2. Toproc ED – Early Drying concrete
3. Toproc UW – Ultra Water resistant concrete
4. Toproc HR – Heat Resistant concrete
5. Toproc SY – Impact and abrasion resistance

5.7 Assignment Questions

1. Define RMC and give out the advantages and disadvantages of RMC.
2. Define light weight concrete.
3. What are the types of light weight concrete?
4. Explain the properties of light weight concrete.
5. What are the applications of light weight concrete?
6. Define Self compacting concrete.
7. What are the materials required for manufacturing SCC?
8. Write a note on properties of SCC.
9. Explain the tests performed for determining the fresh properties of SCC.
10. What are the applications of SCC?
11. Define Fiber reinforced concrete.
12. What are the types of fibers? Explain their properties.
13. What are the factors affecting the properties of fiber?

14. What are the applications of FRC?

5.8 Outcome

Gives knowledge about RMC, lightweight concrete, Self-compacting concrete and fiber reinforced concrete.

5.9 Future scope

By studying this one can design Light weight, self -compacting and fiber reinforced concrete mixes.