CE8404

CONCRETE TECHNOLOGY L T P C 3 0 0 3

SYLLABUS

OBJECTIVES: To impart knowledge to the students on the properties of materials for concrete by suitable tests, mix design for concrete and special concretes.

UNIT I CONSTITUENT MATERIALS

Cement-Different types-Chemical composition and Properties -Tests on cement-IS SpecificationsAggregates-Classification-Mechanical properties and tests as per BIS Grading requirementsWater- Quality of water for use in concrete

. **UNIT II CHEMICAL AND MINERAL ADMIXTURES**

Accelerators-Retarders- Plasticisers- Super plasticizers- Water proofers - Mineral Admixtures like Fly Ash, Silica Fume, Ground Granulated Blast Furnace Slag and Metakaoline -Their effects on concrete properties

UNIT III PROPORTIONING OF CONCRETE MIX

Principles of Mix Proportioning-Properties of concrete related to Mix Design-Physical properties of materials required for Mix Design - Design Mix and Nominal Mix-BIS Method of Mix Design - Mix Design Examples

UNIT IV FRESH AND HARDENED PROPERTIES OF CONCRETE

Workability-Tests for workability of concrete-Slump Test and Compacting factor Test-Segregation and Bleeding-Determination of Compressive and Flexural strength as per BIS - Properties of Hardened concrete-Determination of Compressive and Flexural strength-Stress-strain curve for concrete-Determination of Young‟s Modulus

UNIT V SPECIAL CONCRETES

Light weight concretes - High strength concrete - Fibre reinforced concrete – Ferrocement - Ready mix concrete - SIFCON-Shotcrete – Polymer concrete - High performance concrete- Geopolymer Concrete

TOTAL : 45 PERIODS

OUTCOMES:

The student will possess the knowledge on properties of materials required for concrete• **tests on those materials and design procedures for making conventional and special concretes.**

TEXT BOOKS: 1. Gupta.B.L., Amit Gupta, "Concrete Technology", Jain Book Agency, 2010. 2. Shetty,M.S, "Concrete Technology", S.Chand and Company Ltd, New Delhi, 2003

REFERENCES: 1. Santhakumar,A.R; "Concrete Technology" , Oxford University Press, New Delhi, 2007

2. Neville, A.M; "Properties of Concrete", Pitman Publishing Limited, London,1995

3. Gambir, M.L; "Concrete Technology", 3 rd Edition, Tata McGraw Hill Publishing Co Ltd, New Delhi, 2007 4. IS10262-1982 Recommended Guidelines for Concrete Mix Design, Bureau of Indian Standards, New Delhi, 1998

CE8404

CONCRETE TECHNOLOGY

UNIT I

CONSTITUENT MATERIALS

CEMENT

- In the most general sense of the word, cement is a binder, a substance which sets and hardens independently. And can bind other materials together. The word "cement" traces to the Romans. Who used the term "opus caemeruicium" to describe masonry which resembled concrete and was made from crushed rock with burnt lime as binder.
- The volcanic ash and pulverized brick additives which were added to the burnt lime to obtain a hydraulic binder were later referred to as cementum, cimentum, cament and cement. Cements used in construction are characterized as hydraulic or non-hydraulic
- The most important use of cement is the production of mortar and concrete - the bonding of natural or artificial aggregates to form a strong building material which is durable in the face of normal environmental effects. Cement should not be confused with concrete as the term cement explicitly refers to the Dry powder substance. Upon the addition of water and/or additives the cement mixture is referred to as concrete especially if aggregates have been added.
- Cement can be defined as the material which possesses very good adhesive and cohesive properties making it capable of bonding mineral fragments in lo a compact mass.
- It was introduced by Joseph Aspidin in 1824.The most common form of the cement is ordinary Portland Cement (OPC)

Early uses:

It is uncertain where it was first discovered that a combination of hydrated non - hydraulic lime and a pozzolan produces a hydraulic mixture (sec also: Pozzolanic reaction), but concrete made from such mixtures was first used on a large scale by Roman engineers. They used both natural pozzolans (trass or pumice) and artificial pozzolans (ground brick or pottery) in these concretes. Many excellent examples of structures made from these concretes are still standing, notably the huge monolithic dome of the

Pantheon in Rome and the massive Baths of Caracalla. The vast system of Roman aqueducts also made extensive use of hydraulic cement. The use of structural concrete disappeared in medieval Europe although weak pozzolanic concretes continued to be used as a core fill in stone walls and columns.

Uses of cement:

- Building (floors, beams, columns, roofing, piles. bricks, mortar. panels, plaster)
- Transport (roads. pathways. crossings, bridges. sleepers. viaducts, runnels, stabilization, runways. parking)
- Water (pipes. culverts. kerbing, drains, canals, weirs. dams. tanks. pools)
- Civil (piers. docks, retaining walls, silos, warehousing, poles. pylons. fencing)
- Agriculture (buildings, processing. housing. feedlots. irrigation)

Chemical composition or raw mater1als of Portland cement and their functions:

Principal raw materials are:

1. Calcareous material
2. Argillaceous materials
3. Siliceous materials

Functions:

1. Lime (CaO)

It constitutes 2J3N of cement and the important factor which contributes strength of cement Excess lime nukes the cement unsound and causes the cement to expand and disintegrate.

2. Silica (SIO_2):

- It imparts strength to cement due to the formation of CJS and c.s.
- If silica is present in excess quantity the strength of cement increases but the setting time is prolonged.

3. Alumina (Al_20_3)

- Imparts quick setting.
- Extra alumina weakens the cement

4. Iron Oxide (Fe_20_3):

- It imparts color, hardness to cement

5. Magnesia (Mg0):

- High content of MgO makes the cement unsound.

6. Alkalies ($K10.Na_20$):

- Excess content causes alkali aggregate reaction, efflorescence
- These are harmful materials

MANUFACTURE OF ORDLNARY PORTLAND CEMENT (OPC):

There are three main operations involve in the manufacture of OPC. Mixing or raw materials There are two methods in mixing of raw materials of cement,

1. Mixing

a) Dry Process:

In dry process the calcareous material such as lime stones and argillaceous material such as clay are separately ground in ball mills or jaw crushers. This powder is then stored in silos or hoppers. Then they are mixed in correct proportion. This material is stored in storage tanks.

(b) Wet process:

In wet process calcareous materials are crushed and store din silos or storage tanks. The crushed lime stones front silos and wet clay from basin are conveyed to ball mills or lube mill and ground lo form slurry.

2. Burning:

The burning of the mixture of fine slurry is carried in a long rotary kiln. The rotary kiln consists of a steel tube or diameter varies from 250cm lo 300cm and of length from 60cm to 120 cm, his bid with a slight inclination of 1 in 30 towards the down end. The kiln rotates about longitudinal axis at the rate of one rpm,

Collected slurry is injected at the upper end of the kiln.

The hot gases or flames are farted through the lower end of the kiln.

Portion of kiln near its upper end is known as dry zone and in this zone the water from the slurry is evaporated.

As the dried slurry descends towards the burning zone, C02 from the slurry is evaporated and it is converted in to small lumps called nodules. As the nodules are healed 10 the temperature of 1500°C to I 700°C in the kiln the material undergo some reactions and finally fuse lo form dark grey granules of 5mm to 10mm size called clinkers.

The hot clinkers are then cooled co room temperature and collected in containers of suitable size.

3. Grinding:

- The grinding of these clinkers is done in ball mills or lube mills.
- A small quantity of gypsum (Ca(SO), is added. Gypsum controls the initial setting of setting time of cement.
- Finely ground cement is stored in silos. It is then weighed and packed in bags.

Grade of Cement

Grade is the 28 days compressive strength when tested as per Indian Standards under standard conditions. Ordinary Portland Cement (OPC) is classified into 3 grades, viz. 33, 43 & 53 grades .lf it is 33-grade cement then it has strength equivalent to 33 MPa (330 kg/cm^2). Similarly 43 & 53 grades can be defined. 33 grade is virtually phased out and has been replaced by 43/53 grades.

Details on different grades of Cement

Sl.No	Grade of Cement	Details
1.	33 Grade Ordinary Portland Cement(IS: 269 -1989)	• The compressive strength after 28 days is 33 N/mm^2 • Used for general construction works in normal • Cannot be used where higher grade of concrete above M-20 is required. • The use of this cement has progressively decreased and virtually phased out.
2.	43 Grade Ordinary Portland Cement (IS: 8112 - 1989)	• Most widely used cement for general construction work. • Minimum 28 days Compressive Strength -43 N/mm2. • Used for construction of residential, commercial and industrial buildings, roads, bridges, flyovers. Irrigation projectsand other general civil construction works. • Suitable for all types of applications - RCC, Plastering. Masonl'). • Rajashree is the premium OPC 43 brand in the market giving strength of around 65 MP • a at 28 days
3.	53 Grade Ordinary Portland Cement IS: 12269 - 1987	• Introduced in 1991 by Grasim - Birla Super. • Minimum 28 days Compressive strength - 53 Nlmm2 • Gives 10-15% saving in cement consumption & 5-So/o • saving in steel consumption provided higher grades of • Concrete say M30 and above are used. • Useful for high rise buildings bridges. Flyovers, chimneys and pre-stressed structures where high grade concrete is required.

		• Gives better durability characteristics to concrete - high grade concrete can be made with lower water cement ratio

Bouge's Compounds(Chemical Composition of Cement):

• When water is added to cement the ingredients of cement react chemically with water and form various complicated compounds. These compounds are called Bouge's compounds.

• The formation of these compounds is not simultaneous.

• The compounds are the following

1. C3A

• It is formed within about 24hours after addition of water to the cement.lt is also called as Cellit.

• When water added to cement the quickest to react with water is C3A.

• It is responsible for flash setting (stiffening, without strength development) and thus prevents the hydration of C2S and C1S

• The hardening of concrete is greatly speed up by this compound.

• By increasing the rate of this compound quick setting cement can be manufactured,

• Heat hydration is 865J/Cal

2. C2S:

• This compound if formed very slowly and hence it is responsible for progressive strength to the cement, It is also called as Bellite.

• It imparts strength to chemical attack.

• Heat hydration is 260J/Col

3. C3S

• It is formed within a week or so after addition of water to the cement.

• It is mainly responsible for imparting strength to the cement in early period of setting. It is also called as Allle.

• The hydration of C3S is responsible for 7 day strength and hardness.

• Heal hydration is 500J/Col

4. CAF

• It is also formed within about 24hours after addition of water to the cement. This is also called as fellite.

• Heat hydration is 420J/Col

• It has poorest cementing value

Hydration of Cement:

• The chemical reaction that takes place between cement and water is referred as hydration of cement.

• The hydration is an exothermic reaction.

• The hydration liberates a considerable amount of heat. which is called heat of liberation or heat of hydration.

• On mixing with cement with water a rapid heat of evolution lasting a few minutes occurs. This heat evolution is probably due to the reaction of solution of aluminates and sulphates. This can be depressed by the addition of Gypsum,

• Early heat liberation is mainly due to the hydration of C2S.

• Fineness of cement also influences the rate of development of heat

• Cement generally produces 89-90 Jig in 7 days and 100j/g in 28days.

• Hydration of cement is not an instantaneous one.

• Hydration is faster in early periods and indefinitely at a decreasing rate.

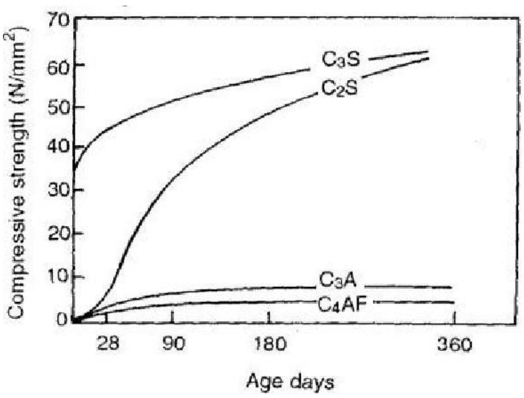
• lt has been observed that complete hydration under nonnal condition is possible only for cement particles smaller than ;o micron.

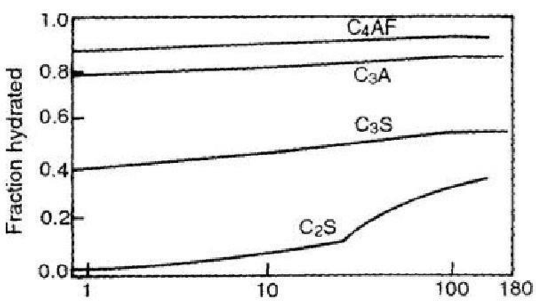
• The rate of hydration is increased by the fineness of cement

• CJS readily reacts with water and produces more heal of hydration.

• C3S is responsible for early strength of concrete. Cement with more CJS is suitable for cold weathering concrete.

• C3S hydrates rather slowly. It is responsible for the later strength of concrete. It produces less heat.





Water requirements for Hydration:

- About an average of 23% of water by weight of cement is required for complete hydration of OPC.
- This water combines chemically with the cement compounds and is known as bound water.
- About 15% of water by weight of cement is required to fill the cement pores and is known as gel water,
- Hence about 380/o of water by weight of cement is required to complete the chemical reaction. Excess water leads to capillary cavities.

Structure of hydrated Cement:

- Concrete is considered as two phase materials namely. The paste phase and the solid phase (aggregate phase)
- Paste phase influences the concrete more than solid phase.
- Strength, permeability, durability , elastic properties, volume change etc of concrete is greatly affected by paste structure.
- The aggregate phase has lesser influences on the properties of concrete than the paste phase.

Concrete Microstructure:

Hardened concrete is composed of coarse and fine aggregate panicles embedded in a matrix of hardened cement paste. The hardened paste. which comprises approximately 25 to 30 percent of the concrete volume, consists primarily of calcium silicate hydrate (CSH) gel. calcium hydroxide (CH), calcium sulfoaluminate and capillary pore space (space originally filled with waler in excess of that required for hydration of the cement). The CSH gel is itself porous, with an intrinsic porosity of approximately 28 percent. The solid portion of the hydrated cement gel is depicted as small black spheres. The interstitial spaces between the spheres are the gel pores. The capillary pores are denoted with a "C". The gel pore diameters range in size from 5 x 10-710 25 x 10·1 mm. The temperature at which water freezes is a function of the pore size: the gel pores are so small thal water cannot freeze inside them at temperatures above -78 \!C. The capillary po.res are considerably larger and vary in size,

Typically ranging from I 0 x I 0.. to 50 x IO-6 mm in well hydrated pastes of low water-cement ratio. whereas in pastes of high water-cement ratio at early ages. size may vary from 3 x 10-J to 5 x 10-J nun. Figure 2 also shows the boundary of an air void, indicating that air voids are usually several orders of magnitude larger than capillaries and gel pores.

Origin of Air In Concrete

All concretes contain natural or entrapped air that is incorporated into concrete during mixing operarions. It is relatively large. often irregularly shaped voids. typically I to I 0 mm or more in size. Entrapped air can comprise abou1 I to 3 percent of the volume in concrete. Air-entrained concrete also contains much smaller. spherical air voids ranging from 0.01 mm to I mm in diameter, A typical average size of entrained air voids is about 0.10 mm. Entrained air is incorporated into the concrete in the same way as entrapped air (mixing); however, entrained air is stabilized as small bubbles in the fresh cement

Products of Hydration:

The products of the reaction between cement and water are termed "hydration products." ln concrete (or mortar or other cementitious materials) there are typically four main types:

1 .Calcium silicate hydrate: this is the main reaction product and is the main source of concrete strength. lt is often abbreviated using cement chemists' notation, 10 "C-S-H." the dashes indicating that no strict ratio ofSi0210 CaO is inferred. The Si/Ca ratio is somewhat variable but typically approximately 0.45-0.50 in hydrated Portland cement but up to perhaps about 0.6 if slag or fly ash or rnicrosilica is present, depending on the proportions.

2. Calcium hvdroxlde - Ca(OH)i: often abbreviated to 'CH.' CH is fanned mainly from alite hydration. Alite has a Ca:Si ratio of 3: I and C-S-H has a C:i/Si ratio of approximately2: I, so excess lime is available to produce CH.

3. AFm and Aft phases: these are two groups of minerals that occur in cement and elsewhere, One of the most common AFnt phases in hydrated cement is monosulfate. By far the most common Aft phase in hydrated cement is enringite. The general definitions of these phases are somewhat technical, but for example, ettringite is an Aft phase because it contains three (t-iri) molecules of anhydrite when written as CJAJC3SQ4.32H20 and monosulfate is an Afm phase because it contains one (m-mono] molecule of anhydrite when written as CJA.CaS0,.12H20.

The most common AFI and Afm phases in hydrated cement are:

a) Ettringite:

Ettringite is present as rod-like crystals in the early stages of reaction or sometimes as massive growths filling pores or cracks in mature concrete or mortar. The chemical formula for ettringite is [Ca1Al(OH)6. I 2H20J2.2fl-0]

b) Monosulfate:

Monosulfate tends to occur in the. later stages of hydration. a day or two after mixing. The chemical formula for monosulfate is CJA.CaSO,. as 2H20.

Monocarbonate:

The presence of limestone, whether interground with the cement or present as fine limestone aggregate. is likely to produce monocarbonate (CJA.CaC0,.11 H20) as some of the limestone reacts with the cement pore fluid,

Transition Zone:

- Transition zone is the interfacial region between the particles of coarse aggregate and hardened cement paste.
- It is a plane of weakness and has far greater influence on the mechanical behavior of concrete.
- Transition zone is composed of same bulk cement paste.
- Quality of cement paste is poor in the transition zone.
- Due 10 drying shrinkage or the temperature variation the transition zone develops micro cracks even before a structure is loaded. When these structures loaded these micro cracks propagate and higher cracks are formed resulting in failure of bond

TYEPS OF CEMENT AND USES

1. **Ordinary Portland Cement (OPC)**

- It is the most widely used cement .lt is manufactured either by wet process or dry process.
- The OPC are classified into 33 grades: 33 grade.43 grade and 53 grade. If the compressive strength of OPC after 28 days of curing is not less than the value 33N/mm, it is called as 33 grade cement.
- For 43 grade cement the compressive strength is not less than 43N/mm and for 53 grade cement is $53N/mm^2$.

2. Rapid Hardening Cement (RHC) lS 8041-19901

It is similar to OPC.

- It develops strength rapidly.
- It develops at the age of 3 days. the same strength as that is expected of OPC at cement 7 days.
- The rapid rate of development of strength of RHC is due to:

➢ Higher fineness
➢ Higher content ofC3S
➢ Lower C2S content
➢ These should not be used in mass concrete structures.

Uses:

- Road repair works
- In pre-fabricated concrete construction Cold weather concreting where the rapid rate of development strength reduces the vulnerability of concrete to the frost damage.

3. Quick Setting Cement:

- This cement sets quickly.

- The early setting property is brought out by reducing ihe Gypsum content al the time of clinker grinding.
- It is required to be mixed. placed and compacted very early.
- Mostly used in under water construction works where pumping is involved.
- Use of such cement in such conditions reduces the pumping time and makes it economical
- Initial setting time is 5 minutes and final setting time is 30 minutes,

4.Low Heat Cement(LHC):

- During the hydration of 'cement, a large amount of heat will liberated. This heat liberation causes the crack formation in the mass concrete structures.
- LHC are the cements \which produces less amount of heat during the hydration.
- Low heat evolution is achieved by reducing the contents of CJS and CJA and Increasing the C2S content.
- The feature of LHC is slow rate of gain of strength. But the ultimate strength of LHC is same as that of OPC.

5. Portland Pozzolana Cement(PPC) IS1489-1991)

- PPC is manufactured by the intergrinding of OPC clinker with I 0 to 25 percent of pozzolanic material.
- A pozzolanic material is essentially a siliceous or aluminous material. The pozzolanic materials generally used for PPC are calcined clay or fly ash.
- PPC produces less heat of hydration and offers greater resistance to the attack of aggressive waters than OPC.
- It reduces the leaching of Ca(OH}i when used in hydraulic structures.
- Commonly used for hydraulic and mass constructions.

Advantages:

- Costly clinker is replaced by cheaper pozzolanic material-hence economical.
- PPC generates low heal of hydration.
- Long term strength.
- Reduction in permeability.

Application

- For hydraulic structures
- For marine structures
- For sewers and sewage disposal works.
- For mass concrete structures like dams, bridge piers etc.

6. Air-Entraining Cement:

This type of cement is not covered by Indian standard.

- This cement is made by mixing a small amount of an air entraining agent with OPC clinker at the time of grinding.
- The air entraining agents are:

  1. Alkali salts of wood resins
  2. Synthetic detergents of the alkali-aryl sulphonate type.
  3. Calcium salts of glues
  4. Calcium ignosulphate

- These agents in liquid or in powder fonn are added co the extent of 0.025-0.1 percent by weight of cement clinker.
- This cement is not covered by Indian standards.
- Air entraining cement will produce al the time of mixing .tough. tiny .discrete non-coalescing air bubbles in the body of the concrete which will modify the properties of plastic concrete w.r.t the workability, segregation and bleeding.

7. Colored Cement

Coloured cements consists of OPC with 5 to 10 percent of colour pigments.

- The properties required of a pigment to be used for coloured cement are the durability of colour under exposure to light and weather, chemical composition.

8. White Cements:

- The process of manufacture of white Portland cement is same as OPC. The raw material used are high purity lime stones(% percent C3C03 and less than

0.07 percent iron oxide),china clay with iron content of about 0.72 to 0.8 percent, silica sand etc.

- The properties of white are same as that of OPC.
- The two famous brands of white cement namely Birla White and J.K. White.

9. Hrdrophobic Cement (IS 8043-1991)

- This type of cement is obtained by grinding OPC clinker with water repellant fil- forming substance such as oleic acid and stearic acid.
- With water repellant film formed around each grain of cement reduces the rate of deterioration of the cement during the long storage. transport. or under unfavorable conditions.
- The film is broken out when cement and aggregates are mixed together at the mixer.
- The film forming water repellant material will entrain certain amount of air in the body of the concrete which incidentally will improve the workability of concrete.
- The properties of these type are same as that of OPC.

- The cost is higher than OPC.

10. Masonry Cement (IS 3466-1988)

Mainly used for masonry construction.

- It contains certain amount of air-entraining agent and mineral ad-mixtures to improve the plasticity and water retentivity.
- These will incorporates all the good properties of lime mortar,

11. Oil –well Cement(IS 8229-1986)

- The cement used to seal off the annular space between steel casing and rock strata is known as oil well cement.
- The desired properties of these cements can be obtained by adjusting the compound composition of cement or by adding retarders to OPC.
- The retarding agents prevents the quick setting and retains the slurry in mobile condition to facilitate the penetration to all fissures and cavities.
- The common retarding agents are starches or cellulose products.

12. Rediset Cement:

- This cement allows a handling time of just about 8 to I 0 minutes
- Strength pattern is similar to that of OPC mortar after one day or 3 day.
- This cement releases a lot of heat which is advantageous in winter concreting but excess heat liberation is detrimental to mass concrete.
- The sulphate resistance is poor.
- The rate of shrinkage is faster.

Applications of Rediset Cement:

I. used for patch repairs and emergency repairs.

2. slip-formed concrete construction

3. very-high early strength concrete and mortar

13. High Alumina Cement (IS 6452 : 1952):

- It is obtained by fusing or sintering a mixture. in suitable proportions of alumina and calcareous material and grinding the resultant product to a fine powder.
- The fusion takes place under I 550"C to 160o"C.
- The cement is maintained in liquid state in the furnace.
- He pigs of fused cement after cooling are crushed and then ground in tube mills to fines.

- After cooling the cement mass resembles a dark. fine grey compact rock.

14. Expansible cement:

- This type of cement which suffers no overall change in volume on drying.
- It is manufactured by grinding about 8-20 parts of sulpho aluminate clinker with 100 parts of the Portland cement and 15 parts of the stabilizer.
- It is also called as shrinkage cement,
- This cement when used in concrete induces compressive stresses which approximately offset the tensile stresses induced by shrinkage and also prestressing structure.

15. Super Sulphated Cement (IS 6909-1990):

- It is manufactured by grinding together a mixture of80-85 percent granulated slag 10-15 percent of hard burnt gypsum and about 5 percent Portland cement clinker.
- This cement more sensitive to deterioration during storage than OPC.
- It has low heat of hydration..
- It has high sulphate resistance and especially used in foundation works,
- Can be used for marine works.

16.Sulphate Resisting Cement (IS 1230-1988):

These low content of CJA and C4AF and are resistant to sulphate attack.

Use of these cements are under the following conditions;:

I. Concrete to be used in marine condition

2.Concrete to be used in foundation and basements

3. Concrete to be used in construction of sewage treatment works,

ASTM CLASSIFICATION OF CEMENT:

The American Society for Testing Materials.(ASTM) classification of cements are as follows:

TYPE I: requiring no special properties

TYPE II: for moderate sulphate attack resistance or moderate heat of hydration application

TYPE III: for high early strength

TYPEIV: for low heat of hydration

TYPE V: with high sulphate resistance

SPECIAL CEMENTS:

These cements are obtained by intimately and uniformly combines OPC with the other chemicals in correct and Controlled proportion.

1. Portland Blast furnace Cement :

- It contains up 10 700/o ground granulated blast furnace slag. with the rest Portland clinker and a little gypsum.
- All compositions produce high ultimate strength, but as slag content is increased, early strength is reduced while sulfate resistance increases and heat evolution diminishes.
- Used as an economic alternative to Portland sulfate-resisting and low-heat

cements,

2. Portland Fly ash Cement:

- It contains up to 30% fly ash. The fly ash is pozzolanic. so that ultimate strength is maintained.
- Fly ash addition allows a lower concrete water content, early strength can also be maintained,

3. Portland Pozzolana cement:

- This includes fly ash cement, since fly ash is a pozzolana, but also includes cements made from other natural or artificial pozzolans.
- In countries where volcanic ashes are available (e.g, Italy. Chile. Mexico. The Philippines) these cements are often the most common form in use.

4. Portland Silica Fume cement:

- Addition of silica fume can yield exceptionally high strengths. and cements containing 5~20% silica fume are occasionally produced.
- Silica fume is more usually added to Portland cement at the concrete mixer,

Storage of Cement:

Portland cement is a moisture-sensitive material: if kept dry. it will retain its quality indefinitely. When stored in contact with damp air or moisture. Portland cement will set more slowly and has less strength than Portland cement that is kept dry. When storing bagged cement, a shaded area or warehouse is preferred. Cracks and openings in storehouses should be closed. When storing bagged cement outdoors. it should be stacked on pallets and covered with a waterproof covering.

Storage of bulk cement should be in a watertight bin or silo. Transportation should be in vehicles with watertight. properly sealed lids. Cement stored for long periods of time should be tested for strength and loss on ignition.

Hydration products:

Reaction of cement with water is exothermic. Different compounds hydrate at different rate .Total quantity of heat librated in complete hydration depend on relative quantities of major compounds in cement

sc.s t6H C~3Ca (OH)2

zc,s +4H C~3Ca (OH}'

- C1S produces lesser quantity of calcium silicate hydrate and more quantity of calcium hydroxide than that formed in the hydration of C2S.
- Calcium hydroxide not desirable gets leached out making concrete porous. C1S readily reacts with water and produces more heat of hydration which is responsible for early strength. C2S hydrates slowly responsible for later strength thereby less heat of hydration .
- The reaction of C3A with water is very fast causing flash setting thereby stiffening without strength development occurs.
- C~A-H phase prevents hydration of C1S and C2S.Son1e calcium sulphate ground in clinker dissolves in water and sulphate ions in solution react with C1S to form insoluble calcium sulpho aluminate which act as protective colloidal membrane and retard direct hydration reaction.
- When all sulphate is consumed hydration process accelerates. TI1e hardening of C,S •PP<""" to be catalysed by C,A so that C,S becomes almost solely responsible for gain of strength and interlocking of C-S-H gel.
- The later age increase in strength is due to hydration of C2S.The rate of strength development modified by changes in relative quantities of these compounds Nonna] cement generally produces heat of 89-90 cal/gm in 7 days and 90-100 cal/gm in 28 days. For usual range of Portland cement one half of total heat is liberated between I and 3 days about three quarter in 7 days and nearly 90% in 6 months.Heat of hydration depends on chemical composition of cement and is approximately equal to swn of heat of hydration of individual pure compounds when their respective propositions by mass are hydrated separately.
- By reducing C,A and c,s heat of hydration and its rate can be reduced Fineness of cement also affect rate of heat Development There is no relation between heat of hydration and cementing properties of individual components

Heat of hydration of pure compounds

Compound	Heat of hydration (cal/=)
cs	120
c.s,	62
C1A	207

Cu\F 100

Calcium Silicate Hydrates(C-S-H):

- During the course of reaction of C3S andC2S with water calcium silicate hydrate (C-S-H) and Ca(OH)2 ore formed. Calcium silicate hydrates are the most important products and determines the good properties of concrete.
- C-S-H occupies 50-60 5 of the volume of solids in a completely hydrated cement paste.
- C3S produces lesser quantity of C-S-H and more quantity of Ca(OH)? than that formed in the hydration of c,s.
- Ca(OHh is soluble in water and gets leached out making the concrete porous especially in hydraulic structures.

TESTS ON CEMENT

1. INITIAL AND FINAL SETTING TIME

We need to calculate the initial and final setting time as per IS: 4031(Part5)- 1988. To do so we need Vicat apparatus conforming to IS: 5513 - 1976. Balance. whose permissible variation al a load of 1000g should be+lIlg, Gauging trowel conforming to JS: 10086- 1982.

Procedure to determine initial and final setting time of cement

i) Prepare a cement paste by gauging the cement with 0.85 times the water required to give a paste of standard consistency.

li) Start a stop-watch, the moment water is added to the cement

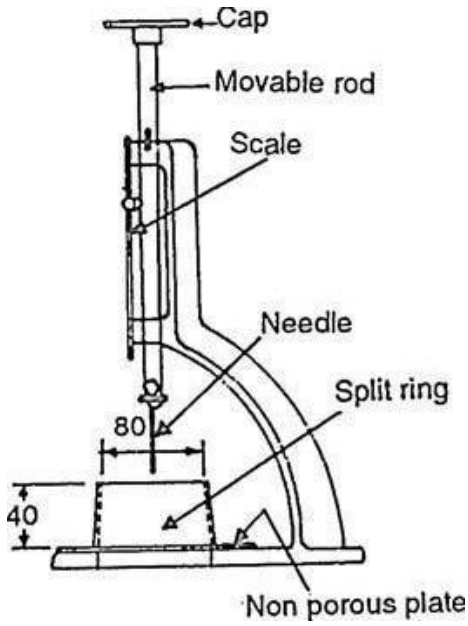
iii) Fill the Vicat mould completely with the cement paste gauged as above, the mould resting on a non-porousplate and smooth off the surface of the paste making it level with the top of the mould. The cement block thus prepared in the mould is the test block.

A) INITIAL SETTING TIME

Place the test block under the rod bearing the needle. lower the needle gently in order to make contact with the surface of the cement paste and release quickly, allowing it 10 penetrate the test block. Repeat the procedure till the needle fails to pierce the test block to a point 5.0 ± 0.5mm measured from the bottom of the mould. The time period elapsing between the time. water is added to the cement and the time. the needle fails to pierce the test block by 5.0 ± 0.5mm measured from the bottom of the mould. is the initial setting time.

B) FINAL SETTING TIME

Replace the above needle by the one with an annular attachment. The cement should be considered as finally set when, upon applying the needle gently to the surface of the test block. the needle makes an impression therein, while the attachment fails to do so. The period elapsing between the time. water is added to the cement and the time, the needle makes an impression on the surface of the test block. while the anachment fails to do so. is the final setting rime.



2. CONSISTENCY

The basic aim is to find out the water content required to produce a cement paste of standard consistency as specified by the IS: 4031 (Part 4)- 1988. The principle is that standard consistency of cement is that consistency at which the Vicat plunger penetrates to a point 5-7m1n from the bottom of Vicat mouJd.

Apparatus- Vicar apparatus conforming to IS: 5513- 1976. Balance. whose permissible variation at a load of 1000g should be +1.0g, Gauging trowel conforming lo IS: 10086 - 1982.

Procedure to determine consistency of cement

i) Weigh approximately 400g of cement and mix it with a weighed quantity of water. The lime of gouging should be between 3 to 5 minutes.

ii) Fill the Vicat mould with paste and level ii with a trowel.

iii) Lower the plunger gently till it touches the cement surface.

iv] Release the plunger allowing it to sink into the paste.

v) Note the reading on the gauge.

vi) Repeat the above procedure taking fresh samples or cement and different quantities of water until the reading on the gauge is 5 to 7mm.

3. SOUNDNESS

Soundness of cement is determined by Le-Chatelier method as per IS: 4031 (Port 3) - 1988.

Apparatus - The apparatus for conducting the Le-Chatelier test should conform to lS: 5514-1969

Balance. whose permissible variation 01 a load of 1000g should be +1.0g and Water both

Procedure to determine soundness of cement:

i) Place the mould on a gloss sheet and fill ii with the cement paste formed by gauging cement with 0.78 rimes the water required to give a paste of standard consistency.

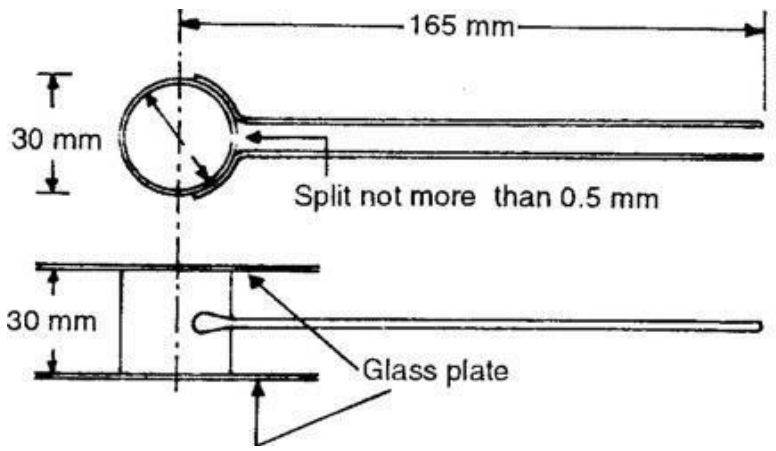
ii) Cover the mould with another piece of glass sheet. place a small weight on this covering glass sheet and immediately submerge the whole assembly in water all a temperature of 27 ± 2oC and keep it there for 24hrs.

iii) Measure the distance separating the indicator points to the nearest 0.5mm (say d l).

iv) Submerge the mould again in water at the temperature prescribed above. Bring the water to boiling point in 25 to 30 minutes and keep it boiling for 3hrs.

v) Remove the mould from the water, allow it to cool and measure the distance between the indicator points (soy d2).

vi) (d2 - d I) represents the expansion of cement.



4. FINENESS

So we need to determine the fineness of cement by dry sieving as per JS: 403 I (Part I) - 1996.The principle of this is that we determine the proportion of cement whose grain size is larger then specified mesh size. The apparatus used are 90µm JS Sieve, Balance capable of weighing 10g to the nearest 10mg. A nylon or pure bristle brush. preferably with 25 to 40mm. bristle, for cleaning the sieve.Sieve shown in pie below is not the actual 90µm seive. Its just for reference.

Procedure to determine fineness of cement:

i) Weigh approximately 100g of cement to the nearest O.Olg and place it on the sieve. ii) Agitate the sieve by swirling, planetary and linear movements. until no more fine material passes through it.

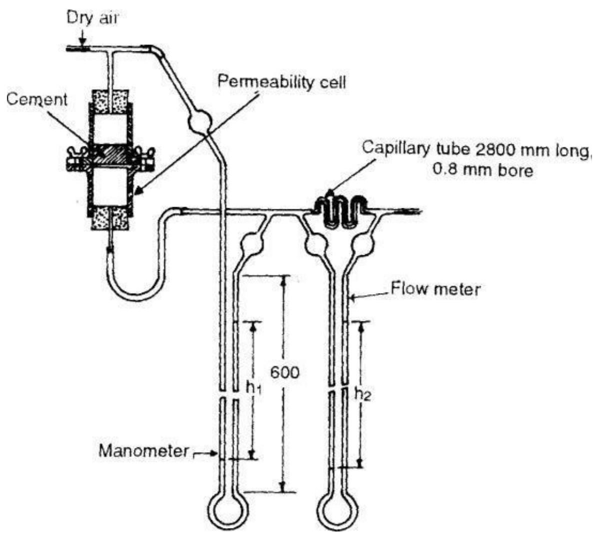
iii) Weigh the residue and express its mass as a percentage RI .of the quantity first placed on the sieve to the nearest 0.1 percent.

iv) Gently brush all the tine material off the base of the sieve.

v] Repent the whole procedure using a fresh I Og sample 10 obtain R2. Then calculate R as the mean of RI and R2 as a percentage. expressed to the nearest 0. I percent When the results differ by more than I percent absolute. carry out a third sieving and calculate the mean of the three values.

5. Air Permeability Method:

The fineness of cement is represented by specific surface, i.e. total surface area in cm^2 per gram or m^2 per kilogram of cement and is measured by Lea and Nurse apparatus or by wagner turbidimeter.. The Lea and Nurse apparatus shown in fig essentially consists of a permeability test cell—where cement is placed and air pressure is applied, flowmeter—to determine the quantity of air passing per second through its capillary tube per unit difference of pressure, and manometer—to measure the air pressure.



To determine the fineness, a cement sample of 20 mm height is placed on a perforated plate (40 micron perforations) and air pressure is applied. The manometer is connected to the top of the permeability cell and the air is turned on. The lower end of the permeability cell is then slowly connected to the other end of the manometer. The rate of flow is so adjusted that the flowmeter shows a pressure difference (h_2) of 30-50 cm. The reading (h_1) in the manometer is recorded. The process is repeated till the ratio h_1/h_2 is constant. The specific surface is given by the expression

$$S = \frac{14}{d\,(1 <)} \quad \frac{A}{KL} \quad \frac{h_1}{h_2}$$

Where L = thickness of cement layer

A = area of cement layer

d = density of cement

Y = porosity of cement (0.475)

h_2 = flowmeter reading

h_1 = manometer reading

K is the flowmeter constant and is obtained by

$$Q = \frac{K h_2 d_1}{P}$$

Where m = viscosity of air

d_1 = density of kerosene

Q = quantity of air passed per

HEAT OR HYDRATION

- The heat of hydration is the heat generated when water and Portland cement react, Heat of hydration is most influenced by the proportion of C3S and C3A in the cement, but is also influenced by water-cement ratio, fineness and curing temperature.

- As each one of these factors is increased. heat of hydration increases. ln large mass concrete structures such as gravity dams. hydration heat is produced significantly faster than it can be dissipated (especially in the center of large concrete masses).

- which can create high temperatures in the center of these large concrete masses that, in tum, may cause undesirable stresses as the concrete cools to ambient temperature. Conversely, the heal of hydration can help maintain favorable curing temperatures during winter (PCA. 1988).

. LOSS ON IGNITION

Loss on ignition is calculated by heating up a cement sample to 900 - I 000°C (I 650 - 1830'F) until a constant weigh! is obtained, The weight Joss of the sample due to healing is then determined, A high loss on ignition can indicate prehydration and carbonation, which may be caused by improper and prolonged storage or adulteration during transport or transfer (PCA. I 988).

6. STRENGTH

- Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water-cement ratio.
- cement-fine aggregate ratio. type and grading of fine aggregate, manner or mixing and molding specimens. curing conditions, size and shape of specimen, moisture content at time of test loading conditions and age (Mindess and Young, 1981).
- Since cement gains strength over time, the time at which a strength lest is to be conducted must be specified, Typically times are I day (for high early strength cement), 3 days, 7 days. 28 days and 90 days (for low heal of hydration cement).
- When considering cement paste strength tests. there are l\\10 items to consider:
- Cement mortar strength is not directly related to concrete strength. Cement paste strength is typically used as a quality control measure. Strength tests are done on cement mortars (cement+ water+ sand) and not on cement pastes.

a) Compressive Strength:

The most common strength test. compressive strength. is carried out on a 50 mm (2-inch) cement mortar test specimen. The test specimen is subjected to a compressive load (usually from a hydraulic machine) until failure. This loading sequence must take no less than 20 seconds and no more than 80 seconds.

AGGREGATES:

- Aggregates are the important constituents of concrete. They give body to concrete and reduce shrinkage. cracks and effect economy.
- Aggregates are the inert materials in concrete.
- Aggregates occupy 70-80 percent of concrete by volume.

Requirements of good aggregates

1. It should be hard strong and durable.
2. It should be free from inorganic materials. oils etc.
3. Porosity should be reduced.
4. It should be angular shaped
5. Low thermal conductivity
6. Should not react with cement or steel
7. Should be well graded
8. Should be free deleterious materials

CLASSIFICATLON OF AGGREGATE

I. Based on nature of formation:

a. Natural aggregates:

- The aggregateswhich are obtained from natural deposits of sand and gravel or from the stone quarrei s by breaking hard rocks are generally known as natural aggregates.

- Eg: Sand ;Gravel, Crushed rocks such as Granite, Basalt. Quartzite

b. Artificial aggregates :

- The aggregates which are obtained by breaking either bricks or blast furnace slag to the graded particles of desired size are called artificial aggregates.
- Eg: Cinder. Expanded clay. Shale etc.

II. Classification based on size:

According to size. 11ggregatrs are classified as :

1. Coarse aggregate

- The aggregates most of which is retained on lS: 4.75 mm sieve are known as coarse aggregates.

These are of two types:

a) graded aggregate:

- The coarse aggregates which contain particles of all sizes from 3 given nominal minin1un1(4. 75mm) to maximum (75 micron) is known as graded coarse aggregates.

These suitable for concrete

b) Single sizes aggregates:

These coarse aggregates contains particles of single sieve size.

2. Flne aggregatess:

- The aggregates which are passing through the I.S 4.75 mm sieve are called fine aggregates.
- River sand is an example.

III. Classification based on shape:

1 .Rounded aggregates:

- These are aggregates with rounded shape due to the action of water attrition.
- The surface area is minimum for rounded aggregate. Hence the concrete produced by using these aggregates require more cement and water,
- The concrete produced will be low strength since the bond between the aggregates and cement is weak.
- River sand or sea shore and windblown are examples,

2. Irregular aggregates:

Partly rounded aggregates are called irregular aggregates.

- Pit sands and gravel are examples.

3. Angular aggregates:

- These aggregates have sharp edges and rough surfaces.
- More cement is required for this type of aggregate.
- Concrete produced with this aggregate is of good strength and durability due to interlocking and higher bond strength between aggregate and cement paste.
- All types of crushed rocks are example

Flaky aggregates

- The aggregates with less thickness compared width and length are called flaky aggregates,
- The concrete made with these aggregates is of poor quality.
- Laminated rocks are example. Elongated aggregates
- When the length of aggregate is considerably greater than the other two dimensions. it is called elongated aggregate.
- The concrete produced by using these aggregates is poor quality and is less durable.

Sources of aggregates:

Fine aggregates are available from:

1. River sand:
    - This is obtained from river beds and river banks.
    - This is bright and clear and consists of sharp or rounded particles.
    - This is best for mortar preparation and can be used for plastering works,

2. Pit sand:

- This sand is obtained from pits dug at a depth of I .S m from to 2 m from the ground soil.
- The particles are sharp. angular, porous and free from the harmful salts and are suitable for mortar

3. Sand:

- This is the sand available in seashores.
- This sand is brown in colour consists of rounded particles..
- These contain objectionable matter. So it is not recommended for construction work

.i. Manufacture sand (M-sand):

- Due to the scarcity of sand from natural sources like rivers. sand is manufactured in stone crushers, which are called m sand.
- These are with Jess impurities and better control over size and quality.

Gradation

An aggregate's particle size distribution. or gradation. is one of its most influential characteristics. ln HMA, gradation helps determine almost every important property including stiffness, stability. durability, permeability, workability, fatigue resistance. frictional resistance and resistance Lo moisture damage (Roberts el al., 1996). Because of this, gradation is a primary concern in HMA mix design and thus most agencies specify allowable aggregate gradations.

Need of grading aggregates -Grading curve

Gradation refers to particle size distribution. It plays an important role in workability and paste requirements. Gradation of FA affects the workability and finish ability of concrete. Effect on packing of particles. resulting in the. reduction of void- in tum influences the water demand & cement content of concrete. Grading is described in terms of cumulative o/o weights passing a particular sieve size in IS 383-1970. Typical grading limits for CA are 80, 63, 40, 20. 16, 12.5. 10. 4. 75, and 2.36. For fine aggregate IO. 4. 75. 2.36, 1.18, 600µ. 300µ, 150µ.Fineness modulus is a gross measure of aggregate gradation and is associated with fine aggregate. is the sum of cumulative percentage of weight retained on a standard set or sieves divided by l00.

Unifonn grading -AU particle are of same size. reduces large volume of voids irrespective of particle size. Paste requirement for concrete is high Continuous or well graded - Combination of particles of many sizes. lt minimizes the volume of voids but increases particle surface area and is the preferred gradation

Gap graded - One or more sizes are omitted -Used for architectural or aesthetic purposes.

Measurement

Gradation is usually measured by a sieve analysis. ln a sieve analysis, a sample of dry aggregate of known weight is separated through a series of sieves with progressively smaller openings. Once separated. the weight of particles retained on each sieve is measured and compared to the total sample weight Particle size distribution is then expressed as a percent retained by weight on each sieve size. Results are usually expressed in tabular or ,graphical format. The typical graph uses the percentage of aggregate by weight passing a certain sieve size on the y-axis and the sieve size raised to the nth power (n = 0.45 is typically used) as the x-axis units. The maximum density appears as a straight line from zero to the maximum aggregate size (the exact location of this line is somewhat debatable,

Grading refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because grading and size affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. In general. if the water-cement ratio is chosen correctly. a wide range in p;radinj!, can be used without a major effect on strength. When gap-graded aggregate are specified. certain particle sizes of aggregate are omitted from the size continuum. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. Close control of mix proportions is necessary to avoid segregation.

Mechanical properties of aggregates:

Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured. angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently the cement content must also be increased to maintain the water-cement ratio.

Generally, flat and elongated particles are avoided or are limited to about 15 percent by weight of the total aggregate. Unit-weight measures the volume that graded aggregate and the voids between them will occupy in concrete. The void content between particles affects the amount of cement paste required for the mix. Angular aggregate increase the void content. Larger sizes of well-graded aggregate and improved grading decrease the void content

Absorption and surface moisture of aggregate are measured when selecting aggregate-because the internal structure of aggregate is made up of solid material and voids that may or may not contain water, The amount of water in the concrete mixture must be adjusted to include the moisture conditions of the aggregate.

Abrasion and skid resistance of an aggregate are essential when the aggregate is to be used in concrete constantly subject to abrasion as in heavy-duty floors or pavements, Different minerals in the aggregate wear and polish at different rates. Harder aggregate can be selected in highly abrasive conditions to minimize wear.

Toughness and abrasion resistance.

Aggregates should be hard and tough enough to resist crushing. degradation and disintegration from activities such as manufacturing, stockpiling, production. placing and compaction.

Durability and soundness.

Aggregates must be resistant to breakdown and disintegration from weathering (wetting/drying]or else they may break apart and cause premature pavement distress.

Particle shape and surface texture. Particle shape and surface texture are important for proper compaction. load resistance and workability. Generally. cubic angular-shaped particles with a rough surface texture are best.

Specific gravity. Aggregate specific gravity is useful in making weight-volume conversions and in calculating the void content in compacted HJ\1A.

Cleanliness and deleterious materials.

Aggregates must be relatively clean when used in Hf-.ilA. Vegetation. soft particles. clay lumps. excess dust and vegetable matter may affect performance by quickly degrading. which causes a loss of structural support andfor prevents binder• aggregate bonding.

TESTS ON AGGREGATE: STRENGTH OF AGGREAGTE:

- Strength of aggregate influence the strength of concrete.

Strength of aggregate can be determined by the following tests.

1. AGGREGATE CRUSHING VALUE IS: 2386(Part1Vl-1963)A:

It is more popular test to determine the strength of concrete.

Procedure:

- The aggregates passing through 12.Smm and retained on 10 mm IS Sieve are oven-dried at a temperature of I 00 to 110°C for 3 to 4hrs
- The cylinder of the apparatus is filled in 3 layers, each layer ramped with 25 strokes of a tamping rod.
- The weight of aggregates is measured (Weight ·A').
- The surface of the aggregates is then leveled and the plunger inserted. The apparatus is then placed in the compression testing machine and loaded at a uniform rate so as to achieve 40t load in I 0 minutes. A fle.r this, the load is released
- The sample is then sieved through a 2.36 mm IS Sieve and the fraction passing through the sieve is weighed (Weight 'B').

Aggregate crushing value= (B/A) x 100%.

2. AGGREGATE IMPACT VALUE [AIV Test! (IS: 2386 (Part IV)-1963).

- This test is used to determine toughness of aggregate
- Toughness is measured as the resistance of the aggregate to failure by impact.

Preparation of Sample

- The test sample should passing through 12.Smm IS Sieve and retained on 10mm IS Sieve
- The sample should be oven-dried for 4hrs. at 3 temperature of 100 to 110 °C and cooled.
- The measure should be about one-third full with the prepared aggregates and tamped with 25 strokes of the lamping rod,
- Struck off the surplus aggregates. using a tamping rod as a straight edge. The net weight of the aggregates in the measure should be determined to the nearest gram (Weight 'A').

Procedure:

- The cup of the impact testing machine should be fixed firmly in position on the base of the machine and the whole of the test sample placed in it and compacted by 25 strokes of the tamping rod.
- The hammer should be raised to 380mn1 above the upper surface of the aggregates in the cup and allowed to fall freely onto the aggregates. The test sample should be subjected to a total of 15 such blows. each being delivered at an interval of not less than one second.
- The sample should be removed and sieved through a 2.36mm JS Sieve. The fraction passing through should be weighed (Weight 'B') ..
- ii) The ratio of the weight of the fines formed to the total sample weight should be

expressed as a percentage.

Aggregate Impact value= (B/A) x 100

- Aggregate impact value shall not exceed 45 % by weight - concrete structure
- Aggregate impact value shall not exceed 30 % by weight - concrete wearing

Surfaces

3. LOS ANGELS ABRASION TEST:

- It is used to determine hardness of aggregate
- Hardness of aggregate is defined as its resistance to wear or abrasion.

Procedure:

- Take 5kg (m)ofsomple for grading A.B.C.or D
- Choose the abrasive charges as per specification.
- Open the cover and feed the aggregate and steel balls in the cylinder.
- Rotate the machine at a uniform speed of 30 to 33 rpm.
- Stop the machine after designed number of revolurions.
- Remove the. dust cover and take out materials
- Separate the steel balls and sieve the material on Zmm sieve
- Take the weight of the aggregate retainedlwi}
- Calculate the percentage of loss materials = 1('"1- \vi)J wt I
- A satisfactory aggregate should have an abrasion value of not more than 30% for wearing surfaces and 50o/o for non wearing surfaces.

II. Stiffness:

- Stiffer aggregate reduces the dimensional changes due to creep and shrinkage of cement paste.

Ill. Bond strength:

- Rougher the surface texture of the particles. better the bond

IV. Shape and texture:

- Rounded aggregates ore highly workable but low yield strength
- Flaky aggregates require more cement paste and produces maximum voids
- Angular aggregates are best

V. Porosity

- The entrapped air bubbles in the rocks during their formation lead to minute holes or cavities known as pores.

- Porosity of rocks is less than 20percent~ the concrete becomes permeable and ultimately affects the bond strength between aggregate and cement paste, resistance to freezing and thawing, abrasion etc.

VI. Moisture Content

- High moisture content increases the effective water cement ratio and may render the concrete weak.

VI I. Soundness:

- Soundness is defined as the ability of aggregate to resist changes in volume as a result of changes in physical conditions.
- Porous and and weak aggregates containing undesirable matter undergo excessive volume changes which leads to the formation of crack

VIII. Fineness modulus(FM):

- Higher the fineness ofaggregate results in harsh concrete mixes and lower fineness modulus result in uneconomical concrete mixes.

IX. SPECIFIC GRAVITY:

- Specific gravity of most of the natural aggregates lies between 2.6-2.7.
- Higher the specific gravity of an aggregate. the harder and stronger it will be.

X. BULK DE'.'ISITY:

- It can be defined as the mass of material in a given volume and is expressed in kgllit
- The bulk density depends on their packing, particles shape. size. grading and moisture content
- Higher bulk density indicates fewer voids to be filled sand and cement.
- If the voids in the concrete are more the strength will be low

4. SIEVE ANALYSIS

Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregates as per IS: 2386 (Part I) - 1963. In this we use different sieves as standardized by the IS code and then pass aggregates through them and thus collect different sized particles left over different sieves

The apparatus used are -

i) A set of IS Sieves of sizes - 80mm, 63rnm. 50mm, 40nun.3 I .5mm. 25mm, 20mm, 16mm. 12.Smm, I0mm. 6.3mm.4.75mm, 3.35mm. 2.36mm, 1.18mm. 600µm, 300µm. 150µm and 75µm.

ii) Balance or scale witb an accuracy 10 measure 0.1 percent of the weight of the test sample.

The weight of sample available should not be less than the weight given below:-

Procedure to determine particle size distribution of Aggregates.

i) The test sample is dried to a constant weight at a temperature of 110 + SoC and weighed.

ii) The sample is sieved by using a set of IS Sieves.

iii) On completion of sieving. the material on each sieve is weighed

iv) Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.

v) Fineness modulus is obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

Fibers have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900s. asbestos fibers were used in concrete. ln the 1950s. the concept of composite materials came into being and fiber-reinforced concrete was one of the topics of interest. Once the health risks associated with asbestos were discovered, there was a need to find 3 replacement for the substance in concrete and other building materials. By the 1960s, steel. glass (GFRC), and synthetic fibers such as polypropylene fibers were used in concrete. Research into new fiber-reinforced concretes continues today.

QUALITIES OF WATER:

- The use ofpotable water is generally safe or 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 or any water contains large quantities ofchlorides tends to cause persistent dampness and efflorescence
- In the case of R.C.C. sea water increases the risk ofcorrosion of the reinforcement
- Water containing less than 2000ppm of dissolved solids con generally be used satisfactorily for making concrete.

- Presence of salts of zinc, copper. tin manganese and lead reduce the concrete strength.
- Sodium phosphate .sodium borate etc. acts as retarders and cause reduction in
- Sugar up to 0.05 percent by weight of water is harmless.
- Sugar up to 0. I 5 percent by weight ofcement retard the setting time. reduce the early strength and increase the 28day strength.
- Sugar up to 0.2 percent causes quick setting of cement.
- Mineral oils in concentration greater than 2 percent by weight of cement may reduce the concrete strength by 20 percent.
- Algae present in water or on the surface of aggregate either reduces 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 0.08 ppm of iron is not recommended for curing
- When aggregates are washed with water containing impurities. they get coaled with silts. salts etc, which reduces the bond strength between cement and aggregate.

Concrete:

Concrete is a chemically combined mass which is manufactured from binding materials and inert materials with water.

Quality of Water for use in Concrete:

Three water serves the following purpose:

1. To wet the surface of aggregates to develop adhesion because the cement pastes adheres quickly and satisfactory to the wet surface of the aggregates than to a dry surface.
2. To prepare a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position and
3. Water is also needed for the hydration of the cementing materials to set and harden during the period of curing.

The quantity of water in the mix plays a vital role on the strength of the concrete. Some water which have adverse effect on hardened concrete. Sometimes may not be harmless or even beneficial during mixing. So clear distinction should be made between the effect on hardened concrete and the quality of mixing water.

Potable water as mixing water:

The common specifications regarding quality of mixing water is water should be fit for drinking. Such water should have inorganic solid less than 1000 ppm. This content lead to a solid quantity 0.05% of mass of cement when w/c ratio is provided 0.5 resulting small effect on strength.

But some water which are not potable may be used in making concrete with any significant effect. Dark color or bad smell water may be used if they do not posses deleterious substances. P^H of water to even 9 is allowed if it not tastes brackish. In coastal areas where local water is saline and have no alternate sources, the chloride concentration up to 1000 ppm is even allowed for drinking. But this excessive amount of alkali carbonates and bicarbonates, in some natural mineral water, may cause alkali-silica reaction.

Determination of Suitability of Mixing Water:

A simple way of determining the suitability of such water is to compare the setting time of cement and the strength of mortar cubes using the water in question with the corresponding results obtained using known suitable or distilled water. About 10% tolerance is generally allowed. Such tests are recommended when water for which no service record is available containing dissolved solids in excess of 2000 ppm or, in excess of 1000 ppm. When unusual solids are present a test is also advisable.

The effect on concreting for different types of contamination or impurities are described belo

Suspended Solids:

Mixing water which high content of suspended solids should be allowed to stand in a setting basing before use as it is undesirable to introduce large quantities of clay and slit into the concrete.

Acidity and Alkalinity:

Natural water that are slightly acidic are harmless, but presence of humic or other organic acids may result adverse affect over the hardening of concrete. Water which are highly alkaline should also be tested.

Algae:

The presence of algae in mixing water causes air entrainments with a consequent loss of strength. The green or brown slime forming algae should be regarded with suspicion and such water should be tested carefully.

Sea Water*:*

Sea water contains a total salinity of about 3.5%(78% of the dissolved solids being NaCl and 15% $MgCl_2$ and $MgSO_4$), which produces a slightly higher early strength but a lower long-term strength. The loss of strength is usually limited to 15% and can therefore be tolerated. Sea water reduces the initial setting time of cement but do not effect final setting time.

Chloride:

Water containing large amount of chlorides tends to cause persistent dampness and surface efflorescence. The presence of chlorides in concrete containing embedded steel can lead to its corrosion.

Moisture Content of Aggregate:

Aggregate usually contains some surface moisture. Coarse aggregate rearlycontains more than 1% of surface moisture but fine aggregate can contain in excess of 10%. This water can represent a substantial proportion of the total mixing water indicating a significant importance in the quality of the water that contributes surface moisture in aggregate.

UNIT-II

CHEMICAL AND MINERAL ADMIXTURES

OVER VIEW

Concrete is being used for wide varieties of purpose make it suitable in different conditions. In these conditions ordinary concrete may fail to exhibit the require quality performance or durability. In such cases, admixture is used to modify the properties of ordinary concrete, so as to make it more suitable for any situation. The following admixtures and construction chemicals and their effects on concrete properties are dealt herewith.

Chemical admixtures

- ✓ Plasticizers
- ✓ Super plasticizers
- ✓ Accelerators
- ✓ Retarders
- ✓ Water proofers

Mineral admixture

- ✓ Fly ash
- ✓ Silica fume
- ✓ Ground granulated blast furnace slag
- ✓ Metakaolin

Admixtures

Admixture is defined as the material, other than cement, water and aggregate that is used as an ingredient of concrete and is added to the batch immediately before or during mixing.

Additive

Additive is a material which is added at the time of grinding cement clinker at the cement factory.

CHEMICAL ADMIXTURE

Some of the chemical admixture are discussed here:

Plasticizers (Water reducer)

Definition

It is a chemical admixture used during the process of fresh concrete to increase the workability of concrete without adding any extra water.

Requirement of right workability is the essence of good concrete. Concrete in different situations requires different degree of workability. A high degree of workability is required in situation like:

- ✓ Deep beams
- ✓ Thin walls structure
- ✓ Structural elements having high percentage of steel reinforcement
- ✓ Beam and column junction
- ✓ Tremie concrete
- ✓ Pumping of concrete
- ✓ Hot weather concrete
- ✓ Concrete to be conveyed for considerable distance
- ✓ Ready mix concrete industries.etc.

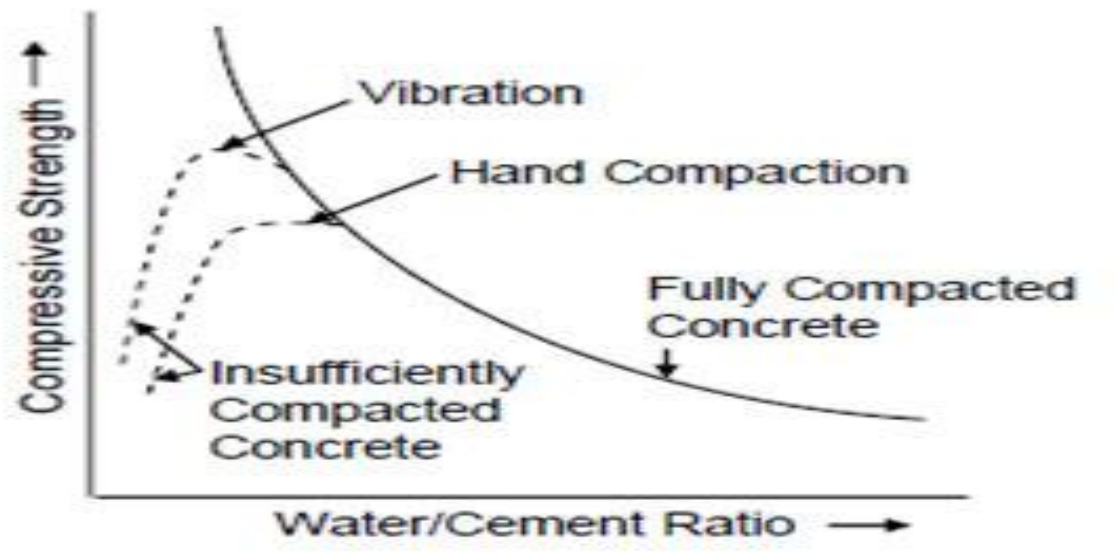
Conventional method for high workability

The conventional method followed for obtaining high workability is by

- ✓ Improving the gradation
- ✓ Use of relatively higher percentage of fine aggregate
- ✓ Increasing the cement content
- ✓ Use of extra work

Effects of use of extra water in concrete

Use of water inn concrete is harmful to concrete strength and durability and will lead to cancer in concrete. Addition of excess of water will improve the fluidity or the consistency but not the workability of concrete. The excess water will not improve the inherent good qualities such as homogeneity and cohesiveness of the mix which reduces the tendency for segregation and bleeding.

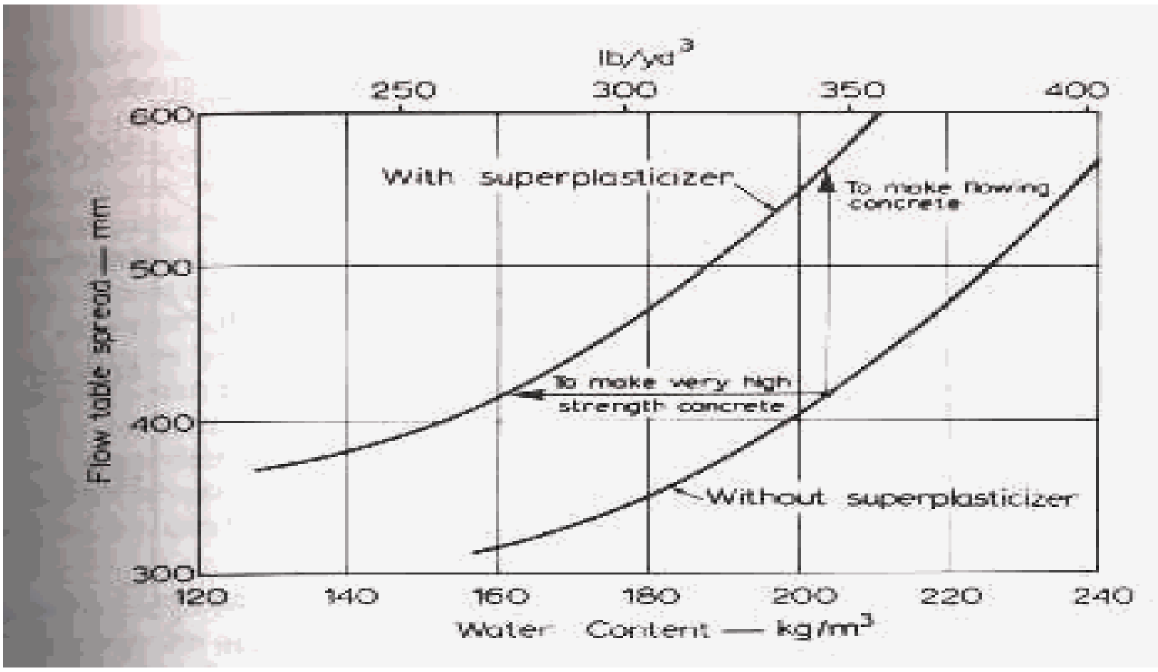


Effects of use of plasticizer in concrete

Use of plasticizers in concrete will improve the desirable qualities demanded of plastic concrete plasticizers are used for almost all the reinforced concrete and even for mass concrete to reduce the water requirement for making concrete of higher workability o flowing concrete. The use of plasticizers has become almost a universe practise to reduce water/cement ratio for the given workability which normally increases the strength. The reduction in water/cement ratio improves the durability of concrete.

Super plasticizers (high range water reducers)

Super plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation(gravel, coarse and fine sands), and to improve the flow characteristics of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste. The strength of concrete increases when the water to cement ratio decreases. However, their working mechanisms lack a full understanding, revealing in certain cases cement-super plasticizer incompatibilities. The addition of super plasticizer in the truck during transit is a fairly new development within the industry. Admixtures added in transit through automated slump management systems, such as allows concrete producers to maintain slump until discharge without reducing concrete quality.



Effects of super plasticizers on fresh concrete

The dramatic improvement in workability is not showing up when plasticizers are added to very stiff or what is called zero slump concrete at nominal dosages. A mix with an initial slump of about 2 to 3 cm can only be fluidized by plasticizers or super plasticizers at nominal dosages. A high dosage is required to fluidity no slump concrete.

Effects of super plasticizers on hardened concrete

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Accelerators

Accelerating admixtures are added to concrete to increase the rate of early strength development in concrete to:

- ✓ Permit earlier removal of formworks
- ✓ Reduce the required period of curing
- ✓ Advance the time that a structure can be placed in service
- ✓ Partially compensate for the retarding effect of low temperature during cold weather concreting
- ✓ In the emergency repair work

Some of the accelerators produce these days are so powerful that it is possible to make the cement set into stone hard in a matter of five minutes are less. With the availability of such powerful accelerators, under the water concreting has become easy. Similarly, the repair work that would be carried out to the water front structures in the region of the tidal variations has become easy. As these materials could be used up to 10^{o}C, they find an unquestionable use in cold weather concreting.

Accelerating plasticizers

Acceleratingplasticizers can be used to increase either the rate of stiffening or setting of the concrete or the rate of hardening and early strength gain to allow earlier formwork striking and de moulding. Most accelerators achieve one rather than both of these functions.

Hardening accelerators are most effective at low temperature. Accelerators can be used with super plasticisers where early age strength is required, especially at lower temperatures.

Concrete containing an accelerator will set faster than the equivalent plain concrete. The reduction in setting time is typically 1–2 hours but is affected by accelerator type, dose and temperature.

Accelerators containing calcium chloride are restricted to unreinforced concrete due to the increased risk of reinforcement corrosion.

Retarders

A retarder is an admixture which slow the setting rate of concrete, are used to counteract the accelerating effect of hot weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.

Use of retarders

The use of this admixture is defined in ASTM C494. There are two kinds of retarders, defined as Type B (Retarding Admixtures) and Type D (Water Reducing and Retarding Admixtures). The main difference between these two is the water-reducing characteristic in Type D that gives higher compressive strengths by lowering w/cm ratio.

Retarding admixtures are used to slow the rate of setting of concrete. By slowing the initial setting time, the concrete mixture can stay in its fresh mix state longer before it gets to its hardened form. Use of retarders is beneficial for:

- Complex concrete placement or grouting
- Special architectural surface finish
- Compensating the accelerating effect of high temperature towards the initial set
- Preventing cold joint formation in successive lifts.

Retarder can be formed by organic and inorganic material. The organic material consists of unrefined Ca, Na, NH_4, salts of lignosulfonic acids, hydroxycarboxylic acids, and carbohydrates. The inorganic material consists of oxides of Pb and Zn, phosphates, magnesium salts, fluorates, and borates. Commonly used retarders are lignosulfonates acids and hydroxylated carboxylic (HC) acids, which act as Type D (Water Reducing and Retarding Admixtures). The use of lignosulfonates acids and hydroxylated carboxylic acids retard the initial setting time for at least an hour and no more than three hours when used at 65 to 100 ^oF.

A study performed on the influence of air temperature over the retardation of the initial set time (measured by penetration resistance as prescribed in ASTM C 403 – 92) shows that decreasing effect with higher air temperature (Neville1995).

The use of retarding admixture has the main drawback of the possibility of rapid stiffening, where rapid slump loss will result in difficulty of concrete placement, consolidation, and finishing. An extended-set admixture has been developed as another retarding admixture. The advantages of this admixture compared to the conventional one is the capability to react with major cement constituents and to control hydration and setting characteristics of concrete while the conventional one will only react with C_3A.

Careful usage of retarder is required to avoid excessive retardation, rapid slump loss and excessive plastic shrinkage. Plastic shrinkage is the change in fresh concrete volume as surface water evaporates. The amount of water evaporation is influenced by temperature, ambient relative humidity, and wind velocity. Proper concrete curing and adequate water supply for surface evaporation will prevent plastic shrinkage cracking.

Retarding material

The most commonly known retards is calcium sulphate. It is inter ground to retard the setting of cement. The appropriate amount of gypsum to be used must be determined carefully for the given job. Use of gypsum for the purpose of retarding setting time is only recommended when adequate inspection and control is available. Otherwise addition of excess amount may cause undesirable expansion and indefinite delay in the setting of concrete. In addition to gypsum there are number of other materials found to be suitable for this purpose. They are starches, cellulose products, sugar, acids or salts of acids. These chemicals may have variable action on different types of cement when used in different quantities.

Retarding plasticizers

Retarding plasticizers or super plasticizers are important category of admixtures often used in the ready mixed concrete industry for the purposes retarding the slump loss, during high temperature, long transportation, to avoid construction or cold joints, slip form construction and regulation of heat of hydration.

Water proofers

In practice one of the most important requirements of concrete is that it must be impervious to water under two conditions, firstly, when subjected to pressure of water on one side, secondly, to the absorption of surface water by capillary action.

Water is essential to concrete production, placement, and curing. But once it fulfills its role in those processes, water is no longer concrete’s friend. Depending on its function and the nature of its exposure, concrete can of course perform well in wet environments. As a naturally porous material, though, and one that is prone to cracking, concrete is vulnerable to water infiltration. The unfortunate results can be freeze/thaw damage and deterioration due to corrosion of embedded steel reinforcement.

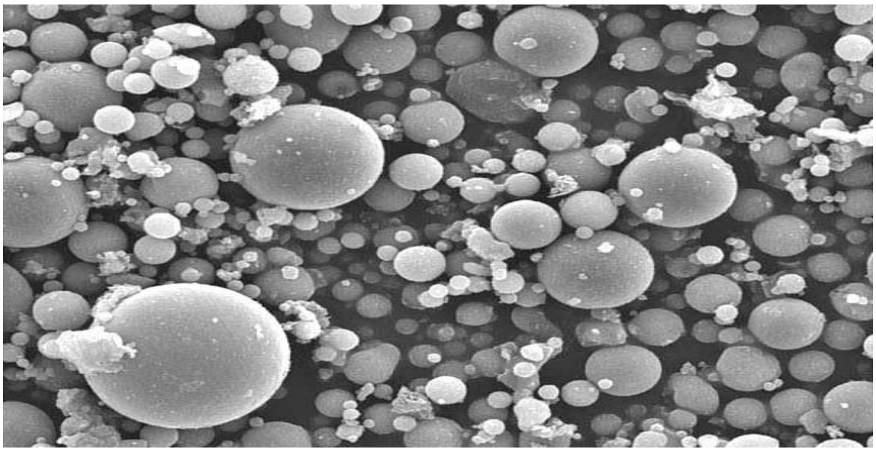
Any number of products and systems are available to help protect concrete structures from damage due to water, from coatings to sealers to membranes and more. Enormous amounts of effort and money are spent to design and apply such protection, with varying degrees of effectiveness.

Some materials like soda, potash soaps, calcium soaps, resin, vegetable oils, fats, waxes and coal tar residues are admixtures.

MINERAL ADMIXTURE

Cement is the backbone for global infrastructure development. Production of every tone of cement dioxide to the tune of about 0.87 ton. Expression it in other way, it can be said that 7% of the world’s carbon dioxide emission is attributable to Portland cement industry. There is a need to economies the use of cement. One of the practical solution to economies cement is to replace cement with supplementary cementing materials like fly ash, silica flume, slag and metakaoline.

Fly ash



Fly ash is a by product from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash.

Fly ash is collected from the exhaust gases by electrostatic precipitators or bag filters. The fine powder does resemble portland cement but it is chemically different. Fly ash chemically reacts with the by product calcium hydroxide released by the chemical reaction between cement and water to form additional cementitious products that improve many desirable properties of concrete.

All fly ashes exhibit cementitious properties to varying degrees depending on the chemical and physical properties of both the fly ash and cement. Compared to cement and water, the chemical reaction between fly ash and calcium hydroxide typically is slower resulting in delayed hardening of the concrete. Delayed concrete hardening coupled with the variability of fly ash properties can create significant challenges for the concrete producer and finisher when placing steel-troweled floors.

Two types of fly ash are commonly used in concrete: Class C and Class F. Class C are often high-calcium fly ashes with carbon content less than 2%; whereas, Class F are generally low-calcium fly ashes with carbon contents less than 5% but sometimes as high as 10%. In general, Class C ashes are produced from burning sub-bituminous or lignite coals and Class F ashes bituminous or anthracite coals.

Performance properties between Class C and F ashes vary depending on the chemical and physical properties of the ash and how the ash interacts with cement in the concrete. Many Class C ashes when exposed to water will react and become hard just like cement, but not Class F ashes. Most, if not all, Class F ashes will only react with the byproducts formed when cement reacts with water.

Use of fly ash

Fly ash in the mix replaces Portland Cement, producing big savings in concrete materials costs. Fly ash is an environmentally-friendly solution that meets or exceeds performance specifications. Fly ash can contribute to LEED (Leadership in Energy and Environmental Design) points.

Characteristics of fly ash

High fineness, low carbon content, good reactivity are the essence of good fly ash. Since fly ash is produced by rapid cooling and solidification of molten ash, a large portion of components comprising fly ash particles are in amorphous state.

The amorphous characteristics greatly contribute to the pozzolonic reaction between cement and fly ash.

Classification of fly ash

ASTM (American Standards for Testing of Machine) broadly classifies fly ash into two classes:

- ✓ Class F
- ✓ Class C

Class F:

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 20% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime—mixed with water to react and produce cementitious compounds. Alternatively, adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geo polymer.

Class C:

Fly ash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash hardens and gets stronger over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator Alkali and sulfate (SO
4) contents are generally higher in Class C fly ashes.

At least one US manufacturer has announced a fly ash brick containing up to 50% Class C fly ash. Testing shows the bricks meet or exceed the performance standards listed in ASTM C 216 for conventional clay brick. It is also within the allowable shrinkage limits for concrete brick in ASTM C 55, Standard Specification for Concrete Building Brick.

It is estimated that the production method used in fly ash bricks will reduce the embodied energy of masonry construction by up to 90%. Bricks and pavers were expected to be available in commercial quantities before the end of 2009

Effect of fly ash on fresh concrete

The use of good quality fly ash with a high fineness and low carbon content reduces the water demand of concrete and, consequently, the use of fly ash should permit the concrete to be produced at a lower water content when compared to a portland cement concrete of the same workability.

Although the exact amount of water reduction varies widely with the nature of the fly ash and other parameters of the mix, a gross approximation is that each 10% of fly ash should allow a water reduction of at least 3%. A well-proportioned fly ash concrete mixture will have improved workability when compared with a portland cement concrete of the same slump. This means that, at a given slump, fly ash concrete flows and consolidates better than a conventional portland cement concrete when vibrated.

The use of fly ash also improves the cohesiveness and reduces segregation of concrete. The spherical particle shape lubricates the mix rendering it easier to pump and reducing wear on equipment.Fly ash is a by product from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash.

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Concrete containing low-calcium (Class F) fly ashes generally requires a higher dose of air-entraining admixture to achieve a satisfactory air-void system. This is mainly due to the presence of unburned carbon which absorbs the admixture. Consequently, higher doses of air-entraining admixture are required as either the fly ash content of the concrete increases or the carbon content of the fly ash increases.

The carbon content of fly ash is usually measured indirectly by determining its loss-on-ignition (LOI). The increased demand for air entraining admixture should not present a significant problem to the concrete producer provided the carbon content of the fly ash does not vary significantly between deliveries. It has been shown that as the admixture dose required for a specific air content increases, the rate of air loss also increases.

Effect of fly ash on hardened concrete

The effect on compressive strength of replacing a certain mass of portland cement with an equal mass of low-calcium (Class F) fly ash and maintaining a constant w/cm. As the level of replacement increases the early-age strength decreases. However, long-term strength development is improved when fly ash is used and at some age the strength of the fly ash concrete will later ages.

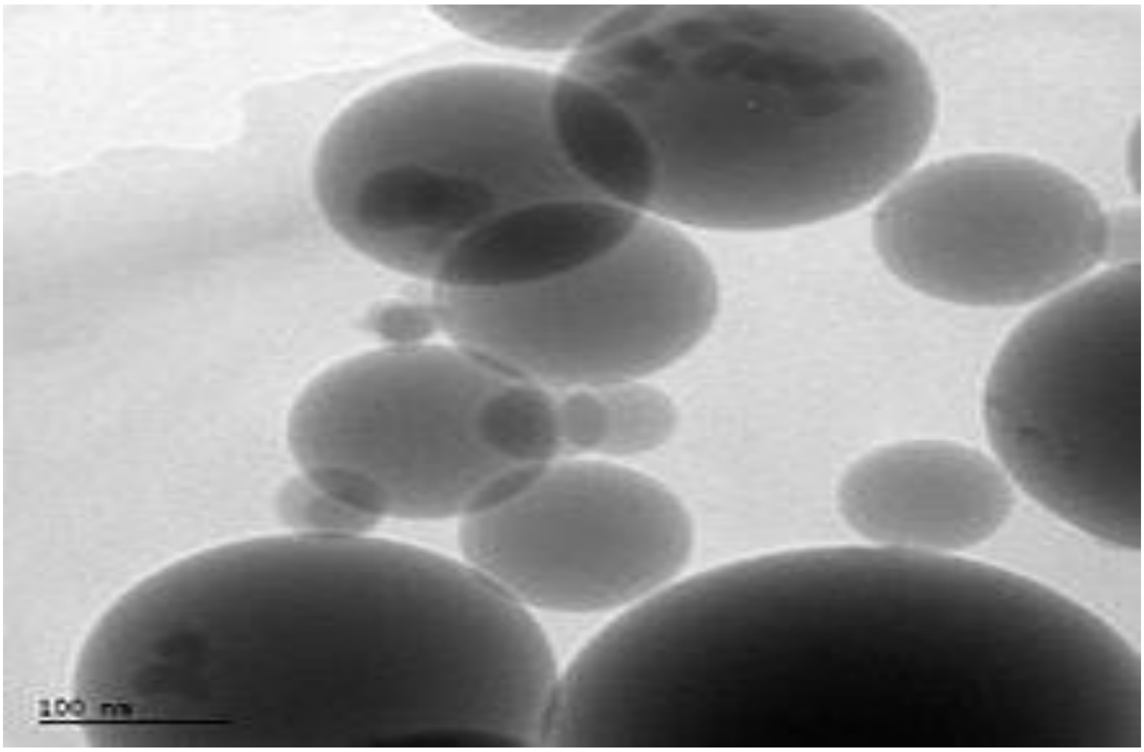
In large sections, or in concrete placed at high temperatures, the difference in the early-age insitu strength of concretes with and without fly ash may be much lower than that predicted on the basis of test specimens stored under standard laboratory conditions. It follows that in small sections placed in cold weather, the strength gain of fly ash concrete could be lower than that predicted on the basis of cylinders stored under standard conditions.

Given the high sensitivity of fly ash concrete to curing temperature, especially when higher levels of fly ash are used, it may be prudent to consider the use of methods (such as temperature-matched curing or cast-in-place cylinders) to determine the in-situ strength of the concrete. If relatively high strengths are required at very early ages, it will usually be necessary to limit the amount of fly ash used unless appropriate means are taken to accelerate the early strength contribution of the fly ash (for example, use of heat-curing or accelerators, or both), especially when the concrete is placed at low temperatures.

Silica fume

Silica fume, also known as microsilica, (CAS number 69012-64-2, EINECS number 273-761-1) is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete.

It is sometimes confused with fumed silica (also known as pyrogenic silica, CAS number 112945-52-5). However, the production process, particle characteristics and fields of application of fumed silica are all different from those of silica fume.



Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements stem from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste.

Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions and those of humid continental roadways and runways (because of the use of deicing salts) and saltwater bridges.

Characteristics of silica fume

Silica fume or micro silica is an important new material, its characteristics are,

- ✓ Micro silica is initially produced as an ultrafine undensified powder
- ✓ At least 85% SiO_2 content.
- ✓ Mean particle size between 0.1 and 0.2 micron
- ✓ Minimum specific surface area is 15000 m^2/kg
- ✓ Spherical particle shape.

Available forms of silica fume

Micro silica is available in the following forms

- ✓ Undensified forms with bulk density of 200-300 kg/m^3

- ✓ Densified forms with bulk density of 500-600 kg/m^3
- ✓ Slurry forms with density 1400 kg/m^3
- ✓ Slurry is produced by mixing undersified micro silica powder and water In equal proportions by weight. Slurry is the easiest and most practical way to introduce micro silica into the concrete mix
- ✓ Surface area 15-20 m^2/g
- ✓ Standard grade slurry pH value 4.7, specific gravity 1.3 to 1.4, dry content of micro silica 48 to 52%.

Effects of silica fume on fresh concrete

Water demand increases is proportion to the amount of micron silica added. The increase in water demand of concrete containing micro silica will be about 1% for every 1% of cement substituted.

Therefore, 20mm maximum size aggregate concrete, containing 10% micro silica will have an increased water content of about 20lit/m^3. Measures can be taken to avoid this increase by adjusting the aggregate grading and using super plasticizers.

The addition of micro silica will lead to lower slump but more cohesive mix. The micro silica makes the fresh concrete sticky in nature and hard to handle.

It was also found that there was large reduction in bleeding and concrete with micro silica could be handled and transported without segregation.

Effects of silica fume on hardened concrete

Concrete containing micro silica showed outstanding characteristics in the development of strength. It has been also found out that modulus of elasticity of micro silica concrete without micro silica at the same level of compressive strength. Concrete with micro silica shows there is improvements in durability. But there are some contradictions, particularly with reference to resistance against frost damage. Silica fume is effective for alkali-aggregate reaction; however, addition of silica fume in small quantities actually increases the expansion.

Ground granulated blast furnace slag

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder.

The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in theblast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production the flux consists mostly of a mixture of limestone and forsterite or in some cases dolomite.

In the blast furnace the slag floats on top of the iron and is decanted for separation. Slow cooling of slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates. To obtain a good slag reactivity or hydraulicity, the slag melt needs to be rapidly cooled or quenched below 800 °C in order to prevent the crystallization of merwinite and melilite.

To cool and fragment the slag a granulation process can be applied in which molten slag is subjected to jet streams of water or air under pressure. Alternatively, in the pelletization process the liquid slag is partially cooled with water and subsequently projected into the air by a rotating drum. In order to obtain a suitable reactivity, the obtained fragments are ground to reach the same fineness as Portland cement.

The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase incompressive strength.

The MgO and Al_2O_3 content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. Several compositional ratios or so-called hydraulic indices have been used to correlate slag composition with hydraulic activity; the latter being mostly expressed as the binder compressive strength.

The glass content of slags suitable for blending with Portland cement typically varies between 90-100% and depends on the cooling method and the temperature at which cooling is initiated.

The glass structure of the quenched glass largely depends on the proportions of network-forming elements such as Si and Al over network-modifiers such as Ca, Mg and to a lesser extent Al.

Increased amounts of network-modifiers lead to higher degrees of network de-polymerization and reactivity.

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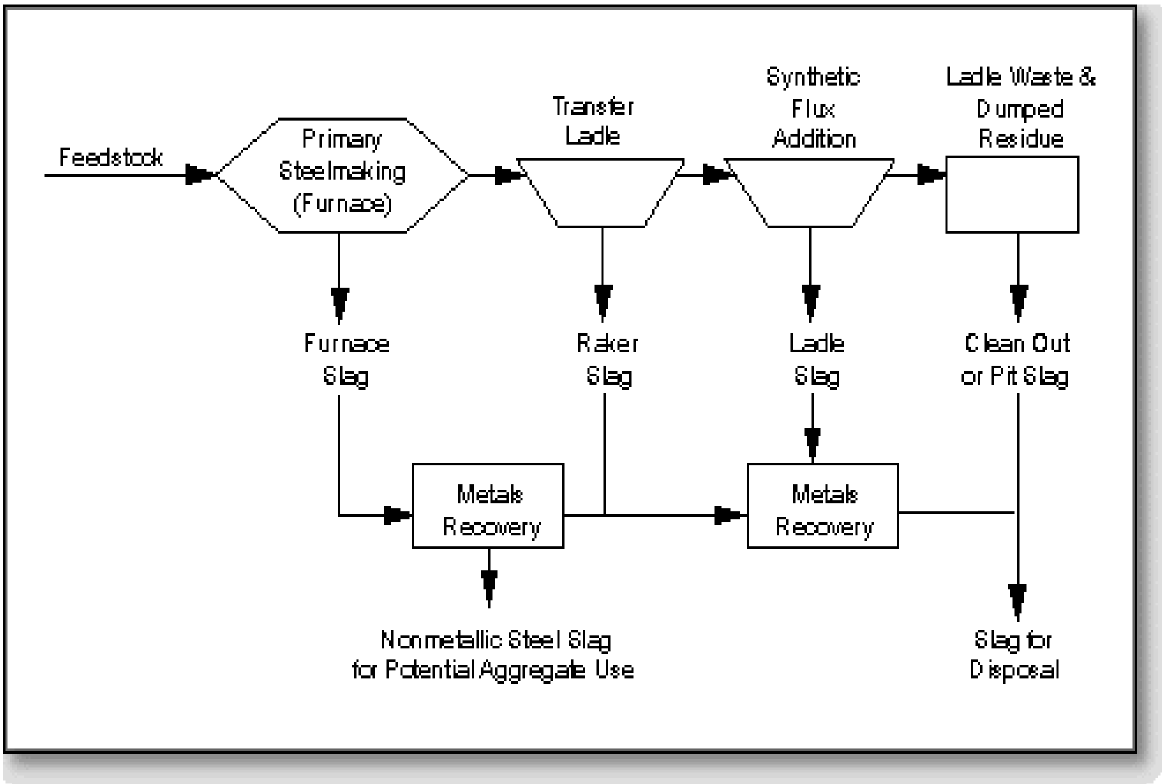
Methods of making blast furnace slag



- **Air-Cooled Blast Furnace Slag**

If the liquid slag is poured into beds and slowly cooled under ambient conditions, a crystalline structure is formed, and a hard, lump slag is produced, which can subsequently be crushed and screened.

- **Expanded or Foamed Blast Furnace Slag**

If the molten slag is cooled and solidified by adding controlled quantities of water, air, or steam, the process of cooling and solidification can be accelerated, increasing the cellular nature of the slag and producing a lightweight expanded or foamed product. Foamed slag is distinguishable from air-cooled blast furnace slag by its relatively high porosity and low bulk density.

- **Pelletized Blast Furnace Slag**

If the molten slag is cooled and solidified with water and air quenched in a spinning drum, pellets, rather than a solid mass, can be produced. By controlling the process, the pellets can be made more crystalline, which is beneficial for aggregate use, or more vitrified (glassy), which is more desirable in cementitious applications. More rapid quenching results in greater vitrification and less crystallization.

- **Granulated Blast Furnace Slag**

If the molten slag is cooled and solidified by rapid water quenching to a glassy state, little or no crystallization occurs. This process results in the formation of sand size (or frit-like) fragments, usually with some friable clinkerlike material.

The physical structure and gradation of granulated slag depend on the chemical composition of the slag, its temperature at the time of water quenching, and the method of production. When crushed or milled to very fine cement-sized particles, ground granulated blast furnace slag (GGBFS) has cementitious properties, which make a suitable partial replacement for or additive to Portland cement.

Effects of GGBS on fresh concrete

The replacement of cement with GGBS will reduce the unit water content necessary to obtain the same slump. This reduction of unit water content will be more pronounced with increase in slag content and also on the fineness of slag.

This is because of the surface configuration and particle shape of slag being different than cement particle. In addition, water used for mixing is not immediately lost, as the surface hydration of slag is slightly slower than that of cement.

Effects of GGBS on hardened concrete

The use of slag leads to the enhancement of intrinsic properties of concrete in both fresh and hardened conditions. The major advantages recognized are:

- ✓ Reduce heat of hydration
- ✓ Refinement of pore structures
- ✓ Reduce permeability to the external agencies
- ✓ Increased resistance to chemical attack

Uses of GGBS

GGBS cement can be added to concrete in the concrete manufacturer's batching plant, along with Portland cement, aggregates and water. The normal ratios of aggregates and water to cementitious material in the mix remain unchanged. GGBS is used as a direct replacement for Portland cement, on a one-to-one basis by weight. Replacement levels for GGBS vary from 30% to up to 85%. Typically 40 to 50% is used in most instances.

The use of GGBS in addition to Portland cement in concrete in Europe is covered in the concrete standard EN 206:2013. This standard establishes two categories of additions to concrete along with ordinary Portland cement: nearly inert additions (Type I) and pozzolanic or latent hydraulic additions (Type II). GGBS cement falls in the latter category. As GGBS cement is slightly less expensive than Portland cement, concrete made with GGBS cement will be similarly priced to that made with ordinary Portland cement.

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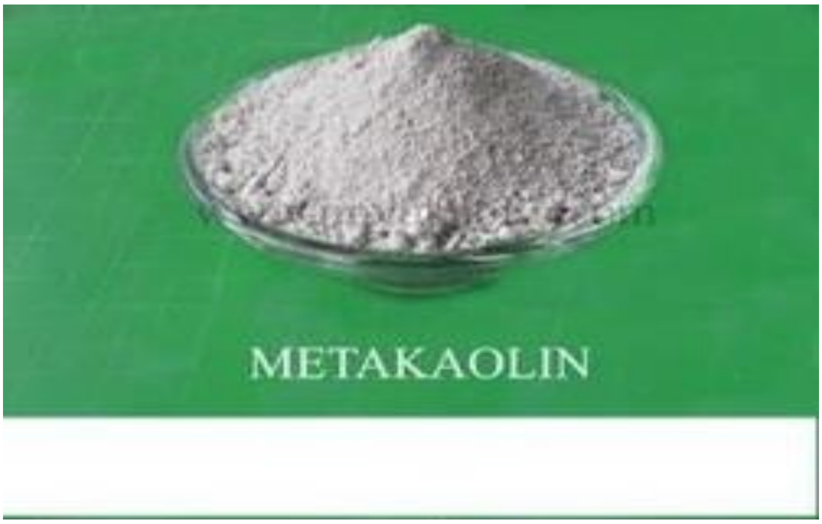
Metakaolin



Metakaolin is a de-hydroxylated form of the clay mineral kaolinite. Stone that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume.

The T-O clay mineral kaolinite does not contain interlayer cations or interlayer water. The temperature of de-hydroxylation depends on the structural layer stacking order. Disordered kaolinite de-hydroxylates between 530 and 570 °C, ordered kaolinite between 570 and 630 °C.

Dehydroxylated disordered kaolinite shows higher pozzolanic activity than ordered. The dehydroxylation of kaolin to metakaolin is an endothermicprocess due to the large amount of energy required to remove the chemically bonded hydroxyl ions. Above the temperature range of dehydroxylation, kaolinite transforms into metakaolin, a complex amorphous structure which retains some long-range order due to layer stacking.

Much of the aluminum of the octahedral layer becomes tetrahedrally and pentahedrally coordinated. In order to produce a pozzolan(supplementary cementitious material) nearly complete de-hydroxylation must be reached without overheating, i.e., thoroughly roasted but not burnt. This produces an amorphous, highly pozzolanic state, whereas overheating can cause sintering, to form a dead burnt, nonreactive refractory, containing mullite and a defect Al-Si spinel.

Reported optimum activation temperatures vary between 550 and 850 °C for varying durations, however the range 650-750 °C is most commonly quoted. In comparison with other clay minerals kaolinite shows a broad temperature interval between dehydroxylation and recrystallization, much favoring the formation of metakaolin and the use of thermally activated kaolin clays as pozzolans. Also, because the octahedral layer is directly exposed to the interlayer (in comparison to for instance T-O-T clay minerals such as smectites), structural disorder is attained more easily upon heating.

Metakaolin Chemical Composition	Wt %
$SiO_2 + Al_2O_3 + Fe_2O_3$	>97.0
Sulphur Trioxide (SO_3)	<0.50
Alkalies (as Na_2O, K_2O)	<0.50
Loss on Ignition	<1.00
Moisture Content	<1.00

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Air-entraining Admixtures

Air entrained concrete is made by mixing a small quantity of air entraining agent or by using air entraining cement,

These air entraining agents incorporate millions of non-coalescing air bubbles, which will act as flexible ball bearing and will modify the properties of plastic concrete regarding workability. segregation. bleeding and finishing quality of concrete. I

It also modifies the properties or hardened concrete regarding its resistance to frosI action and penneability.

The air voids present in concrete can be brought under two groups.

(a) Entrained air

(b) Entrapped air

Entrained air is intentionally incorporated. minute spherical bubbles of size ranging from 5 microns 10 80 microns distributed evenly in the entire mass of concrete.

The entrapped air is the voids present in the concrete due to insufficient compaction, Their size may range front 10 to 1000 microns or more and they are not uniformly distributed throughout the concrete mass.

Air entraining agents

The following types of air entraining agents are used for making air entrained concrete.

(a) Natural wood resins

(b) Animal and vegetable fats and oils. such as tallow. olive oil and their fuuy acids such as stearic and oleic acids.

(c) Various welting agents such as olkoli soils or sulphated and sulphonated organic compounds.

(d) Water soluble soaps of resin acids. and animal and vegetable fatty acids.

Factors affecting amount of air entrainment

The manufacture of air entrained concrete is complicated by the fact that the amount of air entrainment in a mix is affected by many factors: the important ones are:

(a) The type and quantity of air entraining agent used.

(b) Water/ cement ratio of the mix

(c) Type and grading of aggregate.

(d) Mixing time

(e) The temperature

(f) Type of cement

(g) Influence of compaction

(h) Admixtures other than air entraining agent used.

The Effect or Air Entrainment on the Properties of Concrete

Air entrainment will effect directly the following three properties of concrete:

(a) Increase resistance to freezing and thawing

(b) Improvement in workability

(c) Reduction in strength.

Damp-proofing and Waterproofing Admixture

- Waterproofing admixtures may be obtained in powder. paste or liquid form and may consisl of pore filling or water repellent materials.

- The chief materials in the pore filling class are silicate of soda. aluminium and zinc sulphates and aluminium and calcium chloride.

- Waterproofing admixtures may contain butyl stearate, the action of which is similar to

Gas forming Agents

- A gas forming agent is a chemical admixture such as aluminum powder.
- It reacts with the hydroxide produced in the hydration of cement of cement lo produce minute bubbles of hydrogen gas throughout the mix.
- Usually unpolished aluminum powder is preferred.
- The amount added ore usually 0.005 to 0.02 per cent by weight of cement which is about one teaspoonful to a bag of cement,
- Aluminum powder is also used as an admixture in the production of light weight concrete.

Air-detraining agents

- There have been cases where aggregates have released gas into or caused excessive air entrainment, in plastic concrete which made it necessary 10 use an admixture capable of dissipating the excess of air or other gas.
- lit may be required to remove a part ofthe entrained air from concrete mixture.
- Tributyl phosphate is the most widely used air-detraining agent
- To reduce the alkali-aggregate reaction are aluminum powder and lithiunt salts.

Corrosion Inhibiting

- Calcium lignosulphonate decreased the rate of corrosion of steel embedded. in the concrete. when the steel reinforcement in concrete is subjected 10 alternating or direct current.

- Sodium nitrate and calcium nitrite have been found to be efficient inhibitors of corrosion of steel in autoclaved products.

Bonding Admixtures

- Bonding admixtures are water emulsions of several organic materials that are mixed with cement or mortar grout for application 10 an old concrete surface.

The commonly used bonding admixtures are made from natural rubber, synthetic rubber or front any organic polymers.

- Bonding admixtures fall into l\\VO general categories, namely, re-ernulsifiable types and non-re-emulsifleble types. The latter is better suited for external application since it is resistant to water,

Workability Agents

Workability is one of the most important characteristics of concrete. specially under the following circumstances:

(a) If the concrete is to be placed around closely placed reinforcement. deep beams thin sections etc.

(b) Where special means of placement are required such as termite, chute or pumping methods.

(c) If the concrete is harsh because of poor aggregate characteristics or grading

(d) For making high strength concrete when \\1/c ratio is very low.

Some admixtures can be used to improve workability, The materials used as workability agents are:

(a) finely divided material

(b) plasticizers and super plasticizers.

(c) air-entraining agents

Colouring Agents

- Pigments are often added to produce colour in the finished concrete.
- The requirements of suitable admixtures include

(a) colour fastness when exposed to sunlight

(b) chemical stobility in the presence of alkalinity produced in the set cement

Miscellaneous Admixtures:

There are hundreds of commercial admixtures available in India.

AH these commercial admixtures can be roughly brought under two categories(a) Damp proofers (b) Surface hardeners.

Damp Proofers

(a) Cico: It is a colourless liquid which when admixed with concrete, possesses the properties of controlling setting time, promoting raid hardening, increasing strength and rendering the concrete waterproof

(b) Feb-Mtx-Admls: It is a light yellow coloured liquid claimed to impart waterproofing quality to concrete and increase workability and bond.

(c) Cc,,u!t: It is a waterproofing admixture, The recommended dose is 3 per cent by weight of cement.

Surfare Hardeners

Metal Crete:, Ferrocrete, Metal Crete Steel Patch etc are used as surface hardeners which improves resistance o wear. corrosion etc.

Construction Chemicals

There are other chemicals not used as admixtures but used to enhance the performance of concrete, or used in concrete related activities in the field of construction. Such chemicals are called construction chemicals or building chemicals. They area.

- Concrete Curing Compounds
- Polymer Bonding Agents
- Polymer Modified Mor1ar for Repair and Maintenance
- Mould Releasing Agents
- Installation Aids
- Floor Hardners and Dustproofers
- Non-Shrink High Strength Grout
- Surface Retarders

Mineral admixtures

There are inorganic materials that also have pozzolanic or latent hydraulic properties. These very fine-grained materials are added to the concrete mix to improve the properties or concrete (mineral admixtures)

1. Fly ash:

A byproduct of coal fired electric generating plants. it is used to partially replace Portland cement (by up to 60% by mass). The properties of fly ash depend on the type of coal burnt. In general, silicious fly ash is pozzolanic .. while calcareous fly ash has latent hydraulic properties.

2. Ground granulated blast furnace slag (GGBFS or G·GBS):

A byproduct of steel production, is used to partially replace Portland cement (by up to 80% by mass). It bas latent hydraulic properties.

3. Silica-11 fume:

A by-product of the production of silicon and ferrosilicon alloys. Silica fume is similar to ay ash. but has a particle size I 00 times smaller. This results in a higher surface to volume ratio and a much raster pozzolanic reaction. Silica fume is used to increase strengthand durability or concrete.but generallyrequires the use or superplasticizers for workability.

4. High Reactivity Metakaolin (HRM):

Metakaolin produces concrete with strength and durability similar to concrete made wiih silica fume. While silica fume is usuaJly dark gray or black in color, high reactivity metakaolin is usually bright white in color. making it the preferred choice for architectural concrete where appearance is important.

CONCRETE

Concrete-An artificial stone-like material used for various structural purposes. It is made by mixing cement and various aggregates. such as sand. pebbles. gravel. shale. etc .. with water and allowing the mixture lo harden by hydration.

Cement Concrete:

The concrete means a mixture of a binding material, aggregates as filler materials and water, There are various varieties of concrete like cement concrete, lime concrete and mud concrete.

The cement concrete is a mixture of cement; fine aggregate like sand: coarse aggregate like crushed rocks .pebbles etc. and water, which when placed in the skeleton of forms and allowed to cure becomes hard stone like a stone.

Advantages of concrete:

1. It has sufficient plasticity for working
2. Ingredients are locally and easily available
3. Fresh concrete can be easily moulded into durable structural members of various sizes and shapes
4. It hardens with age. Hardening continues for a long time.
5. It has high compressive strength

6. Free from corrosion and less affected by atmospheric agents.
7. Good sound proofing material
8. Less maintenance cost
9. More economical than other materials
10. More durable and not liable to decay.

Disadvantages:

1. Very weak in tension
2. Tendency to shrink
3. Tendency to be porous
4. Due to low coefficient of thermal expansion. chance of cracks will be there.
5. De-ad weight is more
6. Requires more time to cure and to develop the needed strength.

Factors affecting the Workability

I. Type of Super plasticizers

- The higher the molecular weight the higher is the efficiency.

2. Dosage

- Higher dosage is said to have affected the shrinkage and creep properties.

3. Mix Co111eosltlon

- Wener the mix better is the dispersion of cement groins and hence better workability.

4. Variability in Cement Composition

- The variability in cement with respect to compound composition. in particular CJA content. C1S!C2S ratio, fineness of cement. alkali content and gypsum content are responsible for the lack of compatibility

Slit Problems In the use of Super plasticizer:-

- Slump of reference mix (i.e .• concrete without plasticizer)
- Inefficient laboratory mixer for trial.
- Sequence of addition of plasticizer
- Problem with crusher dust
- Problem with crushed sand
- Compatibility with cement
- Selection of plasticizer and superplasticizer
- Determination of dosage
- Slump loss
- Casting of cubes
- Compacting at site
- Segregation 30d bleeding
- Finishing
- Removal of formwork

Effect of Super plasticizers on the Properties of Hardened Concrete

- Plasticizers or super plasticizers do not participate in any chemical reactions with cement or blending material used in concrete.

- Their actions are only physical in fluidizing the mix made even with low water content

- Plasticizers and superplasticizers improve the workability, compactability and facilitate reduction in w/c ratio, and thereby increase the strength of concrete. it contributes to the alround improvement in the properties of hardened concrete.

- At the same wk: ratio. Super plasticizers do not considerably modify the drying shrinkage of concrete. Al the same consistency they sometime reduce drying shrinkage appreciably.

- Superplasricizers owing to the reduction in \v/c ratio. reduce the penetration of chlorides and sulphate into the concrete and therefore. improve their resistance to the de-icing effect of salt or sea water,

- For the same reason. the resistance to sulphate attack is also improved.

Retarders

- A. retarder is an admixture that slows down the chemical process of hydration so that concrete remains plastic and workable for a longer time than concrete without the retarder.

- Retarders are used to overcome the accelerating effect of high temperature on setting properties of concrete in hot weather concreting.

- The retarders are used in casting and consolidating large number of pours 'vithout the formation of cold joints They are also used in grouting oil wells.

- The most conunonly known retarder is calcium sulphate. It is interground to retard the setting of cement.

- Common sugar is one of the most effective retarding agents used as an admixture for delaying the setting time of concrete without detrimental effect on the ultimate strength. Addition of excessive amounts \\~I) cause indefinite delay in setting.

Retarding Plasticizers

- It is mentioned earlier that all the plasticizers and superplasticizers by themselves show certain extent of retardation.

- Retarding plasticizers are used in the Ready mixed concrete industry for the purposes of retaining the slump loss, during high temperature, long transportation. to avoid construction or cold joints. slip form construction and regulation of heat of hydration.

- On account of heterogeneous nature and different molecular weight of retarders used wub plasticizers, they tend to separate out.

Accelerators

Accelerating admixrures are added to concrete to increase the rate of early strength development in concrete to

- permit earlier removal of formwork
- reduce the required period of curing
- advance the time that a structure can be placed in service:

- partially compensate for the retarding effect of low· temperature during cold weather concreting.
- in the emergency repair work

The recent studies have shown that calcium chloride is harmful for reinforced concrete and prestressed concrete.

Accelerating Plasticizers

When accelerating superplasticizers added to concrete strength will increase the accelerating materials added to plasticizers or superplasticizers are iriethenolamine chlorides. calcium nutria. nitrates and flousilicates etc.

UNIT-III

PROPORTIONING OF CONCRETE MIX

CONCRETE MIX DESIGN

Concrete mix design is defined as the appropriate selection and proportioning of constituents to produce a concrete with pre-defined characteristics is the fresh and hardened states. In general, concrete mixes are designed in order to achieve a define workability, strength and durability.

The selection and proportioning of materials depend on:

- The structure requirements of the concrete
- The environment to which the structure will be exposed
- The job site conditions, especially the methods of concrete
  - ✓ Production
  - ✓ Transport
  - ✓ Placement
  - ✓ Compaction and
  - ✓ Finishing

Principle of concrete mix design

There have been many methods developed from the simple volumetric batching to prescribed rules to the highly complicated using computer simulations. In all cases, some or all of the following parameters need to be specified from the outset to enable a concrete to be designed for a particular purpose; maximum water-cement (w/c) ratio, minimum cement content, air content, slump, maximum size of aggregate, and strength requirement. Estimating the required batch weights for the concrete involves a sequence of logical straightforward steps whether based on a series of trial mixes, computer simulations, sound rule of thumb advice or a combination of all three.

An essential part of mix design is to minimise voids in order to produce a closed structure. It is assumed that any voids (micro- not entrapped air) within the concrete will be filled with water. By minimising these a lower water content and, for a given w/c ratio, cement content are needed. However, the concrete must contain enough fine material (less than say 63 micron) so that the voids become filled with hydration products from the cement, additions, admixture and water combination. The pore structure resulting determines the concrete's resilience to carbonation, chloride ingress etc. Inadequate fines will lead to harsh concrete that has a tendency to entrap air. In comparison, high levels of fines can lead to cohesive mixes which can entrap air.

The volume of fines needed for a closed structure increases with the size of the coarse aggregate. Fines are derived from the cements and additions, the smaller sand fraction and crushed rocks etc.

Design of concrete mixes involves determination of the proportions of the given constituents, namely, cement, water, coarse and fine aggregates and admixtures, if any, which would produce concrete possessing specified properties both in the fresh and hardened states with the maximum overall economy.

Workability is specified as the important property of concrete in the fresh state; for hardened state compressive strength and durability are important. The mix design is, therefore, generally carried out for a particular compressive strength of concrete with adequate workability so that fresh concrete can be properly placed and compacted, and to achieve the required durability.

The following basic assumptions are made in design of plastic concrete mixes of medium strength :

- ✓ The compressive strength of concrete is governed by its water-cement ratio, and
- ✓ For a given aggregate characteristics, the workability of concrete is governed by its water content.

Mix design on the basis of recommended guidelines is really a process of making an initial guess at the optimum combination of ingredients and final mix proportions is obtained only on the basis of further trial mixes.

Factors in the Choice of Mix Design: -

Both IS : 456-1978[3] as well as IS : 1343-1980[4] envisage that design of concrete mix be based on the following factors:

- ✓ Grade designation,
- ✓ Type of cement
- ✓ Maximum nominal size of aggregates,
- ✓ Minimum water-cement ratio,
- ✓ Workability, and
- ✓ Minimum cement content.

Outline of Mix Design Procedure :-

The various factors for determining the concrete mix proportions and the step by step procedure for concrete mix design can be schematically represented. The basic steps involved can be summarised as follows:

- ✓ Arrive at the mean target strength from the characteristic strength specified and the level of quality control,
- ✓ Choose the water-cement ratio for mean target strength and check for requirements of durability,
- ✓ Arrive at the water content for the workability required,
- ✓ Calculate cement content and check for requirements of durability,
- ✓ Choose the relative proportion of the fine and coarse aggregates from the characteristics of coarse and fine aggregates,
- ✓ Arrive at the concrete mix proportions for the first trial mix, and
- ✓ Conduct trial mixes with suitable adjustments till the final mix composition is arrived at.

Most of the available mix design methods are essentially based on the above procedure.

Factors in the choice of mix proportioning

The mix proportion of concrete mix may be based on the following factors

- ✓ Grade designation
- ✓ Type of cement
- ✓ Maximum nominal size of aggregate
- ✓ Minimum water-cement ratio
- ✓ Workability and
- ✓ Minimum cement content

Properties of concrete related to mix design

Every concrete technologist should familiarize themselves with the most important properties of concrete

- ✓ Workability
- ✓ Durability
- ✓ Strength
- ✓ Volume change
- ✓ Air entrainment
- ✓ Density

All of these affect the finished product and knowledge of these properties is essential to produce a quality final product.

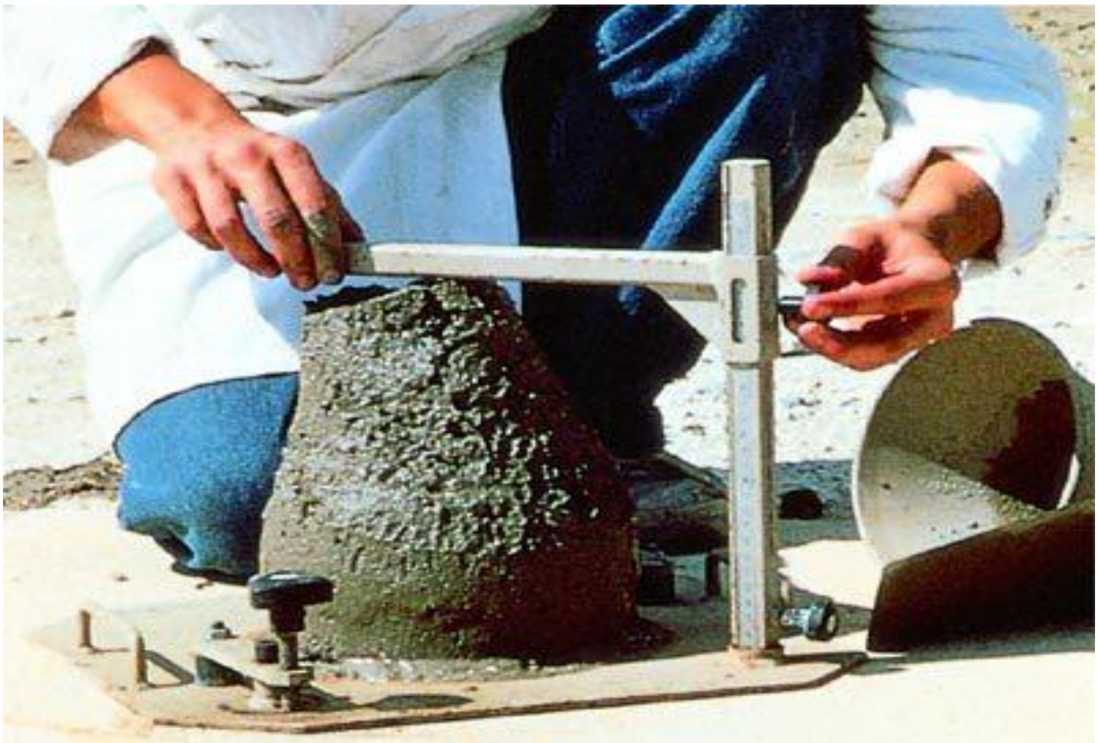
Workability

According to Granville “it is that property of the concrete which determines the amount of useful internal work necessary to produce full compaction.”

Powers defined it as “that property of plastic concrete mixture which determines the ease with which it can be placed and the degree to which it resists segregation”

ACI (American Concrete Institute) defines it as ‘that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished’.

ASTM (American Society for Testing and Materials) defines it as “that property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity”.



Importance and significance

From these above definition it is very clear that there exist no straightforward definition for the term "Workability". In very simple words we can say that workability of concrete means the ability to work with concrete. A concrete is said to be workable if

- It can be handled without segregation
- It can be placed without loss of homogeneity
- It can be compacted with specified effort
- It can be finished easily

In every construction work we use different quantitative or qualitative terms to express workability. Before specifying workability for any work a concrete technologist must keep the following things in mind.

- Type of construction work
- Method of mixing
- Thickness of section
- Extent of reinforcement
- Mode of compaction
- Distance of transporting
- Method of placing
- Environmental condition

Concrete that can be placed readily without segregation or separation in a mass dam could be entirely unworkable in a thin structural member.

Workable concrete compacted by means of high frequency vibrators would be unworkable if vibrators could not be used and hand tamping and spading were required.

Concrete having suitable workability for a pavement might be unsuitable for use in a heavily reinforced section.

Durability

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.

Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance.

Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than indoor concrete.

Durability is the ability to last a long time without significant deterioration. A durable material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement. The production of replacement building materials depletes natural resources and can produce air and water pollution.

Concrete resists weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and the properties desired. Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of the concrete.

The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years or longer. Because of their durability, most concrete and masonry buildings are demolished due to functional obsolescence rather than deterioration. However, a concrete shell or structure can be repurposed if a building use or function changes or when a building interior is renovated. Concrete, as a structural material and as the building exterior skin, has the ability to withstand nature's normal deteriorating mechanisms as well as natural disasters.

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than an indoor concrete floor.

Strength

Cement like water, aggregates and some times admixtures is one of the ingredient of concrete. The mixing of these materials in specified proportions produces concrete. Accordingly cement alone is not a building material, it is the concrete which is a building material. For a given cement and acceptable aggregates, the strength that may be developed by a workable, properly placed mixture of cement, aggregates, and water (under same mixing, curing and testing conditions) is influenced by the :

- ✓ Grading, surface texture, shape, strength, and stiffness of aggregate particles. Maximum size of aggregate.
- ✓ Strength of concrete is directly related to the structure of the hydrated cement paste. Air in concrete produces voids.
- ✓ Excess of water in concrete evaporate leave the voids in the concrete. Consequently, as the W/C ratio increases, the porosity of the cement paste in the concrete also increases. As the porosity increases, the compressive strength of the concrete decreases.
- ✓ It is not possible to design a concrete mix of high strength with cement of low strength. The variation in strength of cement is due largely to the lack of uniformity in the raw materials used in its manufacture, not only between different source of supply, but also with in a quarry.
- ✓ Further, differences in details of the process of manufacture and above all, the variation in the ash content of coal used to fire the kilin, contribute to the variation in the properties of commercial cements. This is not to deny that the modern manufacturing of cement is a highly sophisticated process.
- ✓ Upto 1975, the mass production of cement in India was only OPC-33 Grade. It was found difficulty in obtaining high strength concrete with this cement.
- ✓ The consumer has been normally finding it difficult to get consistent and ensured supply of high strength cement for prestressed concrete and certain items of precast concrete. For these special requirements BIS published IS:8112, Specification for OPC-43 Grade cement. Now, the varieties of cement manufactured in India are:
- ✓ 1. Ordinary Portland Cement (Grade OPC-33, OPC-43 and OPC-53. OPC-33 Grade almost vanished from Indian market)
  2. Portland Pozzolana Cement (PPC)
  3. Sulphate Resistance Cement (SRC)

- ✓ Test results of different brand of cement minimum to maximum compressive strength are given in the table-1.
- ✓ Due to variation of cement strength, the concrete made from these cement will also have variable strength.
- ✓ For a correct approach in the Concrete Mix Design, if the facilities at site are available, with the given set of materials, requirements and site conditions own W/C ratio v/s compressive strength of concrete curve should be developed at site itself.
- ✓ It is often observed that cement bags marked as OPC-43 Grade may really be containing cement of much higher grade. PPC cement as per IS Code is only of 33 Grade. Where as on bags it is marked as 43 MPa or 53 MPa.
- ✓ Site cement samples should be tested for its actual strength and other properties. There are instances where higher grade cement is being used even for low strength concrete, as mortar or even for plastering. This can lead to unnecessary cracking of concrete/surfaces.
- ✓ In low grade OPC, the gain in strength will continue beyond 28th day. Due to early strength gain of higher grade of OPC the concrete strength do not increase much beyond 28th day. The heat of hydration of higher grade OPC being higher, the chances of micro-cracking of concrete is much greater.
- ✓ Thus during initial setting period of concrete, the higher head of hydration can lead to damaging micro-cracking with in the concrete which may not be visible at surface. The situation can be worse when we tend to increase the quantity of the cement in concrete with a belief that such increase are better for both strength and durability of concrete.

Volume change

The resistance to deformation that makes concrete a useful material means also that volume changes of the concrete itself can have important implications in use. Any potential growth or shrinkage may lead to complications, externally because of structural interaction with other components or internally when the concrete is reinforced. There may even be distress if either the cement paste or the aggregate changes dimension, with tensile stresses set up in one component and compressive stresses in the other. Cracks may be produced when the relatively low tensile strength of the concrete or its constituent materials is exceeded.

Cracking not only impairs the ability of a structure to carry its design load but may also affect its durability and damage its appearance. In addition, shrinkage and creep may increase deflections in one member of a structure, adversely affecting the stability of the whole. These factors have to be considered in design. Volume change of concrete is not usually associated with changes that occur before the hardened state is attained. Quality and durability, on the other hand, are dependent on what occurs from the time the concrete mix has been placed in the mold.

Following hydration and hardening, cement consists of a mixture of several compounds, all chemically combined with water in different ways. The compound that has the greatest influence on the characteristics of hydrated cement, including shrinkage, is calcium silicate, which has a large internal surface area of 25 to 50 thousand square yards per pound. This internal surface is composed of the walls of the tiny pores and fissures within the physical dimensions of the specimen. (It is the character of this surface that makes hydrated cement an effective cementing agent and provides the versatility of concrete in forming bodies of high strength and almost any desired shape. When surfaces are very close to each other there is a mutual gravitation-like attraction that forms a strong "weld." When the internal surface area is high the many strong welds develop the strength and rigidity of the body.)

Thus concrete is not a solid inert mass but a vast number of small pores or capillaries that in total can account for up to 50 per cent of the volume of the concrete. During curing the pores and capillaries are usually full of water and no stresses exist. As drying takes place, three mechanisms cause shrinkage:

1. The unstable nature of newly-formed calcium silicate hydrate results in shrinkage as drying occurs; the exact nature of this mechanism is not clearly understood but it is permanent and irreversible;
2. Compressive stresses are set up in the concrete because of the development of menisci in the capillaries as drying progresses;
3. Energy changes occur at the surface of calcium silicate as the water evaporates.

These mechanisms (phenomena) acting separately or in combination cause initial drying shrinkage of the concrete. Part of it, 30 per cent or more, is irreversible.

Although the mechanism of volume change that occurs during moisture change is not fully understood, much has been learned to provide useful information for engineering purposes. When concrete is dried, the first water to be removed causes no change in volume. This is considered to be free water held in rather large "pores." With continued drying, shrinkage becomes quite large and at equilibrium in 50 per cent RH values in excess of 0.10 per cent have been recorded for some concretes.

The above behaviour is somewhat similar to that of wood (in a qualitative manner). Shrinkage values for neat cement paste have been observed in excess of 0.40 per cent; the difference of this value from that of concrete is due to various restraints. A large portion of concrete is made up of relatively inert aggregate (from 3 to 7 times the weight of cement) and this, together with reinforcement, reduces shrinkage.

In addition to internal restraints, some restraint arises from non-uniform shrinkage within the concrete member itself. Moisture loss takes place at the surface so that a moisture gradient is established. The resultant differential shrinkage is associated with internal stresses, tensile near the surface and compressive in the core, and may result in warping or cracking.

If concrete that has been allowed to dry in air at 50 per cent RH is subsequently placed in water, it will swell. Not all initial shrinkage obtained on drying is recovered, however, even after prolonged storage. For the usual range of concretes the irreversible part of shrinkage is about 30 to 60 per cent of total drying shrinkage, the lower value being more common.

Because shrinkage has such an influence on the performance of concrete structures much work has been carried out to obtain information on the factors affecting it.

Air entrainment

Air-entrained concrete contains billions of microscopic air cells per cubic foot. These air pockets relieve internal pressure on the concrete by providing tiny chambers for water to expand into when it freezes. Air-entrained concrete is produced using air-entraining portland cement, or by the introduction of air-entraining agents, under careful engineering supervision, as the concrete is mixed on the job. The amount of entrained air is usually between four and seven percent of the volume of the concrete, but may be varied as required by special conditions.

Density

The density of concrete is a measure of its unit weight. Concrete is a mixture of cement, fine and coarse aggregates, water, and sometimes some supplementary materials like fly ash, slag, and various admixtures.

A normal weight concrete weighs 2400 kg per cubic meter or 145 lbs per cubic foot (3915 lbs per cubic yard).

The unit weight of concrete (density) varies depending on the amount and density of the aggregate, the amount of entrained air (and entrapped air), and the water and cement content.

Physical properties of materials required for mix design

Cement

The important properties of cement required for mix design are strength/grade of cement and initial and final setting of cement.

Strength/grade of cement

This ordinary 'Portland' cement is used maximum in the country. It is more suitable cement for masonry and general concrete works where the members are not taken to very high stresses. It is not suitable where 'Sulphate' is in the soil or in the ground water.

43 grades of cement are used where high early strength in 1 to 28 days range is required. These days the 'Structural Engineers' propose these cements mainly for RCC works where a member takes high tensile stress.

53 grades of cement are used where high early strength in 1 to 28 days range is required. These days 'Structural Engineers' propose these cements mainly for RCC works, where a member takes high tensile stress.

The strength of 53 grade cement does not increase much after 28th day because of early gain while 33 grade cement continues to gain strength after 28th day.

In addition, due to faster hydration process, the concrete releases heat of hydration at much faster rate initially and release of heat is the highest in case of 53 grades. The heat of hydration being higher, the chances of micro-cracking of concrete is much greater. Thus during initial setting period of concrete, the higher heat of hydration can lead to the damage of micro-cracking within the concrete which may not be visible at surface.

This cracking is different from shrinkage or cracks which occur due to faster dryness of concrete in windy conditions. The situation can be worse when we tend to increase the quantity of the cement in concrete with a belief that such increments are better for both strength and durability of concrete.

Thus it is very essential to be very careful in advance that higher grade cement specially GRADE 53 SHOULD be used only where such use is warranted for making the concrete of higher strength and also where good quality assurance measures are in place by which proper precautions are taken to relieve the higher heat of hydration through chilling of aggregates or by proper curing of concrete.

Initial and final setting time of cement

Initial setting time is that time period between the time water is added to cement and time at which 1 mm square section needle fails to penetrate the cement paste, placed in the Vicat's mould 5 mm to 7 mm from the bottom of the mould.

Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm attachment does not make any impression.

1. Before commencing setting time test, do the consistency test to obtain the water required to give the paste normal consistency (P).
2. Take 400 g of cement and prepare a neat cement paste with 0.85P of water by weight of cement.
3. Gauge time is kept between 3 to 5 minutes. Start the stop watch at the instant when the water is added to the cement. Record this time (t_1).
4. Fill the Vicat mould, resting on a glass plate, with the cement paste gauged as above. Fill the mould completely and smooth off the surface of the paste making it level with the top of the mould. The cement block thus prepared is called test block.

INITIAL SETTING TIME

1. Place the test block confined in the mould and resting on the non-porous plate, under the rod bearing the needle.
2. Lower the needle gently until it comes in contact with the surface of test block and quick release, allowing it to penetrate into the test block.
3. In the beginning the needle completely pierces the test block. Repeat this procedure i.e. quickly releasing the needle after every 2 minutes till the needle fails to pierce the block for about 5 mm measured from the bottom of the mould. Note this time (t_2).

FINAL SETTING TIME

1. For determining the final setting time, replace the needle of the Vicat's apparatus by the needle with an annular attachment.
2. The cement is considered finally set when upon applying the final setting needle gently to the surface of the test block; the needle makes an impression thereon, while the attachment fails to do so. Record this time (t_3).

Fine aggregate

The important properties of fine aggregate of fine aggregate required for mix design are gradation of fine aggregate, specific gravity of fine aggregate and silt content by weight.

Gradation of fine aggregates

This experiment is carried out to find and check the gradation of the fine aggregate i.e. sand. Theconcrete consists of three basic solid materials, one is the sand whose fineness is checked byexperiment no 1, the other two materials are the coarse aggregate that is the crush while the third is the fine aggregate that is the sand.
As there are different types of sand, so we will have to judge that which type of sand is the best to be used.

The sand is differentiated on the basis of its gradation. The sand will be called graded if it consists of particles having a variety of dimensions, such type of sand is recommended for use because this type of sand will posses the capability to form a compact structure thus will have more strength as compared to fine sand.

The fine sand will also form compact structure but will increase the amount ofwater needed in concrete, which will decrease the strength of the concrete.
So the degree of gradation will decide about the sand to be used. Degree of gradation is also calledfineness modulus of sand. We find fineness modulus and compare it the standard recommendedvalues.

Apparatus

- ✓ The apparatus consists of six different types of sieves i.e. #4, #8, #16, #30, #50, and #100 sieve. The smallest sieve number is at the top and the others are arranged in ascending order. The whole apparatus is shacked for 15 minutes with the of sieve shaker. Calculations are done according to the table.
- ✓ Sieve Apparatus or sieve set
- ✓ 500 gram sample of sand
- ✓ Triple beam balance
- ✓ Brittle brush
- ✓ Empty plate

Procedure

- ✓ Take the triple beam balance and set the reading of the scale to zero.
- ✓ Take a pan and measure its weight.
- ✓ Put some sand in the pan and with the help of triple beam balance measure 500 gram of the sand.
- ✓ Put the sand in sieve #4, and start the sieve shaker for 15 minutes.
- ✓ After 15 minutes stop the shaker and separate the sieve #4 from the apparatus.
- ✓ Then with the help of triple beam balance measure the weight of retained particles, note this weight in the table.
- ✓ Then similarly measure the weight of the particles retained in each sieve and note them in the table.
- ✓ Then in the next step calculate the percentage of the weight retained on each sieve.
- ✓ In the next step find the percentage of the weight which has passed through the each sieve. For sieve#4 the total amount which entered will be 500 gram. But for the sieve #8 it will not be the same because some weight has retained by the upper sieve, so the percentage of the passed will becalculated relative to the amount which actually entered that sieve. Similarly for sieve #16 the total amount entering the sieve will be less the value for the upper sieve, similarly for other sieves the same method should be adopted for calculating the percentage of the weight passed.
- ✓ In the next column the percentage cumulated is calculated.
- ✓ This is the percentage of the weightwhich would be retained if the sand is put directly on that sieve.
- ✓ For sieve #4 it will be the same as it is, but for sieve #8 it would be the sum of the percentage retained by the sieve #4 plus that retained by itself. Similarly the percentage cumulated for other sieves is calculated, this is denoted by a_1, a_2, a_3,and so on.
- ✓ Then at the end to find the fineness modulus of the sand add the cumulated percentage of each sieve and divide it by 100, that is :
  Fineness modulus= $(a_1 + a_2 + a_3 + a_4 + a_5 + a_6)/100$

Specific gravity of fine aggregate

Apparatus

1.A balance of capacity not less than 3kg ,readable and accurate to 0.5 gm and of such a type as to permit the weighing of the vessel containing the aggregate and water .

2.A well ventilated oven to maintain a temperature of 100ºC to 110ºC

3.Pyconometer of about 1 littre capacity having a metal conical screw top with a 6mm hole at its apex . The screw top shall be water tight .

4.a means supplying a current warm air .

5.A tray of area not less than 32cm^2.

6.An air tight container large enough to take the sample.

7.Filter papers and funnel.

Procedure

- ✓ Take about 500g of sample and place it in the pycnometer.
- ✓ Pour distilled water into it until it is full.
- ✓ Eliminate the entrapped air by rotating the pycnometer on its side ,the hole in the apex of the cone being covered with a finger.
- ✓ Wipe out the outer surface of pycnometer and weigh it (W)
- ✓ Transfer the contents of the pycnometer into a tray , care being taken to ensure that all the aggregate is transferred .
- ✓ Refill the pycnometer with distilled water to the same level .
- ✓ Find out the weight (W1)
- ✓ drink water from the sample through a filter paper .
- ✓ Place the sample in oven in a tray at a temperature of 100ºC to 110º C for 24±0.5 hours ,during which period ,it is stirred occasionally to facilitate drying .
- ✓ Cool the sample and weigh it (W2)

Calculation

Apparent specific gravity = (weight of dry sample/weight of equal volume of water)

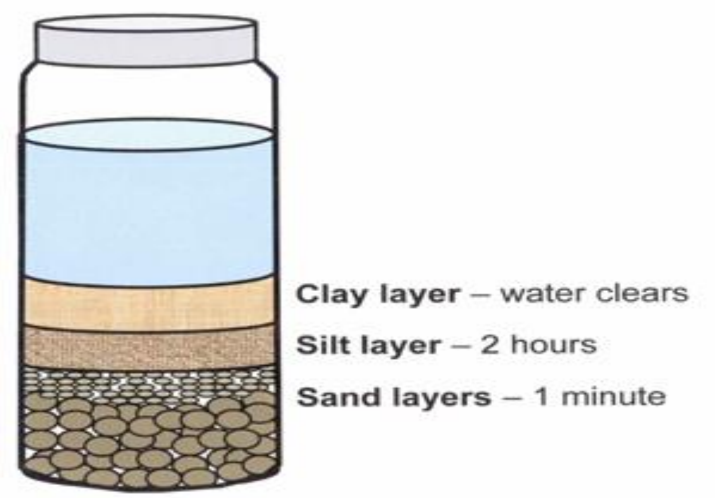
= W2/(W2- (W-W2))

Silt content by weight

There are two types of harmful substances preset in fine aggregates i.e. organic matter produced by decay of vegetable matter and/or clay and silt, which form coating thus preventing a good bond between cement and the aggregates. If present in large quantities, result in the increase water-cement ratio and finally affecting the strength of concrete.

Field test is generally conducted in order to determine the volumetric percentage of silt in natural sand for percentage up to 6%, otherwise more detailed test as prescribed by standard code are required to be conducted.

1. Fill 1% solution of common salt and water in the measuring cylinder up to 50 ml mark.
2. Now add sand to be tested to this solution till the level of the salt solution shows 100 ml mark.
3. Top up the level of salt solution up to 150 ml mark.
4. Shake the mixture of sand and salt solution well and keep it undisturbed for about 3 hours.
5. The silt being of finer particles than sand, will settle above the sand in a form of layer.
6. Measure the thickness of this silt layer.



3.5.3 Coarse aggregate

Coarse aggregate shall consist of naturally occurring materials such as gravel, or resulting from the crushing of parent rock, to include natural rock, slags, expanded clays and shales (lightweight aggregates) and other approved inert materials with similar characteristics, having hard, strong, durable particles, conforming to the specific requirements of this Section. Coarse aggregate for use in non-structural concrete applications or hot bituminous mixtures may also consist of reclaimed Portland cement concrete meeting the requirements of 901-5. Washing of this material will not be required if the requirements of 901-1.2 for maximum percent of material passing the No. 200 sieve can be met without washing. Materials substantially retained on the No. 4 sieve, shall be classified as coarse aggregate.

Maximum size of coarse aggregate

For the same strength or workability, concrete with large size aggregate will require lesser quantity of cement than concrete with a smaller size aggregate. In a mass concrete work the use of larger size aggregate will be useful due to the lesser consumption of cement. This will also reduce the heat of hydration and the corresponding thermal stresses and shrinkage cracks. But in practice the size of aggregate cannot be increased to any limit on account of the limitation in the mixing, handling and placing equipment. In large size aggregates surface area to be wetted per unit weight is less, and the water cement ratio is less which increases the strength. On the other hand in smaller size aggregates the surface area is increased which increases w/c ratio and lower strength is achieved. In general for strength upto 200 kg/cm^2 aggregates upto 40 mm may be used and for strength above 300 kg/cm^2 aggregate upto 20 mm may be used.

The following conditions decide the maximum size of coarse aggregate to be used in concrete

1. It should not be more than one fourth of the minimum thickness of the member provided that the concrete can be placed without difficulty so as to around all reinforcement thoroughly and fill the corner of the form.

2. Plump (large undressed stone embedded with others in concrete on large work) above 160 mm and upto any reasonable size may be used in plain concrete work upto a maximum limit of 20 percent by volume of concrete.
3. For heavily reinforced concrete members the nominal maximum size of the aggregate should be usually restricted to 6 mm less than the minimum clear distance between the main bar or 5 mm less than the minimum cover to the reinforcement, whichever is less.
4. Where the reinforcement is widely spaced as in solid slabs, limitations of the size of the aggregate may not be so important and the nominal maximum size may sometime be as great as or greater than the maximum cover except where porous aggregate are used.
5. For reinforced concrete work aggregates having a maximum size of 20 mm are generally considered satisfactory.

Grading of coarse aggregate

The coarse aggregate grading requirements of ASTM C 33 (AASHTO M 80) permit a wide range in grading and a variety of grading sizes. The grading for a given maximum-size coarse aggregate can be varied over a moderate range without appreciable effect on cement and water requirement of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability. Mixture proportions should be changed to produce workable concrete if wide variations occur in the coarse-aggregate grading. Since variations are difficult to anticipate, it is often more economical to maintain uniformity in manufacturing and handling coarse aggregate than to reduce variations in gradation.

The maximum size of coarse aggregate used in concrete has a bearing on the economy of concrete. Usually more water and cement is required for small-size aggregates than for large sizes, due to an increase in total aggregate surface area. The water and cement required for a slump of approximately 75 mm (3 in.) for a given water-cement ratio, the amount of cement required decreases as the maximum size of coarse aggregate increases. The increased cost of obtaining and/or handling aggregates much larger than 50 mm (2 in.) may offset the savings in using less cement. Furthermore, aggregates of different maximum sizes may give slightly different concrete strengths for the same water-cement ratio.

In some instances, at the same water-cement ratio, concrete with a smaller maximum-size aggregate could have higher compressive strength. This is especially true for high-strength concrete. The optimum maximum size of coarse aggregate for higher strength depends on factors such as relative strength of the cement paste, cement aggregate bond, and strength of the aggregate particles. The terminology used to specify size of coarse aggregate must be chosen carefully. Particle size is determined by size of sieve and applies to the aggregate passing that sieve and not passing the next smaller sieve.

When speaking of an assortment of particle sizes, the size number (or grading size) of the gradation is used. The size number applies to the collective amount of aggregate that passes through an assortment of sieves. As shown in Table 5-5, the amount of aggregate passing the respective sieves is given in percentages; it is called a sieve analysis. Because of past usage, there is sometimes confusion about what is meant by the maximum size of aggregate. ASTM C 125 and ACI 116 define this term and distinguish it from nominal maximum size of aggregate.

The maximum size of an aggregate is the smallest sieve that all of a particular aggregate must pass through. The nominal maximum size of an aggregate is the smallest sieve size through which the major portion of the aggregate must pass.

The nominal maximum-size sieve may retain 5% to 15% of the aggregate depending on the size number. For example, aggregate size number 67 has a maximum size of 25 mm (1 in.) and a nominal maximum size of 19 mm (3⁄4 in.). Ninety to one hundred percent of this aggregate must pass the 19-mm (3⁄4-in.) sieve and all of the particles must pass the 25-mm (1-in.) sieve. The maximum size of aggregate that can be used generally depends on the size and shape of the concrete member and the amount and distribution of reinforcing steel.

These requirements may be waived if, in the judgment of the engineer, the mixture possesses sufficient workability that the concrete can be properly placed without honeycomb or voids.

Grading of coarse aggregate

Aggregate is sometimes analyzed using the combined grading of fine and coarse aggregate together, as they exist in a concrete mixture. This provides a more thorough analysis of how the aggregates will perform in concrete. Sometimes mid-sized aggregate, around the 9.5 mm (3⁄8 in.) size, is lacking in an aggregate supply, resulting in a concrete with high shrinkage properties, high water demand, poor workability, poor pumpability, and poor place ability.

Strength and durability may also be affected. Fig. 5-10 illustrates an ideal gradation; however, a perfect gradation does not exist in the field—but we can try to approach it. If problems develop due to a poor gradation, alternative aggregates, blending, or special screening of existing aggregates, should be considered. Refer to Shilstone (1990) for options on obtaining optimal grading of aggregate. The combined gradation can be used to better control workability, pumpability, shrinkage, and other properties of concrete. Abrams (1918) and Shilstone (1990) demonstrate the benefits of a combined aggregate analysis:

With constant cement content and constant consistency, there is an optimum for every combination of aggregates that will produce the most effective water to cement ratio and highest strength. graded aggregates may produce higher strengths than normal aggregates used with comparable cement contents.

Because of their low fine-aggregate volumes and low water-cement ratios, gap-graded mixtures might be considered unworkable for some cast-in-place construction. When properly proportioned, however, these concretes are readily consolidated with vibration.

Shape of coarse aggregate

ROUNDED AGGREGATE

The aggregate with rounded shape has the minimum percentage of voids ranging from 32 to 33%. It gives minimum ratio of surface area to given volume and hence requires minimum water for lubrication. It gives good workability for the given amount of water and hence needs less cement for a given water cement ratio. The only disadvantages is that the interlocking between its particles is less and hence the development of bond is poor. This is why rounded aggregate is not suitable for high strength concrete and for pavements subjected to tension.

IRREGULAR OR PARTLY ROUNDED AGGREGATE

The aggregate with irregular shape has higher percentage of voids ranging from 35 to 37%. It gives lesser workability than rounded aggregate for the given water content. Water requirement is higher and hence more cement is needed for constant water cement ratio. The interlocking between aggregate particles is better than rounded aggregate but not adequate to be used for high strength concrete and pavements subjected to tension.

ANGULAR AGGREGATE

The aggregate with angular shape has the maximum percentage of void ranging from 38 to 45%. It requires more water for lubrication and hence it gives least workability for the given water cement ratio. For constant water cement ratio and workability the requirement of cement increase. The interlocking between the aggregate particles is the best and hence the development of bond is very good. This is why angular aggregate is very suitable for high strength concrete and for pavements subjected to tension.

FLAKY AGGREGATE

The aggregate is said to be flaky when its least dimension is less than $3/5^{th}$ (or 60%) of its mean dimension. Mean dimension is the average size through which th particles pass and the sieve size on which these are retained. For example, mean size of the particles passing through 25 mm sieve and retained on 20 mm sieve is (20+25)/2=22.5 mm. if the least dimension is less than 3/5 x (22.5) = 13.5 mm, then the material is classified as flaky. Flaky aggregate tends to be oriented in one plane which affects the durability.

ELONGATED AGGREGATE

The aggregate is said to be elongated when its length is greater than 180% of its mean dimension.

FLAKY & ELONGATED AGGREGATE

Aggregate is said to be flaky and elongated when it satisfies both the above conditions. Generally elongated or flaky particles in excess of 10 to 15% are not desirable.

Strength of the aggregate

Strength is a measure of the ability of an aggregate particle to stand up to pulling or crushing forces. Elasticity measures the "stretch" in a particle. High strength and elasticity are desirable in aggregate base and surface courses. These qualities minimize the rate of disintegration and maximize the stability of the compacted material. The best results for portland cement concrete may be obtained by compromising between high and low strength, and elasticity. This permits volumetric changes to take place more uniformly throughout the concrete.

Aggregate absorption

The internal pore characteristics are very important properties of aggregates. The size, the number, and the continuity of the pores through an aggregate particle may affect the strength of the aggregate, abrasion resistance, surface texture, specific gravity, bonding capabilities, and resistance to freezing and thawing action. Absorption relates to the particle's ability to take in a liquid. Porosity is a ratio of the volume of the pores to the total volume of the particle. Permeability refers to the particle's ability to allow liquids to pass through. If the rock pores are not connected, a rock may have high porosity and low permeability.

NOMINAL MIX AND DESIGN MIX

Mix design is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete of having certain minimum workability, strength and durability as economically as possible.
A mix design can be designed in two ways as explained below

1. Nominal Mix
2. Design

Nominal mix

It is used for relatively unimportant and simpler concrete works. In this type of mix, all the ingredients are prescribed and their proportions are specified. Therefore there is no scope for any deviation by the designer. Nominal mix concrete may be used for concrete of M-20 or lower. The various ingredients are taken as given in the table below

Grade	Max. quantity of dry Aggregates per 50 kg of cement	Fine Aggregate to Coarse Aggregate Ratio, by mass	Max. Quantity of water in litres
M-5	800	Generally 1:2 but may varies from 1:1.5 to 1:2.5	60
M-7.5	625		45
M-10	480		34
M-15	330		32
M-20	250		30

Design mix

It is a performance based mix where choice of ingredients and proportioning are left to the designer to be decided. The user has to specify only the requirements of concrete in fresh as well as hardened state. The requirements in fresh concrete are workability and finishing characteristics, whereas in hardened concrete these are mainly the compressive strength and durability.

Decision variables in mix design

In general, there are four variables which are influences the concrete mix design and they are:

- Water/cement ratio
- Cement content
- Relative proportion of fine aggregate and course aggregate
- Use of admixtures

Water/cement ratio

The water–cement ratio is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and form. Workability can be resolved with the use of plasticizers or super-plasticizers.

Often, the ratio refers to the ratio of water to cement plus pozzolan ratio, w/(c+p). The pozzolan is typically a fly ash, or blast furnace slag. It can include a number of other materials, such as silica fume, rice husk ash or natural pozzolans. Pozzolans can be added to strengthen concrete.

The notion of water–cement ratio was first developed by Duff A. Abrams and published in 1918. Refer to concrete slump test.

Concrete hardens as a result of the chemical reaction between cement and water (known as hydration, this produces heat and is called the heat of hydration). For every pound (or kilogram or any unit of weight) of cement, about 0.42 pounds (or 0.42 kg or corresponding unit) of water is needed to fully complete hydration reactions.

However, a mix with a ratio of 0.42 may not mix thoroughly, and may not flow well enough to be placed. More water is therefore used than is technically necessary to react with cement. Water-cement ratios of 0.45 to 0.60 are more typically used. For higher-strength concrete, lower ratios are used, along with a plasticizer to increase flowability.

Too much water will result in segregation of the sand and aggregate components from the cement paste. Also, water that is not consumed by the hydration reaction may leave concrete as it hardens, resulting in microscopic pores (bleeding) that will reduce final strength of concrete. A mix with too much water will experience more shrinkage as excess water leaves, resulting in internal cracks and visible fractures (particularly around inside corners), which again will reduce the final strength.

The 1997 Uniform Building Code specifies a maximum of 0.50 ratio when concrete is exposed to freezing and thawing in a moist condition or to de-icing chemicals, and a maximum of 0.45 ratio for concrete in a severe or very severe sulfate condition.

Cement content

Generally, the cement content itself would not have a direct role on the strength of concrete; if cement content is required to increase the workability of concrete mix for a given water-cement ratio, then the compressive strength may increase with the richness of the mix. However, for a particular water-cement ratio there would @ways be an optimum cement content resulting in 28-day compressive strength being the highest.

Increasing the cement content above the optimum value may not increase the strength of concrete specially for mixes with low water-cement ratio and larger maximum size aggregate.

Recommendations for making durable concrete in various codes of practices envisage limits for maximum water-cement ratio, minimum cement content, cover thickness, type of cement and amount of chlorides and sulphates in concrete, etc. All these recommendations taken together tend to result in concrete being dense, workable, placeable and having as low a permeability as possible under the given situation. Therefore, adherence to one limit without considering others, or uniform application of these recommendations with no regard to the situation of placing, for example, congestion of reinforcement, cover thickness, workability of concrete or the characteristics of the aggregates, may not ensure the fulfillment of the objectives.

Firstly, it should ensure sufficient alkalinity (PH value of concrete) to provide a passive environment against corrosion of steel, for example, in concrete in marine environment or in sea water, a minimum cement content of 350 kg/m3 or more is required for this consideration13+28. Secondly, the cement content and water-cement ratio is so chosen as to result in sufficient volume of cement paste to overfill the voids in the compacted aggregates. Clearly, this will depend upon the type and nominal maximum size of aggregate employed. For example, crushed rock or rounded river gravels of 20 mm maximum size of aggregate will, in general, have respectively 27 and 22 percent of aggregate voids. A cement content of 400 kg/m3 and water-cement ratio of 0.45 will result in paste volume being 30 percent which may be suitable for the former (that is crushed rock of 20 mm maximum size aggregate), whereas cement content of 300 kg/m3 and watercement ratio of 0.50 will result in 25 percent paste volume (Fig. 37) being sufficient to overfill the voids in 20 mm rounded gravel aggregates. Increasing cement content will result in higher workabilities.

Relative proportion of fine and coarse aggregate

The grading and maximum size of aggregates is important parameters in any concrete mix. They affect relative proportions in mix, workability, economy, porosity and shrinkage of concrete etc. Experience has shown that very fine sands or very coarse sands are objectionable – the former is uneconomical, the latter gives harsh unworkable mixes. Thus the object in this paper is to find the best fineness modulus of sand to get the optimum grading of combined aggregate (all-in-aggregate), which is most suitable, and for economy. In general, the grading of aggregates, which do not have a deficiency or excess of any size of aggregate and give a smooth grading curve, produce the most suitable concrete mix. Further a cohesive mix is also desired for the pumped concrete produced by RMC Plant. In the present investigations, effect of the grading of river sand particles has been investigated for a good Concrete mix. Sand has been sorted in three categories i.e. Fine, Medium, and Coarse. These were mixed with coarse aggregate in different proportions so as to keep the combined Fineness Modulus (all-inaggregate) more or less the same. Various proportions of such aggregate are mixed in preparing M 30 grade of Concrete mix. Effect is studied on concrete workability, cube strength, flexural strength and permeability. The results indicate that with the change in fineness of sand, workability gets affected. The details of findings and its effect on compressive and flexural strength and permeability, influencing durability are reported in this paper.

Use of admixture

Chemical admixtures are the ingredients in concrete other than portland cement, water, and aggregate that are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

Successful use of admixtures depends on the use of appropriate methods of batching and concreting. Most admixtures are supplied in ready-to-use liquid form and are added to the concrete at the plant or at the jobsite. Certain admixtures, such as pigments, expansive agents, and pumping aids are used only in extremely small amounts and are usually batched by hand from premeasured containers.

CONCRETE MIX DESIGN METHODS

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking. The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

Objectives of mix design

- The basic objective of concrete mix design is to find the most economical proportions.
- To achieve the desired end results strength, cohesion, workability, and durability.

As mentioned earlier the proportioning of concrete is based on certain material properties of cement, sand and aggregates. Concrete mix design is basically a process of taking trials with certain proportions.

Factors affect the properties of concrete

- Batching
- Mixing
- Transporting
- Placing
- Compacting
- Curing

Therefore, the specific relationship that are used in proportioning concrete mixes should be considered only as the basis for trial, subject to modification in the light of experience as well as for the particular materials used at the site in each case.

Methods of mix design

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction

Procedure

- Determine the mean target strength ft from the specified characteristic compressive strength at 28-day fck and the level of quality control.

- $f_t = f_{ck} + 1.65\ S$
- where S is the standard deviation obtained from the Table of approximate contents given after the design mix.
- Obtain the water cement ratio for the desired mean target using the empirical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ratio. The water cement ratio so chosen is checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.
- Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.
- Select the water content, for the required workability and maximum size of aggregates (for aggregates in saturated surface dry condition) from table.
- Determine the percentage of fine aggregate in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.
- Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.
- Calculate the cement content form the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability, and greater of the two values is adopted.
- From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relations:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p}\frac{f_a}{S_{fa}}\right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p}\frac{C_a}{S_{ca}}\right] \times \frac{1}{1000}$$

- where V = absolute volume of concrete = gross volume (1m3) minus the volume of entrapped air
- Sc = specific gravity of cement
- W = Mass of water per cubic metre of concrete, kg
- C = mass of cement per cubic metre of concrete, kg
- p = ratio of fine aggregate to total aggregate by absolute volume
- fa, Ca = total masses of fine and coarse aggregates, per cubic metre of concrete, respectively, kg, and
- S_{fa}, S_{ca} = specific gravities of saturated surface dry fine and coarse aggregates, respectively
- Determine the concrete mix proportions for the first trial mix.
- Prepare the concrete using the calculated proportions and cast three cubes of 150 mm size and test them wet after 28-days moist curing and check for the strength.
- Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

Basic steps in mix design

- Fine the target mean strength
- Determine the curve of cement based on its strength
- Determine water/cement ratio
- Determine cement content
- Determine fine aggregate proportions
- Determine coarse aggregate proportions

Information required for mix design

- Grade of concrete
- Degree of workability
- Maximum temperature of fresh concrete
- Type of cement
- Minimum cement content
- Maximum water cement ratio
- Type of aggregate
- Maximum nominal size of aggregate
- Type of admixtures, if required
- Level of quality assurance
- Exposure condition
- Method of placing
- Degree of supervision

BIS method of mix design

The Bureau of Indian Standards (BIS) has released the final code on concrete mix proportioning in December 2009. Before this, the draft code was circulated among practitioners. Significant changes have been made in the new code adapting from international codes on concrete mix design. The new code can now be used for designing a variety of concrete mixes using both mineral and chemical admixtures. With this code RMC having high degree of workability facilitating pumping can also be designed. In this paper an effort has been made to examine the major differences between BIS and the American Concrete Institute (ACI) methods of concrete mix design. Using both these methods, step-by-step procedure for calculating the ingredients is given. The difference between the old BIS (IS 10262:1982) and new BIS (IS 10262:2009) is also highlighted.

Mix design is a process of specifying the mixture of ingredients required to meet anticipated properties of fresh and hardened concrete. Concrete mix design is a well established practice around the world. Adapting from developed countries, many developing countries have standardised their concrete mix design methods. These methods are mostly based on empirical relations, charts, graphs, and tables developed through extensive experiments and investigations using locally available materials.

Step by step procedure (Refer the concrete Code book IS10262:2000)

Step:1 Target mean strength for mix design

Design Procedure

1. Target mean strength of concrete

$$f_{ck}^* = f_{ck} + tS$$

$$f_{ck} = 20,\ t = 1.64\ ,\ S = 4$$

$$f_{ck}^* = 26.6\ \text{MPa}$$

CONCRETE MIX DESIGN 67

The mix design M-50 grade (Using Admixture –Sikament) provided here is for reference purpose only. Actual site conditions vary and thus this should be adjusted as per the location and other factors.

Parameters for mix design M50
Grade Designation = M-50
Type of cement = O.P.C-43 grade
Brand of cement = Vikram (Grasim)
Admixture = Sika [Sikament 170 (H)]
Fine Aggregate = Zone-II
Sp. Gravity
Cement = 3.15
Fine Aggregate = 2.61
Coarse Aggregate (20mm) = 2.65
Coarse Aggregate (10mm) = 2.66
Minimum Cement (As per contract) =400 kg / m^3
Maximum water cement ratio (As per contract) = 0.45
Mix Calculation: –
1. Target Mean Strength = 50 + (5 X 1.65) = 58.25 Mpa

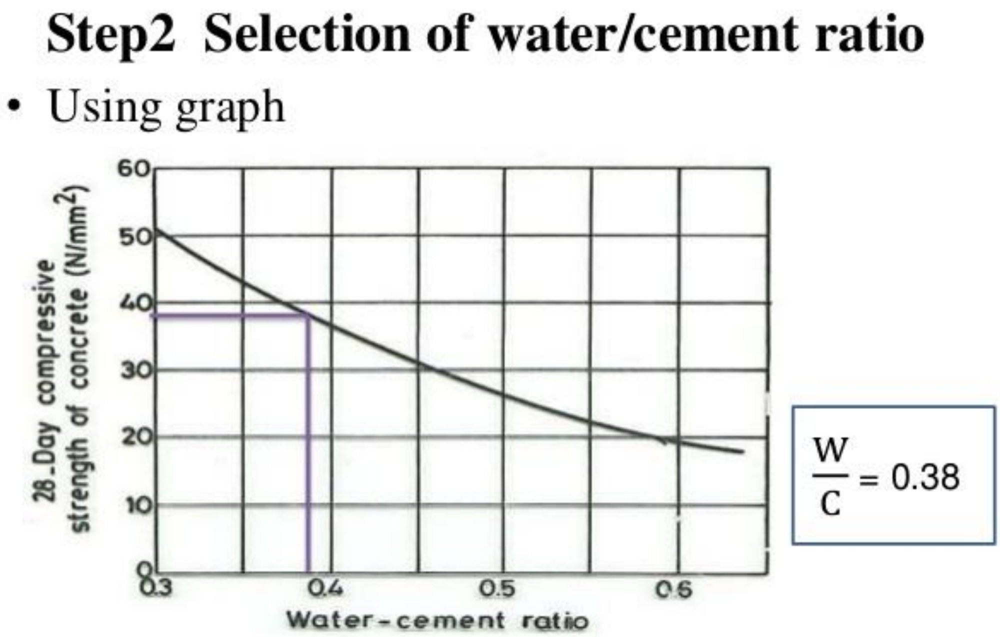
2. Selection of water cement ratio:-
Assume water cement ratio = 0.35
3. Calculation of water: –
Approximate water content for 20mm max. Size of aggregate = 180 kg /m^3 (As per Table No. 5 , IS : 10262). As plasticizer is proposed we can reduce water content by 20%.
Now water content = 180 X 0.8 = 144 kg /m^3
4. Calculation of cement content:-
Water cement ratio = 0.35
Water content per cum of concrete = 144 kg
Cement content = 144/0.35 = 411.4 kg / m^3
Say cement content = 412 kg / m^3 (As per contract Minimum cement content 400 kg / m^3)
Hence O.K.
5. Calculation for C.A. & F.A.: [Formula’s can be seen in earlier posts]-

Volume of concrete = 1 m^3
Volume of cement = 412 / (3.15 X 1000) = 0.1308 m^3
Volume of water = 144 / (1 X 1000) = 0.1440 m^3
Volume of Admixture = 4.994 / (1.145 X 1000) = 0.0043 m^3
Total weight of other materials except coarse aggregate = 0.1308 + 0.1440 +0.0043 = 0.2791 m^3
Volume of coarse and fine aggregate = 1 – 0.2791 = 0.7209 m^3
Volume of F.A. = 0.7209 X 0.33 = 0.2379 m^3 (Assuming 33% by volume of total aggregate)
Volume of C.A. = 0.7209 – 0.2379 = 0.4830 m^3
Therefore weight of F.A. = 0.2379 X 2.61 X 1000 = 620.919 kg/ m^3
Say weight of F.A. = 621 kg/ m^3
Therefore weight of C.A. = 0.4830 X 2.655 X 1000 = 1282.365 kg/ m^3
Say weight of C.A. = 1284 kg/ m^3
Considering 20 mm: 10mm = 0.55: 0.45
20mm = 706 kg .
10mm = 578 kg .
Hence Mix details per m^3
Increasing cement, water, admixture by 2.5% for this trial
Cement = 412 X 1.025 = 422 kg
Water = 144 X 1.025 = 147.6 kg
Fine aggregate = 621 kg
Coarse aggregate 20 mm = 706 kg
Coarse aggregate 10 mm = 578 kg
Admixture = 1.2 % by weight of cement = 5.064 kg.
Water: cement: F.A.: C.A. = 0.35: 1: 1.472: 3.043

Observation: –
A. Mix was cohesive and homogeneous.
B. Slump = 120 mm
C. No. of cube casted = 9 Nos.

7 days average compressive strength = 52.07 MPa.
28 days average compressive strength = 62.52 MPa which is greater than 58.25MPa
Hence the mix accepted.

Step:2 Selection of water/cement ratio



The **water–cement ratio** is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and form. Workability can be resolved with the use of plasticizers or super-plasticizers.

Often, the ratio refers to the ratio of water to cement plus pozzolan ratio, w/(c+p). The pozzolan is typically a fly ash, or blast furnace slag. It can include a number of other materials, such as silica fume, rice husk ash or natural pozzolans. Pozzolans can be added to strengthen concrete.

The notion of water–cement ratio was first developed by Duff A. Abrams and published in 1918. Refer to concrete slump test.

Concrete hardens as a result of the chemical reaction between cement and water (known as hydration, this produces heat and is called the heat of hydration). For every pound (or kilogram or any unit of weight) of cement, about 0.42 pounds (or 0.42 kg or corresponding unit) of water is needed to fully complete hydration reactions.

However, a mix with a ratio of 0.42 may not mix thoroughly, and may not flow well enough to be placed. More water is therefore used than is technically necessary to react with cement. Water-cement ratios of 0.45 to 0.60 are more typically used. For higher-strength concrete, lower ratios are used, along with a plasticizer to increase flowability.

Too much water will result in segregation of the sand and aggregate components from the cement paste. Also, water that is not consumed by the hydration reaction may leave concrete as it hardens, resulting in microscopic pores (bleeding) that will reduce final strength of concrete. A mix with too much water will experience more shrinkage as excess water leaves, resulting in internal cracks and visible fractures (particularly around inside corners), which again will reduce the final strength.

The 1997 Uniform Building Code specifies a maximum of 0.50 ratio when concrete is exposed to freezing and thawing in a moist condition or to de-icing chemicals, and a maximum of 0.45 ratio for concrete in a severe or very severe sulfate condition.

Step:3 Estimation of entrapped air

Air permeability (Ka) and air-filled porosity (Ea), at negative heads (h) ranging from 0 to 240 mm, were measured for 106 undisturbed soil cores. The measurement employed an air pressure gradient to compensate for gravity, and imbibition to h = 0 preceded measurements at sequentially increasing h. The presence of trapped air and measurable airflow at h = 0 confounded analysis of permeability and porosity relations. Thus, a K-weighted scaling of experimental heads was conducted, analogous to a characteristic length scale, such that Kr = 0 at h* = 0 where Kr is the relative permeability, Ka/Ka(240), and h* is the scaled head. Expressing the degree of air saturation, Sf = Ea/Ea (240), as a function of h* provided an estimation of the maximum degree of trapped air observed at h* = 0. The degree of trapped air ranged from 0 to 0.83 (mean = 0.38) indicating that a sizable proportion of air-filled porosity is non-conducting. With these adjustments, a Mualem-type expression for Kr as a function of the degree of conducting air allowed estimation of a tortuosity factor, n. Values of n ranged from 0.27 to 9.1 (mean = 2.9), the interpretation of which will be discussed.

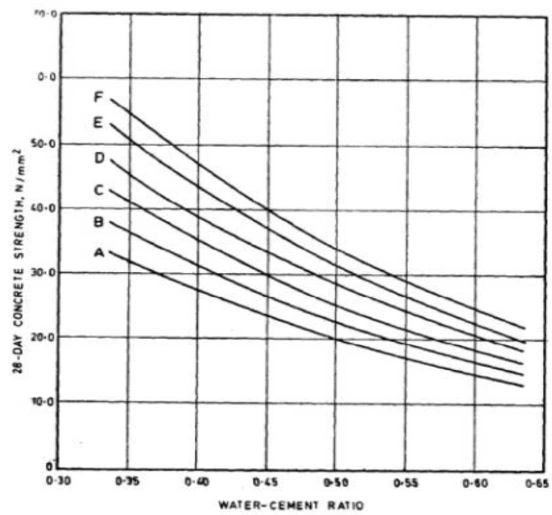


Fig 4.2 Relation between W/C Ratio and Concrete Strength for Different Cement Strength

4.5 ESTIMATION OF AIR CONTENT

Approximate amount of entrapped air to be expected in normal concrete is given

Table4.3 Approximate Air Content

Normal Maximum Size of Aggregate in mm	Entrapped Air, Percentage Of Volume Of Concrete
10	3.0
20	2.0
40	1.0

Step:4 Calculation of cement content

As you might be knowing, the unit weight of concrete is taken to be 25KN per metre cube, which roughly comes out to be 2500kg/metre cube. One of the handy thumb rules to keep in mind is that the sum total of the weights of aggregates, water and cement should roughly be equal to 2500 kg while preparing 1 metre cube of concrete. IS 456 specifies the water cement ratio for various exposure levels. It also specifies the weight of sand with respect to something(forgive me for not being able to recollect the exact details at this moment). The bottom line one can get the water cement ratio and the quantity of sand from IS 456.

Basic design procedure can be taken from IS Codes-

UNIT-IV

FRESH AND HARDENED PROPERTIES OF CONCRETE

FRESH CONCRETE

Fresh concrete or plastic concrete is freshly mixed material which can be moulded into any size and shape. The relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state. The right proportions of aggregate, sand, cement water in concrete are ensured by experience in volumetric proportion.

Workability

Some of the definitions are given by scientists and researches for the workability of concrete. They are given as below:

According to Granville "it is that property of the concrete which determines the amount of useful internal work necessary to produce full compaction".

Powers defined it as "that property of plastic concrete mixture which determines the case ease with which it can be placed and the degree to which it resists segregation".

ACI (American Concrete Institute) defines it as ' that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished'.

ASTM (American society for Testing and Materials) defines as "that property determine the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity".

Importance and significance of workability

From these above definition it is very clean that there exist no straight forward definition for the term "workability". In very simple words it can be stated that the workability of concrete means the ability to work with concrete. A concrete is said to be workable if:

- It can be handled without segregation
- It can be placed without loss of homogeneity
- It can be compacted with specified effort
- It can be finished easily

In every construction work, different quantitative or qualitative terms to express workability are used. Before specifying workability for any work a concrete technologist must keep the following things in mind:

- Type of construction work
- Method of mixing

- Thickness of section
- Extent of reinforcement
- Mode of compaction
- Distance of transporting
- Method of placing
- Environmental condition

Concrete that can be placed readily without segregation or separation in a mass dam could be entirely unworkable in a thin structure member. Workable concrete compacted by means of high frequency vibrators tamping and spading were required. Concrete having suitable workability for a pavement might be unsuitable for use in a heavily reinforced section.

Factors affecting workability

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming.The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction. If the concrete shows more lubricant nature then it will have the following advantages, such as:

- It will exhibit little internal friction between particle and particle
- It will overcome the frictional resistance offered by the surface of the formwork and reinforcement contained in the concrete
- It can be consolidated with minimum compacting are given below:
    - Water content
    - Aggregate
    - Size of the aggregate
    - Shape of the aggregate
    - Grading of aggregate
    - Surface texture of aggregate
    - Use of admixture

Water content

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

Aggregate / Cement ratio

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

Size of the aggregate

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

Bigger size aggregate have following advantages as compared to smaller size aggregate:

- It has less surface area
- Requires less amount of water for wetting surface
- Requires less amount of paste for lubricating the surface

So for a given water content and paste, bigger aggregate size will have higher workability.

Shape of aggregate

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

- Angular aggregate
- Flaky aggregate
- Elongated aggregate
- Rounded aggregate
- Sub-rounded aggregate
- Cubical aggregate etc.

Grading of aggregate

This is one of the factors which will have maximum influence on workability. A well graded aggregate is the one which has least amount of voids in a given volume. Other factors being constant, when the total voids are less, excess paste is availableto give better lubricating

effect. With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles. Aggregate particles will slide past each other with the least amount of compacting efforts. The better the grading, the less is the void content and higher the workability. The above is true for the given amount of paste volume.
g. Use of admixtures: Of all the factors mentioned above, the most important factor which affects the workability is the use.

Surface structure of aggregate

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

Use of admixture

The wright way of improving workability is to use chemical admixtures such as plasticizers, super plasticizers, air entraining agents etc.Of all the factors mentioned above, the most important factor which affects the workability is the use of admixtures. It is to be noted that initial slump of concrete mix or what is called slump of reference mix should be about 2 – 3 cm to enhance the slump many fold at a minimum doze. Without initial slump of 2-3 cm, the workability can be increased to higher level but it requires higher dosage – hence uneconomical.

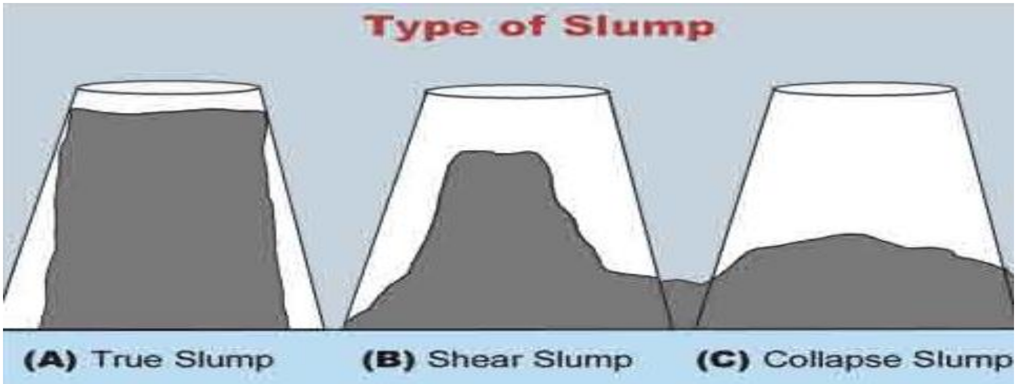
Tests for workability of concrete

Workability of concrete is a complex property. There are different methods of measuring the workability of fresh concrete. Each of them measures a particular aspect of it and there is no unique test which measures workability of concrete in its totality. The following tests are most commonly used method for testing workability of concrete and they are:

- Slump test
- Compaction factor test
- Vee bee consistometer test
- Flow test
- Kelly ball test

Slump test

Unsupported fresh concrete flows to the sides and a sinking in height takes place. This vertical settlement is known as slump. In this test fresh concrete is filled into a mould of specified shape and dimensions, and the settlement or slump is measured when supporting mould is removed. Slump increases as water-content is increased. For different works different slump values have been recommended. The slump is a measure indicating the consistency or workability of cement concrete. It gives an idea of water content needed for concrete to be used for different works. A concrete is said to be workable if it can be easily mixed, placed, compacted and finished. A workable concrete should not shown any segregation or bleeding. Segregation is said to occur when coarse aggregate tries to separate out from the finer material and a concentration of coarse aggregate at one place occurs. This results in large voids, less durability and strength. Bleeding of concrete is said to occur when excess water comes up at the surface of concrete. This causes small pores through the mass of concrete and is undesirable. By this test we can determine the water content to give specified slump value. In this test water content is varied and in each case slump value is measured till we arrive at water content giving the required slump value. This test is not a true guide to workability. For example, a harsh mix cannot be said to have same workability as one with a large proportion of sand even though they may have the same slump.



Apparatus

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

Procedure

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

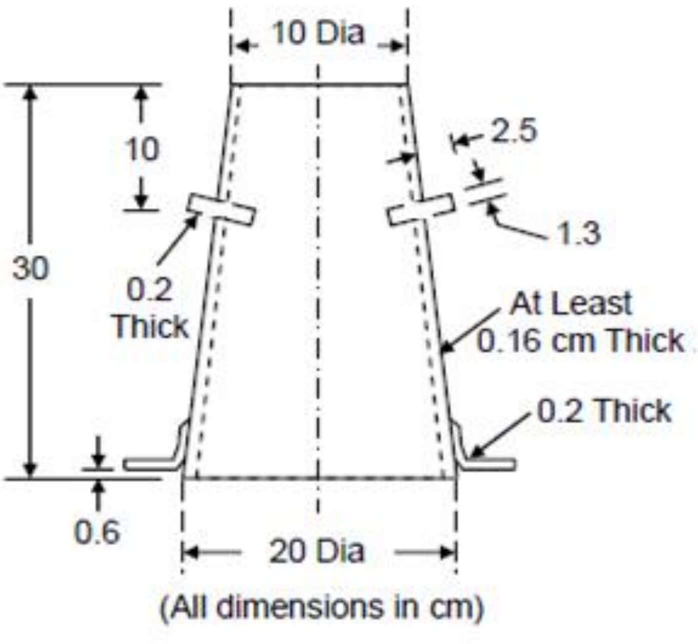
1) Mix the dry constituents thoroughly to get a uniform colour and then add water

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

3) Strike off the top with a trowel or tamping rod so that the mould is exactly filled. 4) Remove the cone immediately, raising it slowly and carefully in the vertical direction.

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

Note: Slump test is adopted in the laboratory or during the progress of work in the field for determining consistency of concrete where nominal maximum size of aggregate does not exceed 40mm. Any slump specimen which collapses or shears off laterally gives incorrect results and if this occurs the test is repeated, only the true slump should be measured.

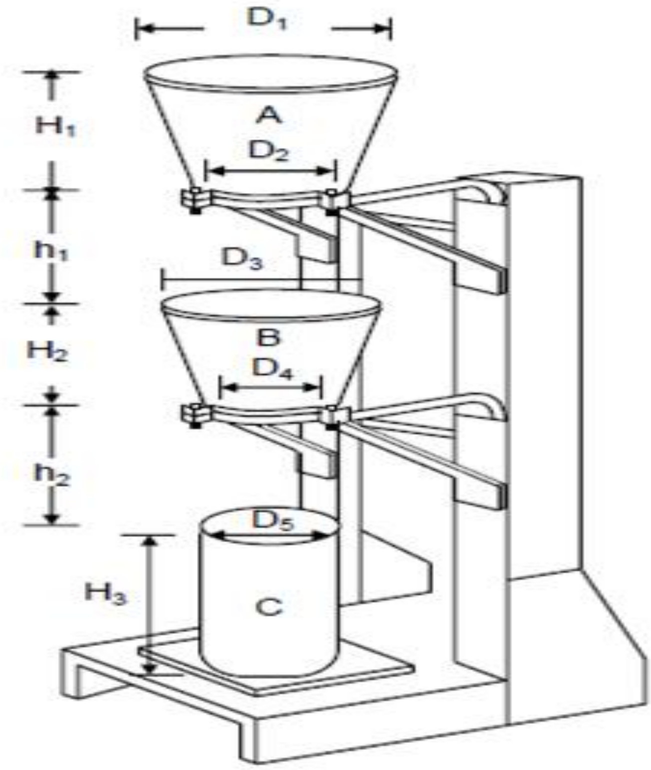


Standard values

Sl.No.	Name of works	Slump, mm	Water-cement ratio

1	Concrete for roads and mass concrete	25 to 50	0.70
2	Concrete for R.C.C. beams and slabs	50 to 100	0.55
3	Columns and retaining walls	75 to 125	0.45
4	Mass concrete in foundation	25 to 50	0.70

4.1.4.2 Compacting factor test



Compaction factor test is adopted to determine the workability of concrete, where nominal size of aggregate does not exceed 40mm, and is primarily used in laboratory. It is based upon the definition, that workability is that property of the concrete which determines the amount of work required to produce full compaction. The test consists essentially of applying a standard amount of work to standard quantity of concrete and measuring the resulting compaction. To find the workability of freshly prepared concrete, the test is carried out as per specification of IS: 1199-1959. Workability gives an idea of the capability of being worked, i.e., idea to control the quantity of water in cement concrete mix to get uniform strength. It is more sensitive and precise than slump test and is particularly useful for concrete mixes of low workability. The compaction factor (C.F.) test is able to indicate small variations in workability over a wide range.

Apparatus

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

Essential dimension of the compacting factor apparatus for use with aggregate not exceeding 40 mm Nominal Maximum Size. Upper hopper A Dimension (Cm)

Upper hopper A	**Dimension (Cm)**
Top internal diameter	25.4
Bottom internal diameter	12.7
Internal height	27.9
Lower hopper B	
Top internal diameter	22.9
Bottom internal diameter	12.7
Internal height	22.9
Cylinder C	
Internal diameter	15.2
Internal height	30.5
Distance between bottom of upper hopper and top of lower hopper	20.3
Distance between bottom of lower hopper and top cylinder	20.3

Procedure

1. Keep the compaction factor apparatus on a level ground and apply grease on the inner surface of the hoppers and cylinder.

2. Fasten the flap doors.

3. Weigh the empty cylinder accurately and note down the mass as W1 kg.

4. Fix the cylinder on the base with fly nuts and bolts in such a way that the central points of hoppers and cylinder lie on one vertical line. Cover the cylinder with a plate.

5. Four mixes are to be prepared with water-cement ratio (by mass) 0.50, 0.60, 0.70, and 0.80, respectively. For each mix take 9 kg of aggregate, 4.5 kg sand 2.25 kg of cement. With each mix proceed as follows: a) Mix sand and cement day, until a mixture of uniform colour is obtained. Now mix the coarse aggregate and cement-sand mixture until coarse aggregate is uniformly distributed throughout the batch. b) Add the required amount of water to the above mixture and mix it thoroughly until concrete appears to be homogeneous.

6. Fill the freshly mixed concrete in upper hopper gently and crefully with hand scoop without compacting.

7. After two minutes, release the trap door so that the concrete may fall into the lower hopper brining the concrete into standard compaction.

8. Immediately after the concrete has come to rest, open the trap door of lower hopper and allow the concrete to fall into the cylinder bringing the concrete into standard compaction.

9. Remove the excess concrete above the top of the cylinder by a pair of trowels, one in each hand will blades horizontal slide them from the opposite edges of the mould inward to the centre with a sawing motion.

10. Clean the cylinder from all sides properly. Find the mass of partially compacted concrete thus filled in the cylinder, say W2 kg.

11. Refill the cylinder with the same sample of concrete in approximately 50mm layers, vibrating each layer heavily so as to expel all the air and obtain full compaction of the concrete.

12. Struck off level the concrete and weigh and cylinder filled with fully compacted concrete. Let the mass be W3 kg.

$$\textbf{Compaction Factor} = \frac{\textbf{Weight of the partially compacted concrete}}{\textbf{Weight of fully compacted concrete}}$$

Standard Values of Workability, Slump and Compacting Factor of Concretes with 20 mm or 40 mm Maximum size of Aggregate

Degree of workability	**Small apparatus**	**Large apparatus**	**Use for which concrete is suitable**
Very low	0.78	0.80	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand operated machines.
Low	0.85	0.87	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	0.92	0.935	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration
High	0.95	0.96	For sections with congested reinforcement. Not normally suitable for vibration.

Vee Bee consistometer test

The workability of fresh concrete is a composite property, which includes the diverse requirements of stability, mobility, compactability, placeability and finishability. There are different methods for measuring the workability. Each of them measures only a particular aspect of it and there is really no unique test, which measures workability of concrete in its totality. This test gives an indication of the mobility and to some extent of the compactibility of freshly mixed concrete. The test measures the relative effort required to change a mass of concrete from one definite shape to another (i.e., from conical to cylindrical) by means of vibration. The amount of effort called remoulding effort is taken as the time in seconds required to complete the change. The results of this test are of value in studying the mobility of the masses of concrete made with varying amounts of water, cement and with various types of gradings of aggregate. The time required for complete remoulding in seconds is considered as a measure of workability and is expressed as the number of Vee-Bee seconds. The method is suitable for dry concrete. For concrete of slump in excess of 50mm, the remoulding is so quick that the time cannot measured.

Apparatus

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

Procedure

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

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

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

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

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

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

Standard Values

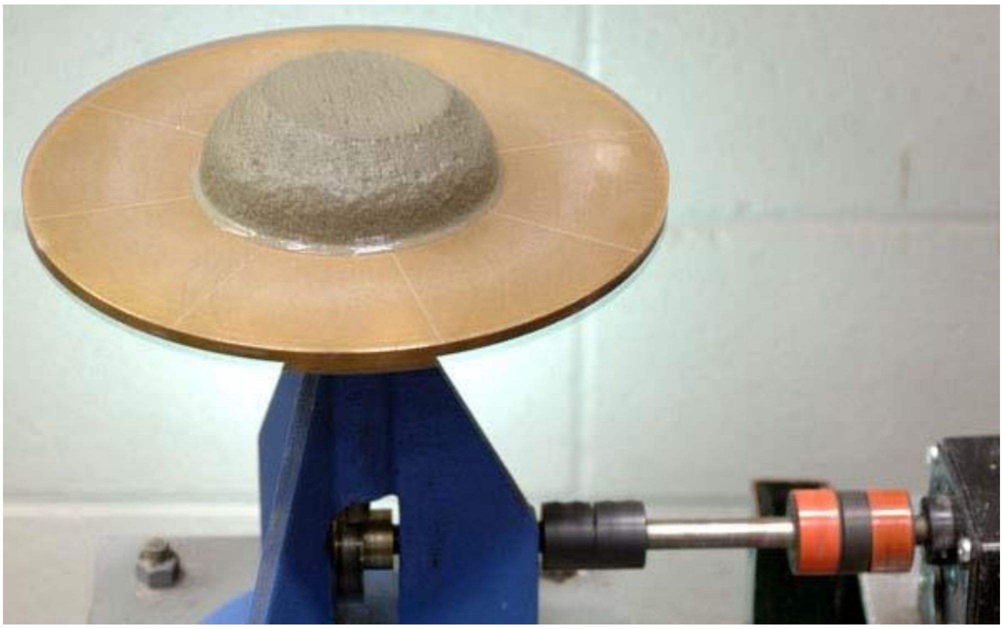
Workability description	**Vee-Bee Time, Seconds**
Extremely dry	32-18
Very stiff	18-10
Stiff	10-5
Stiff plastic	5-3
Plastic	3-0
Flowing	-

Flow test

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

The spread or the flow of the concrete is measured and this flow is related to workability. Figure shows the details of apparatus used.

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



The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould Spread diameter in cm - 25 x 100 Flow, percent - 25 The value could range anything from 0 to 150 per cent. A close look at the pattern of spread of concrete can also give a good indication of the characteristics of concrete such as tendency for segregation.

Flow Table Apparatus

The BIS has recently introduced another new equipment for measuring flow value of concrete. This new flow table test is in the line with BS 188 I part 105 of 1984 and DIN 1048 part I. The apparatus and method of testing is described below. The flow table apparatus is to be constructed in accordance with Figure (a) and (b) Flow table top is constructed from a flat metal of minimum thickness 1.5 mm. The top is in plan 700 mm x 700 mm. The centre of the table is marked with a cross, the lines which run paralled to and out to the edges of the plate, and with a central circle 200 mm in diameter. The front of the flow table top is provided with a lifting handle as shown in Fig (b) The total mass of the flow table top is about 16 ± 1 kg. The flow table top is hinged to a base frame using externally mounted hinges in such a way that no aggregate can become trapped easily between the hinges or hinged surfaces. The front of the base frame shall extend a minimum 120 mm beyond the flow table top in order to provide a top board. An upper stop similar to that shown in Fig (a) is provided on each side of the table so that the lower front edge of the table can only be lifted 40 ± I mm. The lower front edge of the flow table top is provided with two hard rigid stops which transfer the load to the base frame. The base frame is so constructed that this load is then transferred directly to the surface on which the flow table is placed so that there is minimal tendency for the flow table top to bounce when allowed to fall.

Kelly ball test

The Kelly ball test (Powers 1968; Bartos 1992; Scanlon 1994; Ferraris 1999; Bartos, Sonebi, and Tamimi 2002) was developed in the 1950s in the United States as a fast alternative to the slump test. The simple and inexpensive test can be quickly performed on in-place concrete and the results can be correlated to slump. The test apparatus consists of a 6 inch diameter, 30 pound ball attached to a stem, as shown in Figure 6. The stem, which is graduated in ¼ inch increments, slides through a frame that rests on the fresh concrete. To perform the test, the concrete to be tested is stuck off level. The ball is released and the depth of penetration is measured to the nearest ¼ inch. At least three measurements must be made for each sample

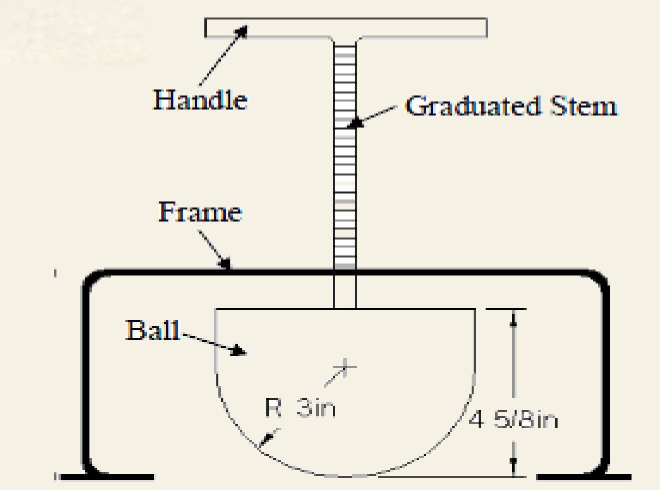


Figure 6: Kelly Ball Test Apparatus

The Kelly ball test provides an indication of yield stress, as the test essentially measures whether the stress applied by the weight of the ball is greater than the yield stress of the concrete (Ferraris 1999). For a given concrete mixture, the results of the Kelly ball test can be correlated to slump. Equations based on empirical testing have been published for use on specific types of concrete mixtures (Powers 1968). Typically, the value of slump is 1.10 to 2.00 times the Kelly ball test reading. It has been claimed that the Kelly ball test is more accurate in determining consistency than the slump test (Scanlon 1994). The Kelly ball test was formerly standardized in ASTM C360-92: “Standard Test Method for Ball Penetration in Freshly Mixed Hydraulic Cement Concrete.” The ASTM standard was discontinued in 1999 due to lack of use. The test has never been used widely outside the United States (Bartos 1992). The test is applicable to a similar range of concrete consistencies as the slump test and is applicable to special mixes, such as lightweight and heavyweight concretes. The precision of the test declines with the increasing size of coarse aggregate (Bartos 1992).

Segregation

Segregation is defined as the separation of the constituents of a homogeneous mixture of concrete. It is caused by the differences in sizes and weights of the constituent particles. Segregation can be controlled by properly choosing the grading of aggregates and by carefully handling wet mixes. In relatively lean and dry mixes, segregation can be caused by the coarser particles separating out because they travel farther along the slope or settle to a greater extent than finer particles. The second form of segregation occurs in very wet mixes in which the cement – water paste separates from the mix. Segregation can also be caused by poor handling, such as dropping wet concrete from a considerable height, passing long chutes along a slope, and discharging concrete carelessly against some firm obstruction. It may also be caused by the vibration of concrete. Though vibration provides a useful means of compaction, over – vibration leads to segregation. This can happen when vibration is allowed to continue for too long. It leads to the separation of coarse aggregates from the mix. These aggregates settle at the bottom, and the cement – water paste moves to the top in the form of laitance (scum). This laitance is different from bleed water. Segregation is difficult to measure. However, its occurrence is easily detected. The flow test can indicate the susceptibility of a mix that is likely to segregate. In dry mixes, heavier particles move away and occupy the edges of the flow table. In wet mixes, the cement paste trends to move away from the middle and the centre of the flow table is left only with coarser particles.

Conditions favourable for segregation

Segregation is the separation of the different materials of concrete. A good concrete is one which is homogeneous in nature.If a sample of concrete exhibits a tendency for separation of say, coarse aggregate from the rest of the ingredients, then, that sample is said to be showing the tendency for segregation.

Such concrete is not only going to be weak; lack of homogeneity is also going to induce all undesirable properties in the hardened concrete. There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete. Therefore, it is natural that the materials show a tendency to fall apart.

Segregation may be of three types — firstly, the coarse aggregate separating out or settling down from the rest of the matrix, 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 matrix do not allow the aggregate to fall apart, at the same time, the matrix itself is sufficiently contained by the aggregate. Similarly, water also does not find it easy to move out freely from the rest of the ingredients.

The conditions favourable for segregation are, as can be seen from the above para, the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates. Insufficiently mixed concrete with excess water content shows a higher tendency for segregation. Dropping of concrete from heights as in the case of placing concrete in column concreting will result in segregation.

When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades, concrete shows a tendency for segregation. Conveyance of concrete by conveyor belts, wheel barrow, long distance haul by dumper, long lift by skip and hoist are the other situations promoting segregation of concrete.

The most important method of concrete compaction is Vibration. Only comparatively dry mix should be vibrated. When a too wet a mix is excessively vibrated, it is likely to get segregated. Vibration also to be continued just for required time for optimum results. If the vibration is continued for a long time, particularly, in too wet a mix, it is likely to result in segregation of concrete due to settlement of coarse aggregate in matrix.

Concrete is used with very high slump now a days particularly in RMC. The slump value required at the batching point may be in the order of 150 mm and at the pumping point the slump may be around 100 mm.

At both these points cubes are cast. One has to take care to compact the cube mould with these high slump concrete. If sufficient care and understanding of concrete is not exercised, the concrete in the cube mould may get segregated and show low strength. Similarly care must be taken in the compaction of such concrete in actual structures to avoid segregation.

In case of floors or pavement finishing, with a view to achieve a smooth surface, masons work too much with the trowel, float or tamping rule immediately on placing concrete. This immediate working on the concrete on placing, without any time interval, is likely to press the coarse aggregate down, which results in the movement of excess of matrix or paste to the surface.

Segregation caused on this account, impairs the homogeneity and serviceability of concrete. The excess mortar at the top causes plastic shrinkagecracks.

So it can be concluded that the tendency for segregation can be remedied by correctly proportioning the mix, by proper handling, transporting, placing, compacting and finishing. If segregation is observed, it is advisable to remixing for a short time which would make the concrete again homogeneous.

As mentioned earlier, a cohesive mix would reduce the tendency for segregation. For this reason, use of certain workability agents and pozzolanic materials greatly help in reducing segregation. The use of air-entraining agent appreciably reduces segregation.
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.

Remedies for segregation

From the foregoing discussion, it can be gathered that the tendency for segregation can be remedied:

- ✓ By correctly proportioning the mix
- ✓ By proper transporting
- ✓ By proper placing
- ✓ By proper compacting and
- ✓ By proper finishing

At any stages, if segregation is observed, remixing for a short time would make the concrete again homogeneous. As mentioned earlier, a cohesive mix would reduce the tendency for segregation. For this reason, use of certain workability agents and pozzolanic materials greatly help in reducing segregation.

Bleeding

Bleeding isn’t always bad. It lowers the water- c e m e n t ratio and densifies the concrete. But concrete that bleeds too fast or too long can cause a number of problems: rock jams in p u m p l i n e s, sand streaks in walls, weak horizontal construction j o i n t s, and voids beneath re b a r s and aggregate part i c l e s. Even if bleeding isn't excessive, finishing c o n c rete at the wrong time causes a different set of bleeding-re l a t e d problems blistering, scaling, and dusting surfaces. Pre venting harmful effects of bleeding re q u i res knowing why concrete bleeds and how mix proportions affect it. The right finishing methods also help ensure that bleeding problems won't ruin a slab surface.

Almost all freshly placed concrete bleeds. As aggregate and cement particles settle, they force excess mixing water upward. The process continues until settlement stops, either because of solids bridging or because the concrete has set. The total amount of bleeding or settlement depends on mix properties, primarily water content and amount of fines (cement, fly ash, fine sand). Increasing water content increases bleeding, and increasing the amount of fines reduces bleeding. Amount of bleeding is also proportional to the depth of concrete placed. More bleed water rises in deep sections than in thin ones.

Bleeding usually occurs gradually by uniform seepage over the whole surface, but sometimes vertical channels form. Water flows fast enough in these channels to carry fine particles of cement and sand, leaving “worm holes” in the interior or sand streaks at the form face. Channels are more likely to form when concrete bleeds excessively.

Channels that reach the surf a c e a reopen paths for deicing solutions to penetrate the concrete. This leads to freezing and thawing damage and rebar corrosion.

Effects of bleeding on concrete

- ✓ Due to bleeding concrete loses its homogeneity.
- ✓ Bleeding is responsible for causing permeability in concrete.
- ✓ Similarly, water that accumulates below the reinforcing bars, particularly below the cranked bars, reduces the bond between the reinforcement and concrete.
- ✓ In pavement construction bleeding water delays surface finishing and application of curing compound.

Tests for bleeding of concrete

Cylindrical measure, tamping bar, pipette, and graduated jar are the equipment and apparatus required for the determination of relatively quantity of mixing water that will bleed from a sample of freshly mixed concrete

Procedure

1. The container is filled with concrete up to a height of 250±3 mm. It is filled approximately 50 mm deep and each layer is compacted by hand.
2. The minimum numbers of strokes are 60 strokes per layer. The top surface of the concrete is leveled. The mass is recorded.
3. The specimen is kept at a temperature of 27 ± 2^0C. The container is kept on a level surface free from vibration and covered with a lid.

4. Water accumulated at the top is drawn off by means of a pipette, at 10 min intervals during the first 40 min and at 30 min interval subsequently till bleeding water.
5. The water is transferred to graduated jar and accumulated quantity of water is recorded after each transfer.

Calculation

Accumulated bleeding water expressed as a percentage of the net mixing water is calculated as follows.

$$\text{Bleeding water}(\%) = \frac{V_w}{\frac{ws}{W}} \times 100$$

Where,

V_w=Total mass of the bleeding water, kg
w = net mass of water in the batch, kg

W = Total mass of the batch, kg

s = The mass of sample, kg

Reports

The result is expressed in percentage.

HARDENED CONCRETE

Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete works. It has to be tested to know the strength of concrete in 28 days for each desired grade. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable part of any quality control programme for concrete, which helps to achieve higher efficiency of the material used and greater assurance of the performance of the concrete with regard to both strength and durability. The test methods should be simple, direct and convenient to apply.

Compression test

Procedure

1. Representative samples of concrete shall be taken and used for casting cubes 15 cm x 15 cm x 15 cm or cylindrical specimens of 15 cm dia x 30 cm long.
2. The concrete shall be filled into the moulds in layers approximately 5 cm deep. It would be distributed evenly and compacted either by vibration or by hand tamping.
3. After the top layer has been compacted, the surface of concrete shall be finished level with the top of the mould using a trowel; and covered with a glass plate to prevent evaporation.
4. The specimen shall be stored at site for 24+ ½ h under damp matting or sack. After that, the samples shall be stored in clean water at $27+2^0$C; until the time of test. The ends of all cylindrical specimens that are not plane within 0.05 mm shall be capped.
5. Just prior to testing, the cylindrical specimen shall be capped with sulphur mixture comprising 3 parts sulphur to 1 part of inert filler such as fire clay.
6. Specimen shall be tested immediately on removal from water and while they are still in wet condition.
7. The bearing surface of the testing specimen shall be wiped clean and any loose material removed from the surface.
8. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load cube as cast, that is, not to the top and bottom.
9. Align the axis of the specimen with the steel platen, do not use any packing.
10. The load shall be applied slowly without shock and increased continuously at a rate of approximately 140 kg/sq.cm/min until the resistance of the specimen to the increased load breaks down and no greater load can be sustained.
11. The maximum load applied to the specimen shall then be recorded and any unusual features noted at the time of failure brought out in the report.

Formula

Compressive strength is calculate using the following formula

Compressive strength (kg/cm^2) = W_f / A_p

Where,

W_f = Maximum applied load just before load, (kg)
A_p = Plan area of cube mould, (mm^2)

Factors affecting strength test result of concrete

Compressive strength is the most important property of concrete. The compressive strength of concrete is determined in the laboratory in controlled conditions. On the basis of this test result we judge the quality of concrete. But sometimes the strength test results vary so widely that it becomes difficult to reach at any conclusion. This variation in test results can be avoided by taking necessary steps.

There are 5 factors which influence strength of concrete when tested for compressive strength. These factors are mentioned below.

- ✓ Shape and size of the test specimen
- ✓ Height to diameter ratio
- ✓ Rate of application of load
- ✓ Moisture content in the test specimen
- ✓ Material used for craping

Shape and size of test specimens

Shape & size of specimens affect the strength test result of concrete to a large extent. If two cubes of different sizes but prepared from the same concrete, are tested then they will show different test results. For example, strength of a cube specimen having 10 cm in size is 10% less than strength of a cube specimen having 15 cm in size.

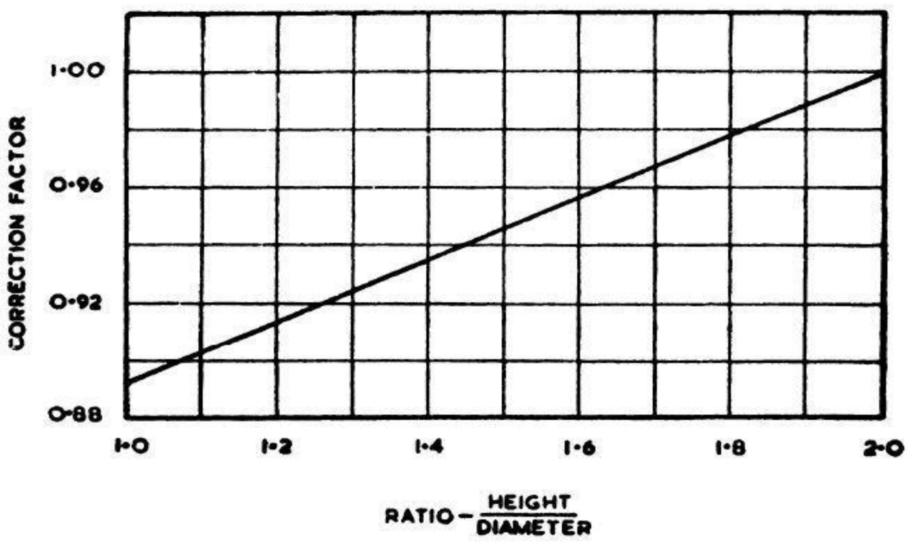
If two cubes of different shapes (such as cube & cylinder) are tested, then they will show different test results. From experiment it has been found that strength of the cylinder of size 15 cm diameter and 30 cm long is equal to 0.8 times the strength of 15 cm cube.

Height to diameter ration

Generally for testing cylindrical concrete specimen, the height to diameter ratio is kept 2. But sometimes it is not possible to keep the height/diameter ratio equal to 2 when the core is cut from road pavement or airfield or any part of the structure.

If the length of the core is too long, it can be trimmed to h/d ratio of 2:1, before testing. But if the length of core specimen is short, it is necessary to apply a correction factor to the test result.

A correction factor according to the height / diameter ratio of the specimen after capping is obtained from the curve as shown below.



The product of this correction factor and the measured compressive strength will give the corrected compressive strength. This corrected compressive strength is equivalent to the strength of a cylinder having height / diameter ratio of 2.

Rate of application of load

Rate of application of load has a considerable influence on the strength test results. If the rate of application of load is slow, or there is some time lag,. Then it will result into lower values of strength. The reason behind this is creep. Due to slower application of load, the specimen will undergo some amount of creep which in turn increases the strain. And this increased strain is responsible for failure of test sample, resulting lower strength values.

Moisture content in the test specimen

The presence of moisture content in the test specimen also affects the test result to a great extent. If two cubes (one is wet & another is dry) prepared from the same concrete, are tested at the same age, then the dry cube will give higher strength than the wet cube. This may be caused due to the reduction of cohesion of concrete ingredients due to presence of water.

To get reproducible results, it is advised that the concrete cubes or cylinders should be tested immediately on removal from the curing tank. Because if you test concrete in dry condition then the test results will vary largely.

Material used for capping

There are various methods available for capping concrete cylinders such as, sulphur capping, gypsum capping & cement mortar capping etc. The type of capping material used has also some amount of effect on the value obtained from strength test. So it is suggested that for a particular construction project, the method of capping the concrete cylinders should be one. And this one method should not be changed at any times. By employing this method we can avoid wide variations in test results and can judge the quality of concrete.

Compressive strength test of concrete

Concrete compression test is done to know the concrete compressive strength. It is one of two well known concrete test. Another one is slump test.For this purpose, either concrete cube or cylinder specimens are tested in the laboratory.
3 concrete specimens are generally made and cured for 28 days at site and then sent to laboratory for testing.

Required things
You'll need following things for testing concrete compressive strength -

* Ruler
* Paper
* Pen/Pencil
* Calculator
* Measuring

Procedure of Concrete Compression Test

Step1 - Preparation*:* Check all the things you need are ready. Check concrete compression machine is in working order.

Step2 - Safety: Wear hand gloves and safety goggles.

Step3 - Taking measurement*:* Take the measurement of concrete specimens (which are sent to laboratory for testing). Calculate the cross sectional area (unit should be on mm2) and put down on paper. Do the same for each specimen.

Step4 - Start machine*:* Turn on the machine. Place one concrete specimen in the centre of loading area.
Step5 - Lowering piston*:* Lower the piston against the top of concrete specimen by pushing the lever. Don't apply load just now. Just place the piston on top of concrete specimen so that it's touching that.
Step6 - Applying load*:* Now the piston is on top of specimen. It is the time to apply load. Pull the lever into holding position. Start the compression test by Pressing the zero button on the display board.
Step7 - Increasing pressure*:* By turning pressure increasing valve counter-clockwise, adjust the pressure on piston so that it matches concrete compression strength value. Apply the load gradually without shock.
Step8 - Test is complete*:* Observe the concrete specimen. When it begins to break stop applyingload.
Step9 - recording*:* Record the ultimate load on paper displaying on machine's display screen.
Step10 - Clean the machine*:* When the piston is back into its position, clean the creaked concrete from the machine.
Step11 - Turning off machine*:* Match your record once again with the result on display screen. The result should still be on display screen. And then turn off the machine.
Step12 - Calculate concrete compressive strength*:* The result we got from testing machine is the ultimate load to break the concrete specimen. The load unit is generally in lb. We have to convert it in newton (N). Our purpose is, to know the concrete compressive strength.

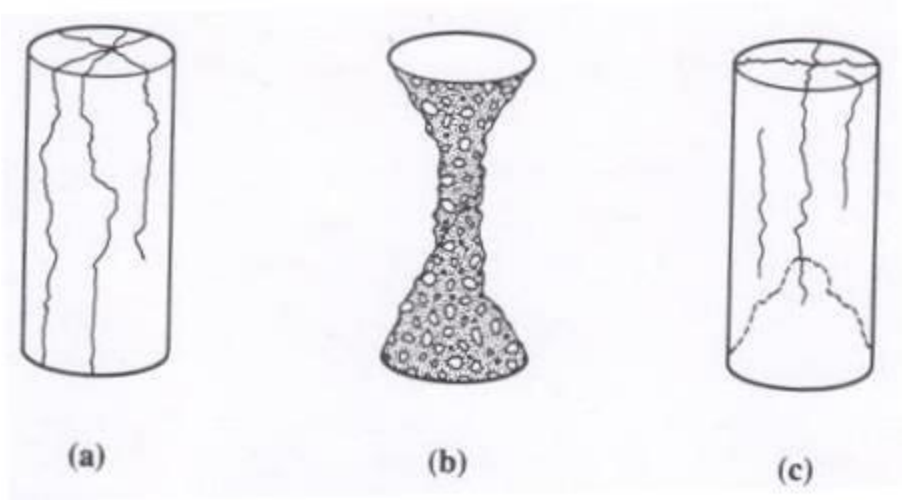
We know, compressive strength is equal to ultimate load divided by cross sectional area of concrete specimen. We took the concrete specimen's measurement before starting the testing and calculated cross sectional area.

Now we got the ultimate load. So we can now calculate the concrete compressive strength.
Compressive strength = Ultimate load (N) / cross sectional area (mm2).
The unit of compressive strength will be N/mm2.

Normally 3 sample of concrete specimens are tested and average result is taken into consideration. If any of the specimen compressive strength result varies by more than 15% of average result, that result is rejected.

Failure of compression specimen

Compression test develops a rather more complex system of stresses. Due to compression load, the cube or cylinder undergoes lateral expansion owing to the poisson’s effect. The steel plates do not undergo lateral expansion to the some extent that of concrete, with the result that steel retrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the adjacent steel plates of the testing machine.



Flexural strength test of concrete

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 6 x 6 inch (150 x 150-mm) concrete beams with a span length at least three times the depth. The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading).

Flexural Strength of Concrete Flexural MR is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design. The MR determined by third-point loading is lower than the MR determined by center-point loading, sometimes by as much as 15%.

Designers of pavements use a theory based onflexural strength. Therefore, laboratory mix design based on flexural strength tests may be required, or a cementitious material content may be selected from past experience to obtain the needed design MR. Some also use MR for field control and acceptance of pavements. Very few use flexural testing for structural concrete. Agencies not using flexural strength for field control generally find the use of compressive strength convenient and reliable to judge the quality of the concrete as delivered.

Beam specimens must be properly made in the field. Pavement concrete mixtures are stiff (1/2 to 21/2-inch slump). Consolidate by vibration in accordance with ASTM C 31 and tap sides to release air pockets. For higher slump, after rodding, tap the molds to release air pockets and spade along the sides to consolidate. Never allow the beam surfaces to dry at any time. Immerse in saturated lime water for at least 20 hours before testing.

Specifications and investigation of apparent low strengths should take into account the higher variability of flexural strength results. Standard deviation for concrete flexural strengths up to 800 psi (5.5 MPa) for projects with good control range from about 40 to 80 psi (0.3 to 0.6 MPa). Standard deviation values over 100 psi (0.7 MPa) may indicate testing problems. There is a high likelihood that testing problems, or moisture differences within a beam caused from premature drying, will cause low strength.

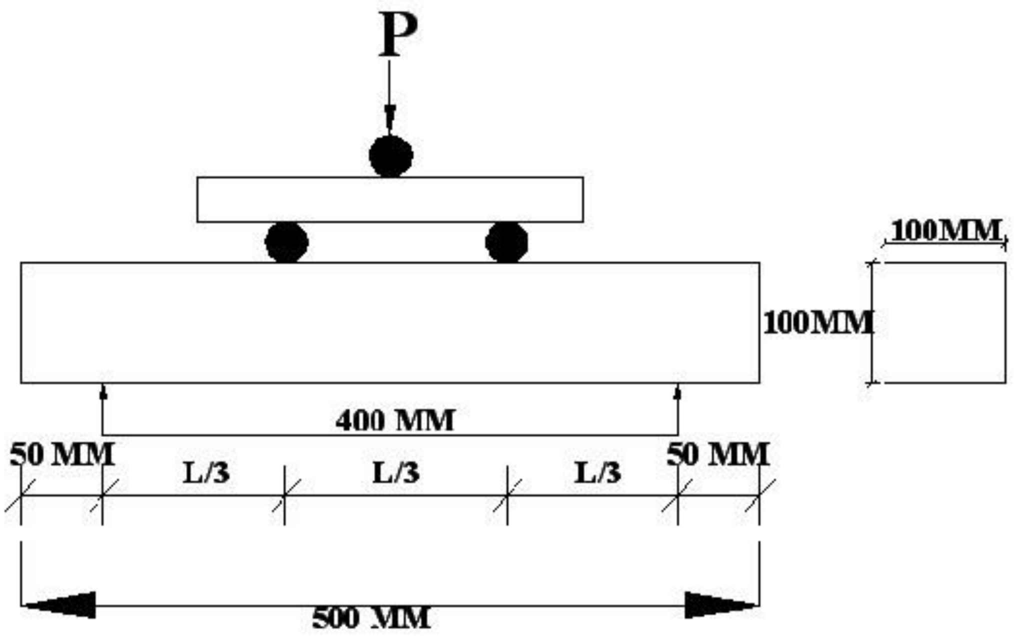
Where a correlation between flexural and compressive strength has been established in the laboratory, core strengths by ASTM C 42 can be used for compressive strength to check against the desired value using the ACI 318 criteria of 85 percent of specified strength for the average of three cores. It is impractical to saw beams from a slab for flexural testing. Sawing beams will greatly reduce measured flexural strength and should not be done. In some instances, splitting tensile strength of cores by ASTM C 496 is used, but experience is limited on how to apply the data.

Flexural Strength Test Results

Normal Size	Type	Load(lbs)	Gross Strength (PSJ)
8"x16"x24"	Poured Concrete	21,750	765
8"x16"x24"	Concrete Block	690	25
10"x16"x24"	Poured Concrete	34,600	770
10"x16"x24"	Concrete Block	2,060	45
12"x16"x24"	Poured Concrete	50,600	775
12"x16"x24"	Concrete Block	1,150	20

Flexural tests are extremely sensitive to specimen preparation, handling, and curing procedure. Beams are very heavy and can be damaged when handled and transported from the jobsite to the lab. Allowing a beam to dry will yield lower strengths. Beams must be cured in a standard manner, and tested while wet. Meeting all these requirements on a jobsite is extremely difficult often resulting in unreliable and generally low MR values.

A short period of drying can produce a sharp drop in flexural strength. Many state highway agencies have used flexural strength but are now changing to compressive strength or maturity concepts for job control and quality assurance of concrete paving. Cylinder compressive strengths are also The data point to a need for a review of current testing procedures. They suggest also that, while the flexural strength test is a useful tool in research and in laboratory evaluation of concrete ingredients and proportions, it is too sensitive to testing variations to be usable as a basis for the acceptance or rejection of concrete in the field.



TWO POINT LOADING SETUP IN FLEXURE TEST

Determination of tensile strength

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials.
For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required.

Tensile specimen

A tensile specimen is a standardized sample cross-section. It has two shoulders and a gage (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area.

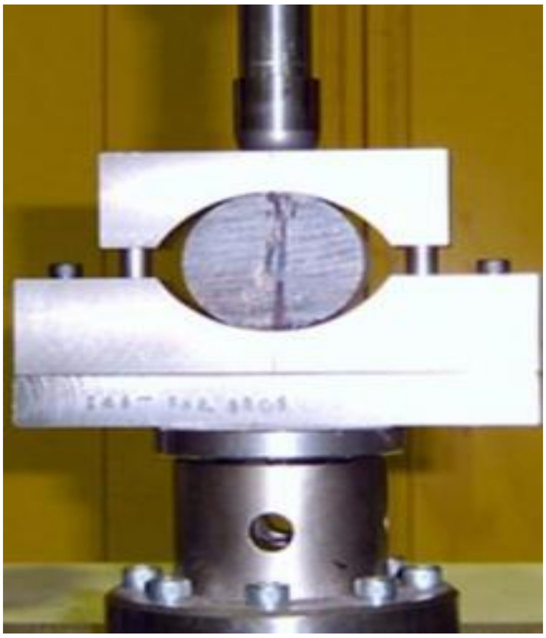
The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine (see the image below). Each system has advantages and disadvantages; for example, shoulders designed for serrated grips are easy and cheap to manufacture, but the alignment of the specimen is dependent on the skill of the technician. On the other hand, a pinned grip assures good alignment. Threaded shoulders and grips also assure good alignment, but the technician must know to thread each shoulder into the grip at least one diameter's length, otherwise the threads can strip before the specimen fractures.

In large castings and forgings it is common to add extra material, which is designed to be removed from the casting so that test specimens can be made from it. These specimens may not be exact representation of the whole workpiece because the grain structure may be different throughout. In smaller workpieces or when critical parts of the casting must be tested, a workpiece may be sacrificed to make the test specimens. For workpieces that are machined from bar stock, the test specimen can be made from the same piece as the bar stock

Procedure

- The specimens provided are made of aluminium, steel and brass. Measure and record specimen dimensions (diameter and gauge length) in a table provided for the calculation of the engineering stress and engineering strain.
- Marking the location of the gauge length along the parallel length of each specimen for subsequent observation of necking and strain measurement. 3.2 Fit the specimen on to the universal Testing Machine (UTM) and carry on testing.
- Record load and extension for the construction of stress-strain curve of each tested specimen. 3.3 Calculate Young's modulus, yield strength, ultimate tensile strength, fracture strain, % elongation and % area of reduction of each specimen and record on the provided table.
- 3.4 Analyze the fracture surfaces of broken specimens using stereoscope, sketch and describe the results. 3.5 Discuss the experimental results and give conclusions.

Indirect tension test method



The standard ITS test is used to test the briquettes under both dry and wet conditions. The ITS is determined by measuring the ultimate load to failure of a specimen which is subjected to a constant deformation rate of 50.8 mm/minute on its diametrical axis according to ASTM D6931. The dry specimen procedure is as follows Bring the specimens to the test temperature of 25°C by placing the briquettes in a dry temperature control system at 25°C ± 1°C for at least 1 hour, but not for longer than 2 hours before testing.

Remove a specimen from the air cabinet and place it into the loading apparatus. Centre the briquette on edge on the lower loading strip. Position the upper loading strip. Take note of the alignment marks on the loading apparatus and position accordingly. Position the assembly centrally under the loading ram of the compression testing device.

Apply the load to the specimen, without shock, at a rate of advance of 50.8 mm per minute until the maximum load is reached. Record this maximum load, P (in N), accurate to zero decimal place.The wet specimen procedure is as follows Condition the 3 briquettes in a wet temperature control system (under a minimum of 25 mm of distilled water cover) for 24 hours.

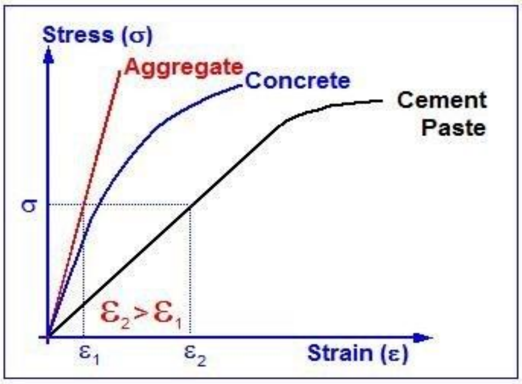
Alternatively, the 3 briquettes can be covered with water at 25°C ± 1°C in a vacuum according to ASTM D2041, with the exception that the vacuum pressure is only increased until the residual pressure manometer reads 50 mm mercury and then once the vacuum is achieved, continue the vacuum and agitation for 60 ± 1 minutes. Remove the specimen and surface dry. Test for the ultimate tensile load, as described above.

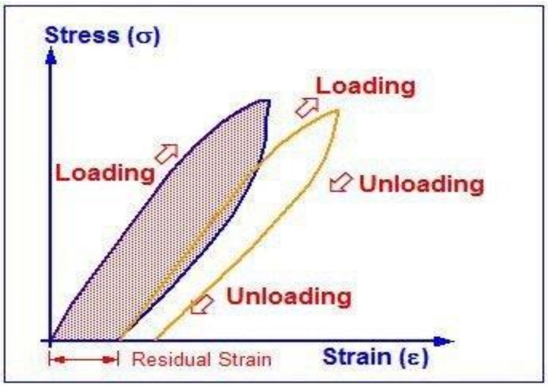
Stress strain curve for concrete

The stress-strain curve for hardened cement paste is almost linear as shown in the figure. The aggregate is more rigid than the cement paste and will therefore deform less (i.e. have a lower strain) under the same applied stress.

The stress strain curve of concrete lies between those of the aggregate and the cement paste. However this relationship is non-linear over the most of the range. The reason for this non-linear behaviour is that micro-cracks are formed.

At the interface between aggregate particles and cement paste as a result of the differential movement between the two phases, andWithin the cement paste itself.These cracks are formed as a result of changes in temperature and moisture and the application of load.

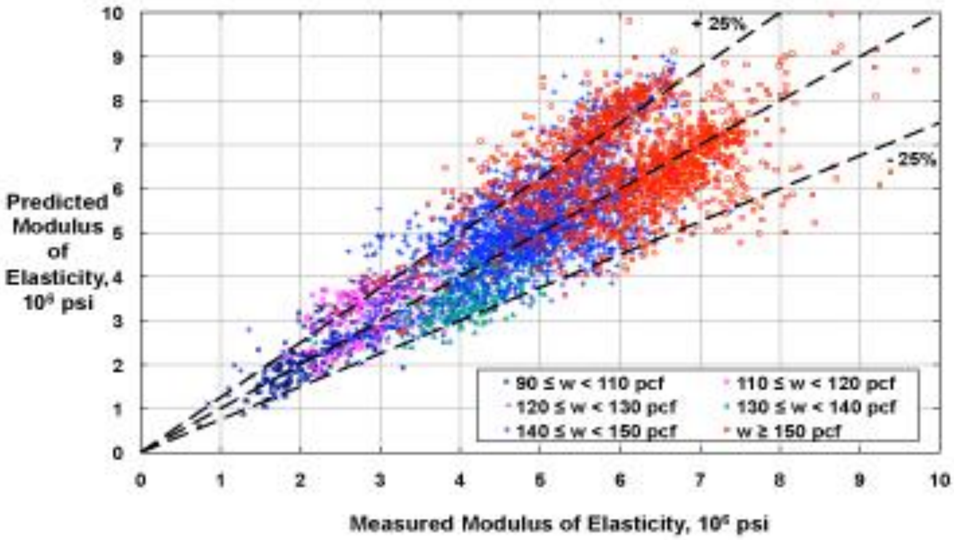




Modulus of elasticity of concrete

The procedure for measuring the static modulus of elasticity in compression is described in ASTM C469. In this procedure, molded concrete cylinders or diamond-drilled concrete cores are subjected to a slowly increasing longitudinal compressive stress. Longitudinal strains are determined using either a bonded or unbonded sensing device that measures the average deformation of two diametrically opposite locations to the nearest 5 millionths of strain. ASTM C469 does not specify the diameter of the test specimens. However, molded concrete cylinders are usually the same size as those used for compressive strength measurements i.e. 6x12-in. or 4x8-in. (152x312-mm or 102x203-mm) cylinders. Concrete cores must have a length-to-diameter ratio greater than 1.50.

The applied load and longitudinal strain are recorded when the longitudinal strain is 50 millionths and when the applied load is equal to 40% of the cylinder compressive strength. Note that it is necessary to determine the compressive strength on companion specimens prior to testing for modulus of elasticity. The modulus of elasticity is calculated as the slope of the straight line between the 40% compressive stress point and the 50 millionths strain point. The same procedure may be used to obtain a stress-strain curve by taking more frequent readings either manually or automatically. ASTM C469 cautions that the modulus of elasticity values will usually be less than the modulus derived under rapid load application and usually greater than values obtained under slow load application, when all other test conditions remain the same.



Different elastic moduli

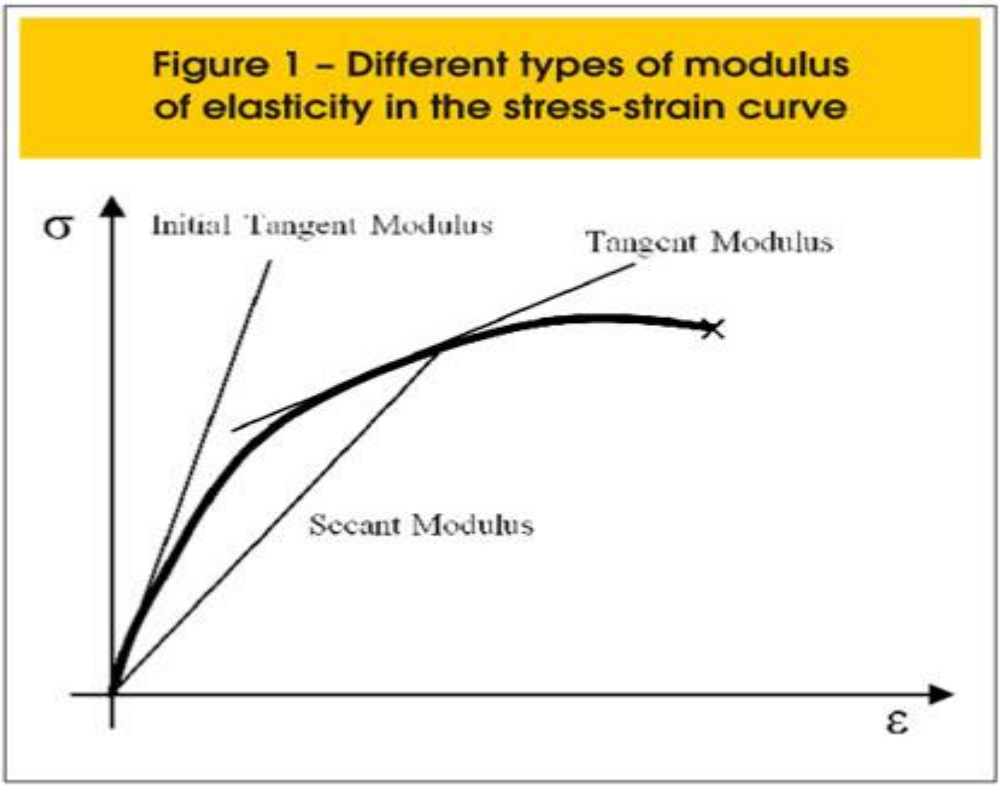
"Young's modulus" or modulus of elasticity, is a number that measures an object or substance's resistance to being deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region. A stiffer material will have a higher elastic modulus. An elastic modulus has the form

$$\lambda \stackrel{\text{def}}{=} \frac{\text{stress}}{\text{strain}}$$

where stress is the force causing the deformation divided by the area to which the force is applied and strain is the ratio of the change in some length parameter caused by the deformation to the original value of the length parameter. If stress is measured in pascals, then since strain is a dimensionless quantity, the units of λ will be pascals as well.[2] The antonym of Elasticity is "Compliance".

Since the strain equals unity for an object whose length has doubled, the elastic modulus equals the stress induced in the material by a doubling of length. While this scenario is not generally realistic because most materials will fail before reaching it, it gives heuristic guidance, because small fractions of the defining load will operate in exactly the same ratio. Thus, for steel with a Young's modulus of 30 million psi, a 30 thousand psi load will elongate a 1 inch bar by one thousandth of an inch; similarly, for metric units, a load of one-thousandth of the modulus (now measured in gigapascals) will change the length of a one-meter rod by a millimeter.

In a general description, since both stress and strain are described by second-rank tensors, including both stretch and shear components, the elasticity tensor is a fourth-rank tensor with up to 21 independent constants.



Specifying how stress and strain are to be measured, including directions, allows for many types of elastic moduli to be defined. The three primary ones are:

- Young's modulus (*E*) describes tensile elasticity, or the tendency of an object to deform along an axis when opposing forces are applied along that axis; it is defined as the ratio of tensile stress to tensile strain. It is often referred to simply as the elastic modulus.
- The shear modulus or modulus of rigidity (*G* or μ) describes an object's tendency to shear (the deformation of shape at constant volume) when acted upon by opposing forces; it is defined as shear stress overshear strain. The shear modulus is part of the derivation of viscosity.
- The bulk modulus (*K*) describes volumetric elasticity, or the tendency of an object to deform in all directions when uniformly loaded in all directions; it is defined as volumetric stress over volumetric strain, and is the inverse of compressibility. The bulk modulus is an extension of Young's modulus to three dimensions.

Three other elastic moduli are Axial Modulus, Lamé's first parameter, and P-wave modulus.

Homogeneous and isotropic (similar in all directions) materials (solids) have their (linear) elastic properties fully described by two elastic moduli, and one may choose any pair. Given a pair of elastic moduli, all other elastic moduli can be calculated according to formulas in the table below at the end of page.

Inviscid fluids are special in that they cannot support shear stress, meaning that the shear modulus is always zero. This also implies that Young's modulus is always zero.

In some English texts the here described quantity is called elastic constant, while the inverse quantity is referred to as elastic modulus.

Determination of modulus of elasticity

Assemble the top and bottom frame by keeping the spacers in position.

(ii) Keep the pivot rod on the screws and lock them in position.

(iii) Keep the tightening screws of the bottom and top frame unscrewed (but not completely).

(iv) Place the specimen on a level surface.

(v) Keep the compressometer centrally on the specimen so that the tightening screw of the

bottom and top frame are at equal distance from the two ends.

(vi) Tighten the screws so that the compressometer is held on the specimen.

(vii)Remove the spacers by unscrewing the spacer screws.

Place the specimen with compressometer in the compression testing machine and center it.

(II) Apply load continuously without stock at a rate of 140 kg /cm²/minute until a stress of

(c+5)kg/cm² is reached where c is the one third of average compressive strength of cubes calculated to the nearest 5kg /cm²(a load of 12.4T)

(III) Maintain the load at this stress for at least one minute and reduce gradually to an average stress of 1.5 kg/ cm^2(a load of 0.3 T)

(IV) Apply the load again at the same rate until an average stress of (c+ 1.5) kg/cm^2 is reached(a load of 11.8T)

(V) Note the compressometer reading at this load.

(VI) Reduce the load gradually and take readings at an interval of 1T up to 0.3T(11.8T,10.8T,9.8T,8.8T,7.8T,…………,1.8T,0.3T)

(VII) Apply load third time and note the compressometer readings at an interval of 1T (0.3T,1.8T,2.8T,………….11.8T).

Durability of concrete:

- FACTORS AFFECTING DURABILITY
- ENVIRONMENT: Environment can be classified as 2 types:

1) PHYSICAL:
Temperature: Temperature affects the rate of hydration. Unfavourable temperature conditions can lead to shrinkage cracks and volume changes. Variation in temperature changes cause secondary stresses in structures.
Moisture: Moisture induces corrosion in steel. Moisture also acts as a carrier of chemicals inside the body of concrete. Moisture can also cause efflorescence on structural surfaces.
Seepage / Leakages cause inconvenience to occupants and deteriorates structures due to permeable concrete.
Freezing and Thawing - Leads to expansion of concrete and cracking.
Ice-melting salts cause erosion of concrete
2) Chemical: When we are dealing with durability, chemical attack which results in volume change, cracking and consequent deterioration of concrete become a major cause of concern
Types of Chemical attack
•Sulphate attack
•Alkali aggregate reaction
•Chloride ion attack - Corrosion
•Carbonation
•Acid Attack
•Effect on concrete in Seawate

- Type and quality of construction material
- Cement content and w/c ratio of concrete:Volume change result in cracks and cracks are responsible for disintegration of concrete. Permeability is the contributory factor for the volume change and higher w/c ratio is the fundamental cause of higher

permeability. For a durable concrete, use of lowest w/c ratio is the fundamental requirement to produce dense and impermeable concrete. It has been found through experiments that low w/c ratio concrete are less sensitive to carbonation, external chemical attack and other effects that cause lack of durability of concrete. It has been reported that it become impossible to corrode unprotected steel reinforcement in accelerated corrosion test of a concrete with very low w/c ratio. In actual practice for many years it has been found difficult to reduce the W/C ratio below 0.4. This situation has changed since the last twenty years in India with the practice of using superplasticizers. The modern superplasticizers are so efficient that it is now possible to make flowing concrete with 3 W/C as low as 0.25 or even as low as 0.20.

The water available can only hydrate the surface of cement particles and there exist plenty of unhydrated particles which can play an important role as they constitute strength in concrete. If for any reasons, structural or environmental, concrete gets cracked, the unhydrated cement particles begin hydrating as soon as water or moisture starts penetrating through cracks. This is to say that unhydrated cement particles on hydration offer self-healing potential to seal up the cracks and improve durability of concrete.

- Workmanship: Batching, Mixing, Transportation, Placing, Compaction and Curing require proper workmanship for a durable concrete.

UNIT-V

SPECIAL CONCRETE

Special concrete is defined as concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices. The requirements may involve enhancements of characteristics such as placement and compaction without segregation, long-term mechanical properties, early-age strength, toughness, volume stability, or service life in severe environments.

Light weight concrete

The use of lightweight aggregate to reduce concrete densities is a well-established procedure where properties such as increased fire resistance, ease of handling and transportation, or reduced structure dead load is desired. Lightweight concrete with compressive strengths of up to 5,000 psi (34.5 MPa) has been used in commercial construction routinely since the early 1930's. During the last two decades, however, much higher strengths have been specified. Aggregates normally constitute 60–70% of a concrete mix, and the physical characteristics of the aggregate will, therefore, have a pronounced influence on the physical property of the concrete.

High strength concrete relies more heavily on the quality of the aggregate than does low or even medium strength concrete. The function of the aggregate, to a large extent, is to act as an inexpensive filler material. The cement paste matrix takes up most of the load imposed on the concrete. As design loads approach and exceed the strength limits of the cement paste matrix, the load carrying capacity of the aggregate and the interplay between aggregate and cement paste become the limiting factors in strength development. For all practical purposes, this limit appears to be in the region of 15,000 to 16,000 psi (100 to 110 MPa) for concrete using normal weight aggregate, approximately 80% of this for concrete using expanded slate lightweight aggregate and probably less than 70% of this for concrete using expanded clay or shale aggregate.

This limitation is more pronounced for lightweight concrete because the mechanical characteristics of the lightweight aggregate are more similar to those of the cement paste matrix than to the normal weight aggregate, and variations in aggregate quality will be more directly reflected in the concrete characteristics. Low absorption lightweight aggregates are most desirable for developing a concrete mixture of high strength and durability. The following table lists typical properties of various lightweight aggregate materials.

In the mid 1980's, the North Carolina Department of Transportation sponsored a two-year study investigating the properties of high strength concrete using materials from North Carolina, including expanded slate aggregate. This study was conducted at North Carolina State University. One of the primary goals was to provide basic "round figure" data on certain "specialty" concretes such as lightweight concrete.

"The purpose of this research was not so much to produce the absolute highest strengths attainable as it was to produce the highest strength which could reasonably be attained in practice with more or less conventional materials and methods." Lightweight concrete was produced with a compressive strength greater than 11,000 psi (76 MPa).

The elastic modulus of high strength lightweight concrete was found to be less than the elastic modulus of normal weight concrete of comparable strength, but the equation recommended in ACI 318, based on unit weight and compressive strength, provided a good estimate of the elastic modulus of the high strength lightweight concrete in this study. The following table presents results from the lightweight concrete mixes investigated in this study.

Advantages of light weight concrete

- It is governed primarily by economic considerations
- Reduced Seismic Forces
- Improved Structural Efficiency
- Reduces the dead load of a structure
- Smaller sections as well as smaller sized foundations can be used
- Formwork will withstand low pressures
- Improved Constructability
- Ease of Transport
- Pumping to large distances
- Self-compaction
- Quick production
- Improved hydration due to internal curing
- Ease of Renovation and repair
- Better thermal insulation
- Can be used as Designer Dirt for Geotechnical Stabilization

Methods for making concrete light

Basically there is only one method for making concrete light that is by the inclusion of air in concrete. This is achieved in actual practice bt three different ways.

- By placing the usual mineral aggregate by cellular porous or lightweight aggregate.
- By introducing gas or air bubbles in mortar. This is known as aerated concrete.
- By omitting sand fraction from the aggregate. This is called no fines concrete.

Classification of lightweight concrete

There are three methods of producing lightweight concrete. First, porous lightweight aggregate whose specific gravity is approximately 2.6. The resultant concrete is generally known by the name **lightweight aggregate** used.

The second method of producing lightweight concrete relies on introducing large voids within the concrete. These voids are clearly distinguished from the extremely fine voids produced byair entraining. This type of concrete is variously known as aerated cellular, foamed or gas concrete.

The third means of obtaining lightweight concrete is by simply omitting the fine aggregate from the mix so that a large number of interstitial voids is present. Coarse aggregate of ordinary weight is generally used. This concrete is described by the term No fines Concrete.

In essence then, the decrease in density is obtained in each case by the presence of voids, either in the aggregate or in the mortar or in the interstices between the coarse particles. It is clear that the presence of these voids reduces the strength of lightweight concrete compared with ordinary concrete., but in many applications high strength is not essential. Lightweight concrete provides a very good thermal insulation but is not highly resistant to abrasion. In general, lightweight concrete is more expensive than ordinary concrete and mixing, handling and placing also require considerably more care and attention than ordinary concrete. However, for many purposes the advantages of lightweight concrete outweight its disadvantage and there is a world wide trend towards using more lightweight concrete and also towards using it's new applications.

Lightweight concrete can also be classified according to the purpose for which it is to be used.**Structural lightweight concrete** (load bearing) and ordinary or non-structural lightweight concrete(non load bearing such as non-load bearing walls for insulation purposes etc). Structural lightweight concrete should have a compressive strength measured on a standard cylinder specimen at 28 days of not less than 2000 psi. The density of such concrete, determined in dry state, is usually above 60 lb/ft3.

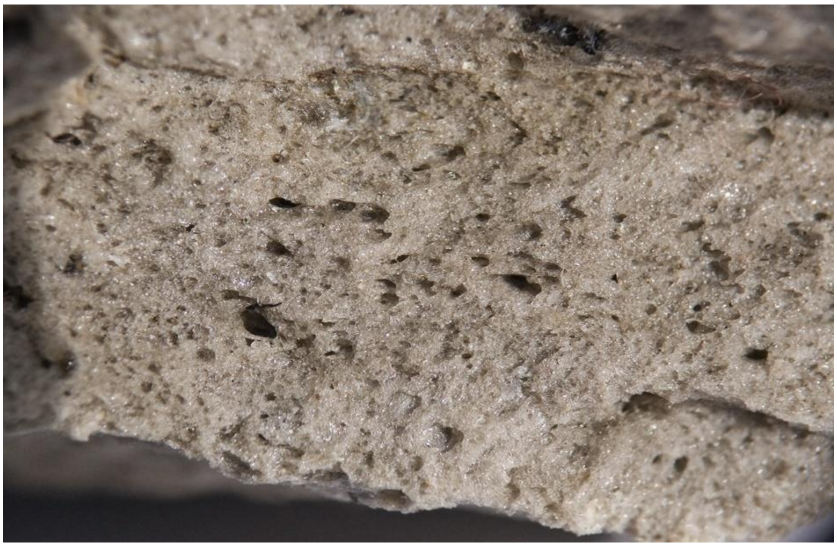
Light weight aggregate

Light weight aggregates can be classified into two categories namely light weight aggregates and artificial light weight aggregate.

Natural aggregate

Although natural aggregate is a high volume/low value commodity that is abundant, new sources are becoming increasingly difficult to find and develop because of rigid industry specifications, political considerations, development and transportation costs, and environmental concerns.

Pumice stone



Pumice is created when super-heated, highly pressurized rock is violently ejected from a volcano. The unusual foamy configuration of pumice happens because of simultaneous rapid cooling and rapid depressurization. The depressurization creates bubbles by lowering the solubility of gases (including water and CO_2) that are dissolved in the lava, causing the gases to rapidly exsolve (like the bubbles of CO_2 that appear when a carbonated drink is opened). The simultaneous cooling and depressurization freezes the bubbles in the matrix. Eruptions under water are rapidly cooled and the large volume of pumice created can be a shipping hazard for cargo ships.

Diatomite

Diatomite is also known as Diatomaceous Earth, Kieselguhr, Kieselgur, and Celite. It is a naturally occurring, soft, chalk-like, sedimentary rock and is primarily composed of the fossilized remains of unicellular fresh water plants, Diatoms. It can be easily crumbled into a fine white to off-white powder. The powder has abrasive feeling which is similar to pumice powder. It is very light-weight because of its porosity.

For millennia, the diatoms have been compresses, creating one of the most effective growing mediums available. Approximately 90% of diatomite is silicon dioxide and the remainder is elemental minerals that are essential for plant growth.

Diatomaceous earth, also known as diatomite, kieselguhr, kieselgur, and Celite, is a naturally occurring, soft, chalk-like, sedimentary rock mineral that is easily crumbled into a fine white to off-white powder. This powder has an abrasive feeling similar to pumice powder and is very light-weight due to its high porosity. It is made primarily of silica and consists of fossilized remains of diatoms, a type of hard-shelled algae. It is used as a filtration aid, as a mild abrasive, as a mechanical insecticide, as an absorbent for liquids, as cat litter, and as a component of dynamite.

Scoria

Scoria is a dark-coloured igneous rock with abundant round bubble-like cavities known as vesicles. It ranges in colour from black or dark grey to deep reddish brown. Scoria usually has a composition similar to basalt, but can also have a composition similar to andesite.

Many people believe that small pieces of scoria look like the ash produced in a coal furnace. That has resulted in particles of scoria being called "cinders" and the small volcanoes that erupt scoria to be called "cinder cones".

Volcanic cinders

Most of the scoria falls to the ground near the vent to build up a cone-shaped hill called a "cinder cone". Cinder cones are generally small volcanoes produced by brief eruptions with a total vertical relief of less than a few thousand feet. They are usually very steep because scoria has an angle of repose of 30 to 40 degrees. In some parts of the world cinder cones occur in clusters of a few to hundreds of individual cones. These areas are called "volcano fields". (See the Google satellite image near the bottom of the right column of this page for a view of a the San Francisco Volcanic Field in Arizona where hundreds of cinder cones can be seen.)

Saw dust

Sawdust or wood dust is a by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood or any other material with a saw or other tool; it is composed of fine particles of wood. It is also the byproduct of certain animals, birds and insects which live in wood, such as the woodpecker and carpenter ant. It can present a hazard in manufacturing industries, especially in terms of its flammability. Sawdust is the main component of particleboard.

A major use of sawdust is for particleboard; coarse sawdust may be used for wood pulp. Sawdust has a variety of other practical uses, including serving as a mulch, as an alternative to clay cat litter, or as a fuel. Until the advent of refrigeration, it was often used in icehouses to keep ice frozen during the summer. It has been used in artistic displays, and as scatter in miniature railroad and other models. It is also sometimes used to soak up liquid spills, allowing the spill to be easily collected or swept aside. As such, it was formerly common on barroom floors.[1] It is used to make Cutler's resin. Mixed with water and frozen, it forms pykrete, a slow-melting, much stronger form of ice.

Sawdust is used in the manufacture of charcoal briquettes. The claim for invention of the first commercial charcoal briquettes goes to Henry Ford who created them from the wood scraps and sawdust produced by his automobile factory.

Rice husk ash (RHA)

RHA, produced after burning of Rice husks (RH) has high reactivity and pozzolanic property. Indian Standard code of practice for plain and reinforced concrete, IS 456- 2000, recommends use of RHA in concrete but does not specify quantities. Chemical compositions of RHA are affected due to burning process and temperature. Silica content in the ash increases with higher the burning temperature. As per study by Houston, D. F. (1972) RHA produced by burning rice husk between 600 and 700°C temperatures for 2 hours, contains 90-95% SiO_2, 1-3% K_2O and < 5% unburnt carbon.

Under controlled burning condition in industrial furnace, conducted by Mehta, P. K. (1992), RHA contains silica in amorphous and highly cellular form, with 50-1000 m^2/g surface area. So use of RHA with cement improves workability and stability, reduces heat evolution, thermal cracking and plastic shrinkage.

This increases strength development, impermeability and durability by strengthening transition zone, modifying the pore-structure, blocking the large voids in the hydrated cement paste through pozzolanic reaction.

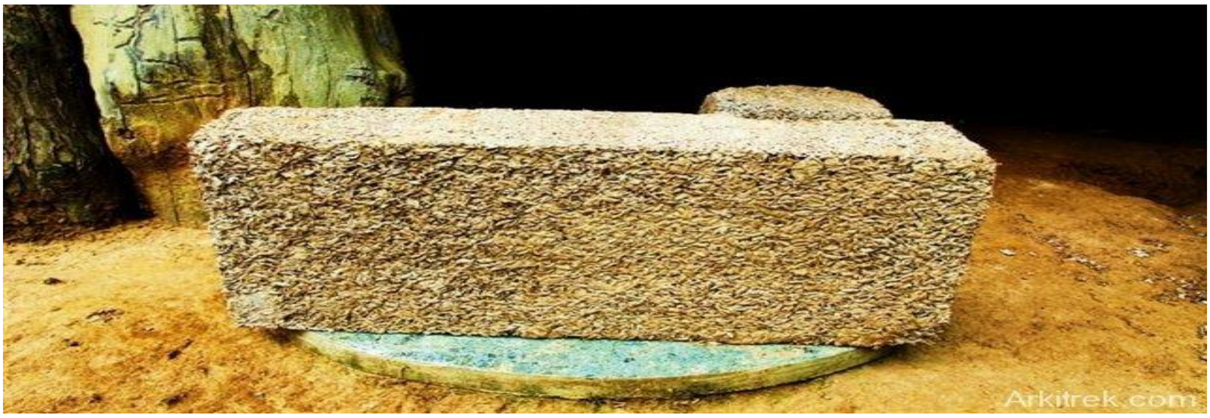
RHA minimizes alkali-aggregate reaction, reduces expansion, refines pore structure and hinders diffusion of alkali ions to the surface of aggregate by micro porous structure.

Portland cement contains 60 to 65% CaO and, upon hydration, a considerable portion of lime is released as free $Ca(OH)_2$, which is primarily responsible for the poor performance of Portland cement concretes in acidic environments.

Silica present in the RHA combines with the calcium hydroxide and results excellent resistance of the material to acidic environments. RHA replacing 10% Portland cement resists chloride penetration, improves capillary suction and accelerated chloride diffusivity.

Pozzolanic reaction of RHA consumes $Ca(OH)_2$ present in a hydrated Portland cement paste, reduces susceptible to acid attack and improves resistance to chloride penetration. This reduces large pores and porosity resulting very low permeability.

The pozzolanic and cementitious reaction associated with RHA reduces the free lime present in the cement paste, decreases the permeability of the system, improves overall resistance to CO_2 attack and enhances resistance to corrosion of steel in concrete. Highly micro porous structure RHA mixed concrete provides escape paths for the freezing water inside the concrete, relieving internal stresses, reducing micro cracking and improving freeze-thaw resistance.



Coconut shell (CS)

The high cost of conventional construction material affects economy of structure. With increasing concern over the excessive exploitation of natural aggregates, synthetic lightweight aggregate produced from environmental waste is a viable new source of structural aggregate material. The uses of structural grade lightweight concrete reduce considerably the self-load of a structure and permit larger precast units to be handled. Recently in the environmental issues, restrictions of local and natural access or sources and disposal of waste material are gaining great importance. Today, it becomes more difficult to find a natural resource. Use of the waste materials not only helps in getting them utilized in cement, concrete and other construction materials, but also has numerous indirect benefits such as reduction in land fill cost, saving in energy, and protecting environment from possible pollution effect. It also helps in reducing the cost of concrete manufacturing. In the present work, coconut shell as partial replacement for coarse aggregate in concrete is studied. The concrete with ground coconut shell was found to be durable in terms of its resistance in water, acidic, alkaline and salty. Density of coconut shell is in the range of 550 - 650 kg/m3 and these are within the specified limits for lightweight aggregate. The characteristic properties of concrete such as compressive strength, flexural strength, impact resistance, bond strength & split tensile strength using the mix made by replacing coarse aggregate with crushed coconut shell aggregate were reviewed in the present work.

Oil palm shell (OPS)

The first part of this experimental program was to determine the structural bond properties of lightweight concrete incorporating solid waste oil palm shell (OPS) as coarse aggregate and also to compare its behaviour with other types of lightweight aggregate concretes. Other properties of OPS concrete namely the split tensile strength, modulus of rupture and modulus of elasticity were also determined. The structural bond properties were determined through pull-out test. The results showed that the experimental bond strength of OPS concrete was much higher than the design bond strength as stipulated by BS 8110. In general, the properties of OPS concrete compared well with that of other structural lightweight concretes and the results obtained encourage the use of OPS as aggregates for the production of structural lightweight concrete. The second part of the experimental program investigates the durability performance of OPS concrete through water permeability and water absorption tests.

Palm kernel shell (PKS)

These concrete mixes of widely differing water/cement ratios were made using palm kernel shell as course aggregate. The properties tested include the physical properties of the shell, the compressive, flexural and tensile splitting strengths of the concrete. These properties were compared with those of similar concrete specimens made with crushed granite as course aggregate. Results of the tests suggest that palm kernel shell cannot produce concrete with compressive strength above 30 MPa. However, for concrete grade 25 and below, the material was found to compare favourably with other conventional aggregate such as crushed granite.

Artificial aggregate

The following light weight aggregates are generally used to produce lightweight concrete:

Brick bats

Waterproofing is a treatment of a surface or structure to prevent the passage of water under hydrostatic pressure. Waterproofing barrier system may be placed on the positive or negative side. Damp proofing is a treatment of a surface or structure to resist the passage of water in the absence of hydrostatic pressure.

A damp proofing barrier system is used to perform the same functions as a waterproofing system but cannot be used to protect against water pressure. Water may be forced through building members by hydrostatic pressure, water vapour gradient, capillary action, wind-driven rain, or any combination of these. This movement is aggravated by porous concrete, cracks or structural defects, or joints that are improperly designed or installed. Leakage of water into structure may cause structural damage, and invariably cause damage to the contents of the structure.

New roofs RB or RCC slabs must be constructed specified by the designer. Roof waterproofing is a widely misunderstood subject. Often inadequate attention given during the construction of RB or RCC roof slab, wrong products used for waterproofing and generally insufficient treatment given, lead to leakage. Movement because of structural deflection, settlement, etc. and steep temperature variation being exposed, cause development of cracks in the roof slab and water start leaking from these cracks.

While constructing RCC roof slab, it should be borne in mind that the practice of using concrete which is not watertight and placing too much reliance on the waterproofing measures is not desirable. Concrete should be made watertight in itself and the waterproofing method should be looked upon as additional safety devices.

The grade of roof slab concrete shall be strictly as specified by the designer. The concrete materials should be properly proportioned, maintaining the specified maximum water, cement ratio, minimum cement content and required workability. The concrete should be admixed with a Super-plasticiser.

Breeze or clinker

Clinker bricks are partially vitrified bricks used in the construction of buildings.

Clinkers are burnt under temperatures so high that the pores of the fuel propertyclosed by the beginning sinter process and are often mis-shapen. Thus they are considerably denser and therefore heavier and more irregular than regular bricks. Clinkers hardly take up water and are very durable, but have higher thermal conductivity than the more porous conventional red bricks, thus lending less insulation to climate-controlled structures. The name comes from the sound they make when banged together.

In early brick firing kilns called brick clamps, the surface of the bricks that were too close to the fire changed into the volcanic textures and darker/purplish colours. They were often discarded, but around 1900, these bricks were discovered by architects to be usable, distinctive and charming in architectural detailing, adding the earthy quality favoured by Arts and Crafts style designers. Modern brick-making techniques can recreate the appearance of these bricks and produce a more consistent product.

In the United States, clinker bricks were made famous by the Pasadena, California architecture firm Greene and Greene who used them (often in combination with native rocks) in walls, foundations, and chimneys.

Foamed slag

In following sections, the properties and use of pelletized slag as a lightweight aggregate will be described largely in terms of experience in Southern Ontario, and the relevant codes and standards in Canada (CSA, ACI, ASTM).For other areas and jurisdictions, local experience, the properties of the available pelletized slag, and relevant codes must of course be considered. Many of the properties of pelletized lightweight slag are similar to those for conventional expanded (foamed) slag. However, there are some important and favourable differences that should be outlined.

Expanded vermiculite slate

Vermiculite is a hydrous phyllosilicate mineral. It undergoes significant expansion when heated. Exfoliation occurs when the mineral is heated sufficiently, and the effect is routinely produced in commercial furnaces. Vermiculite is formed by weathering or hydrothermal alteration of biotite or phlogopite. Large commercial vermiculite mines currently exist in Russia, South Africa, China, and Brazil.

Bloated clay

Clay which has expanded during firing, owing to entrapped air or the breakdown of sulfides or other ingredients in the clay. light and porous; suitable for insulating aggregate inlightweight concrete. Also see expanded clay.

Sintered fly ash

InGlobal Resources, New Delhi focuses on sourcing proven plant and technology, which can produce Artificial Lightweight Aggregate (LWA) from fly ash, a waste product of coal burning power plants. The product is an excellent alternative to natural quarried aggregate, being strong, light and consistent.

- Sintered Flyashlight weight aggregate substitutes natural stone aggregate/chips in Concrete, reducing dead weight.
- It can also be used in production of light weight precast Concrete Blocks, for use in load and non-load bearing elements.
- Local availability of Flyash from Thermal Power plant opens up good potential scope, and more so where stone aggregates are costly or scarce.
- It meets Concrete properties requirements to achieve high compression strength, slump/slump loss, pumpability/workability measured by splitting tensile strength, flexural modulus and modulus of elasticity in Concrete.

Adopted process uses above 90% fly ash mixed with water and in some cases a small volume of additives. After agglomeration and pelletizing, the green pellets are sintered at high temperature, producing light weight aggregate whose characteristics are similar to natural aggregates.

Applications:

- Structural Lightweight Concrete
- Floor and Roof Screeds
- Roof Tiles
- Land Drainage
- Bulk Fill
- Precast
- Arrestor Beds
- Hortag – A Growing Medium
- Filter Media
- Refractory

Energy-Saving and Environmental Protection:

Energy-saving in production process Producer gas from Coal is used for ignition / start of sintering process. After the first layer of sintering bed is ignited, the rest of green pellets will be sintered by the self-contained carbon in fly ash with downdraft air. Gas/Oil can substitute electricity where So ever available and at economic cost.

Energy-saving products Fly ash LWA has an excellent thermal insulation property. The concrete made by fly ash LWA has thermal insulation ratio 0.118 0.6w/m.k, which is much lower than regular concrete. Environmental Protection Fly ash is a by-product of coal burning power plant. Most of fly ash is dumped as waste material.

Using In Global Resources sourced plant and technology; would enable handling large quantity of fly ash, thereby not only saving large volume of scarce land but also protecting air from pollution.

Expanded perlite

Perlite is an amorphous volcanic glass that has a relatively high water content, typically formed by the hydration of obsidian. It occurs naturally and has the unusual property of greatly expanding when heated sufficiently. It is an industrial mineral and a commercial product useful for its light weight after processing.

LIGHTWEIGHT AGGREGATE CONCRETE

The use of LWC (Lightweight concrete) has been a feature in the construction industry for centuries, but like other material the expectations of the performance have raised and now we are expecting a consistent, reliable material and predictable characteristics.

Structural LWC has an in-place density (unit weight) on the order of 90 to 115 lb / ft^3 (1440 to 1840 kg/m^3) compared to normal weight concrete a density in the range of 140 to 150 lb/ft^3 (2240 to 2400 kg/m^3). For structural applications the concrete strength should be greater than 2500 psi (17.0 MPa). The concrete mixture is made with a lightweight coarse aggregate. In some cases a partion or the entire fine aggregates may be a lightweight product. Lightweight aggregates used in structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure. Other products such as air-cooled blast furnace slag are also used. There are other classes of non-structural LWC with lower density made with other aggregate materials and higher air voids in the cement paste matrix, such as in cellular concrete.

Generally, the properties of LWC can be indicated by doing laboratory testing, but the overall performance of the material can only be demonstrated adequately by its performance in the field by testing LWC structure under service. LWC has been successfully used for marine applications and in shipbuilding. LWC ships were produced in the USA during the 1914-1918 war, and their success led to the production of the USS Selma (a war ship). In both 1953 and 1980 the Selma’s durability was assessed by taking cored samples from the water line area. On both occasion little corrosion was noted.

In 1984, Thomas A. Holm estimated that there were over 400 LWC bridges throughout the world especially in USA and Canada. The research carried out by The Expanded Clay and

Slate Institute proves that most of the bridges appeared to be in good condition. According to ACI Material Journal by Diona Marcia, AndrianLoani, MihaiFilip and Ian Pepenar (1994), it was found that in Japan LWC had been used since 1964 as a railway station platform. The study on durability was carried out in 1983 has proven that LWC exhibited similar carbonation depths as normal concrete. Even though some cracks were reported, but these posed no structure problems. A second structure comprising both LWC and normal concrete which had been in sea water for 13 years was examined for salt penetration.

CLASSIFICATION OF LWC

It is convenient to classify the various types of lightweight concrete by their method of production. These are:

1. By using porous lightweight aggregate of low apparent specific gravity, i.e. lower than 2.6. This type of concrete is known as lightweight aggregate concrete.
2. By introducing large voids within the concrete or mortar mass; these voids should be clearly distinguished from the extremely fine voids produced by air entrainment. This types of concrete is variously knows as aerated, cellular, foamed or gas concrete.
3. By omitting the fine aggregate from the mix so that a large number of interstitial voids is present; normal weight coarse aggregate is generally used. This concrete as no-finesconcrete.

LWC can also be classified according to the purpose for which it is to be used: it can distinguish between structural lightweight concrete (ASTM C 330-82a), concrete used in masonry units (ASTM C 331-81), and insulating concrete (ASTM C 332-83).

This classification of structural lightweight concrete is based on a minimum strength: according to ASTM C 330-82a, the 28-day cylinder compressive strength should not be less than 17 MPa (2500 psi). The density (unit weight) of such concrete (determined in the dry state) should not exceed 1840 kg/m^3 (115 lb/ft^3), and is usually between 1400 and 1800 kg/m^3 (85 and 110 lb/ft^3). On the other hand, masonry concrete generally has a density between 500 and 800 kg/m^3 (30 and 50 lb/ft^3) and a strength between 7 and 14 MPa (1000 and 2000 psi).

Concrete of this type has the lowest density, thermal conductivity and strength. Like timber it can be sawn, screwed and nailed, but there are non-combustible. For works insitu the usual methods of aeration are by mixing in stabilized foam or by whipping air in with the aid of an air entraining agent.

The precast products are usually made by the addition of about 0.2 percentaluminums powder to the mix which reacts with alkaline substances in the binder forming hydrogen bubbles. Air-cured aerated concrete is used where little strength is required e.g. roof screeds and pipe lagging. Full strength development depends upon the reaction of lime with the siliceous aggregates, and for the equal densities the strength of high pressure steam cured concrete is about twice that of air-cured concrete, and shrinkage is only one third or less.

Aerated concrete is a lightweight, cellular material consisting of cement and/or lime and sand or other silicious material. It is made by either a physical or a chemical process during which either air or gas is introduced into a slurry, which generally contains no coarse material. Aerated concrete used as a structural material is usually high-pressure steam-cured. It is thus factory-made and available to the user in precast units only, for floors, walls and roofs. Blocks for laying in mortar or glue are manufactured without any reinforcement. Larger units are reinforced with steel bars to resist damage through transport, handling and superimposed loads. Autoclaved aerated concrete, which was originally developed in Sweden in 1929, is now manufactured all over the world.

The term no-fines concrete generally means concrete composed of cement and a coarse (9-19mm) aggregate only (at least 95 percent should pass the 20mm BS sieve, not more than 10 percent should pass the 10mm BS sieve and nothing should pass the 5mm BS sieve), and the product so formed has many uniformly distributed voids throughout its mass. No-fines concrete is mainly used for load bearing, cast in situ external and internal wall, non load bearing wall and under floor filling for solid ground floors (CP III: 1970, BSI). No-fines concrete was introduced into the UK in 1923, when 50 houses were built in Edinburgh, followed a few years later by 800 in Liverpool, Manchester and London.

This description is applied to concrete which contain only a single size 10mm to 20mm coarse aggregate (either a dense aggregate or a light weight aggregate such as sintered PFA). The density is about two-third or three quarters that of dense concrete made with the same aggregates. No-fines concrete is almost always cast in situ mainly as load bearing and non load bearing walls including in filling walls, in framed structures, but sometimes as filling below solids ground floors and for roof screeds.

No-fines concrete is thus an agglomeration of coarse aggregate particles, each surrounded by a coating of cement paste up to about 1·3 mm (0·05 in.) thick. There exist, therefore, large pores within the body of the concrete which are responsible for its low strength, but their large size means that no capillary movement of water can take place. Although the strength of no-fines concrete is considerably lower than that of normal-weight concrete, this strength, coupled with the lower dead load of the structure, is sufficient in buildings up to about 20 storeys high and in many other applications.

LWC CLASSIFICATION

LWC can be classification :-

i. Low density concrete

ii. Moderate strength concrete

iii. Structural concrete

- **LOW DENSITY CONCRETE**

These are employing chiefly for insulation purposes. With low unit weight, seldom exceeding 800 kg/m³, heat insulation value are high. Compressive strength are low, regarding from about 0.69 to 6.89 N/mm2.

- **MODERATE STRENGTH CONCRETE**

The use of these concrete requires a fair degree of compressive strength, and thus they fall about midway between the structural and low density concrete. These are sometimes designed as ‘fill’ concrete. Compressive strength are approximately 6.89 to 17.24 N/mm² and insulation values are intermediate.

- **STRUCTURAL CONCRETE**

Concrete with full structural efficiency contain aggregates which fall on the other end of the scale and which are generally made with expanded shale, clay, slates, slag, and fly-ash. Minimum compressive strength is 17.24 N/mm². Most structural LWC are capable of producing concrete with compressive strength in excess of 34.47 N/mm². Since the unit weight of structural LWC are considerably greater than those of low density concrete, insulation efficiency is lower. However, thermal insulation values for structural LWC are substantially better than NWC.

THE USE OF LWC

- Screeds and thickening for general purposes especially when such screeds or thickening and weight to floors roofs and other structural members.
- Screeds and walls where timber has to be attached by nailing.
- Casting structural steel to protect its against fire and corrosion or as a covering for architectural purposes.
- Heat insulation on roofs.
- Insulating water pipes.
- Construction of partition walls and panel walls in frame structures.

- Fixing bricks to receive nails from joinery, principally in domestic or domestic type construction.
- General insulative walls.
- Surface rendered for external walls of small houses.
- It is also being used for reinforced concrete.

ADVANTAGES OF USING LWC

- Reduced dead load of wet concrete allows longer span to be poured unpropped. This save both labour and circle time for each floor.
- Reduction of dead load, faster building rates and lower haulage and handling costs. The eight of the building in term of the loads transmitted by the foundations is an important factor in design, particular for the case of tall buildings. The use of LWC has sometimes made its possible to proceed with the design which otherwise would have been abandoned because of excessive weight. In frame structures, considerable savings in cost can be brought about by using LWC for the construction floors, partition and external cladding.
- Most building materials such as clay bricks the haulage load is limited not by volume but by weight. With suitable design containers much larger volumes of LWC can haul economically.
- A less obvious but nonetheless important characteristics of LWC is its relatively low thermal conductivity, a property which improves with decreasing density in recent years, with the increasing cost and scarcity of energy sources, more attention has been given the formerly to the need for reducing fuel consumption while maintaining, and indeed improving, comfort conditions buildings. The point is illustrated by fact that a 125mm thick solid wall of aerated concrete will give thermal insulation about four times greater than that of a 230mm clay brick wall.

DURABILITY OF LWC

Durability is defined ass the ability of a material to withstand the effect of its environment. In a building material as chemical attack, physical stress, and mechanical assault:-

- Chemical attack is as aggregate ground-water particularly sulphate, polluted air, and spillage of reactive liquids LWC has no special resistant to these agencies: indeed, it is generally move porous than the ordinary Portland cement. It is not recommended for use below damp-course. A chemical aspects of durability is the stability of the material itself, particularly at the presence of moisture.

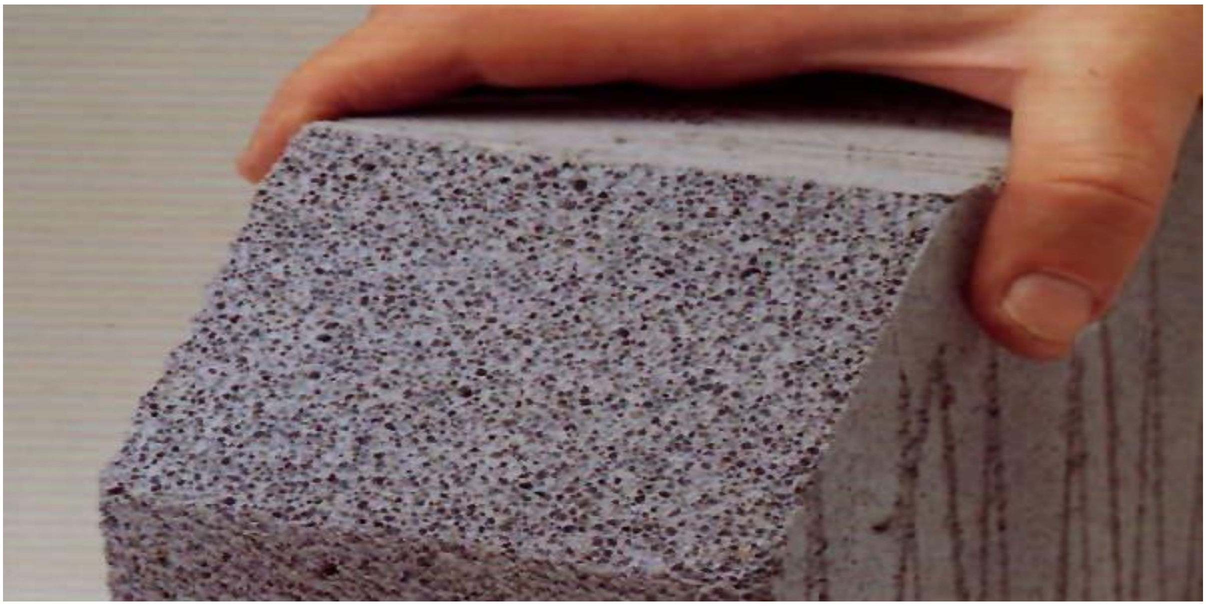
- Physical stresses to which LWC is exposed are principally frost action and shrinkage and temperature stresses. Stressing may be due to the drying shrinkage of the concrete or to differential thermal movements between dissimilar materials or to other phenomena of a similar nature. Drying shrinkage commonly causes cracking of LWC if suitable precautions are not taken.

- Mechanical damage can result from abrasion or impact excessive loading of flexural members. The lightest grades of LWC are relatively soft so that they subject to some abrasion were they not for other reasons protected by rendering.

5.3.1 Application of light weight concrete

- Decks of long span bridges
- Fire and corrosion protection
- Covering for architectural purpose
- Heat insulation on roofs
- Insulation of water pipes
- Filling for floor and roof slabs
- Construction of partition walls and panel walls in framed structures
- Production precast building blocks and low cost housing

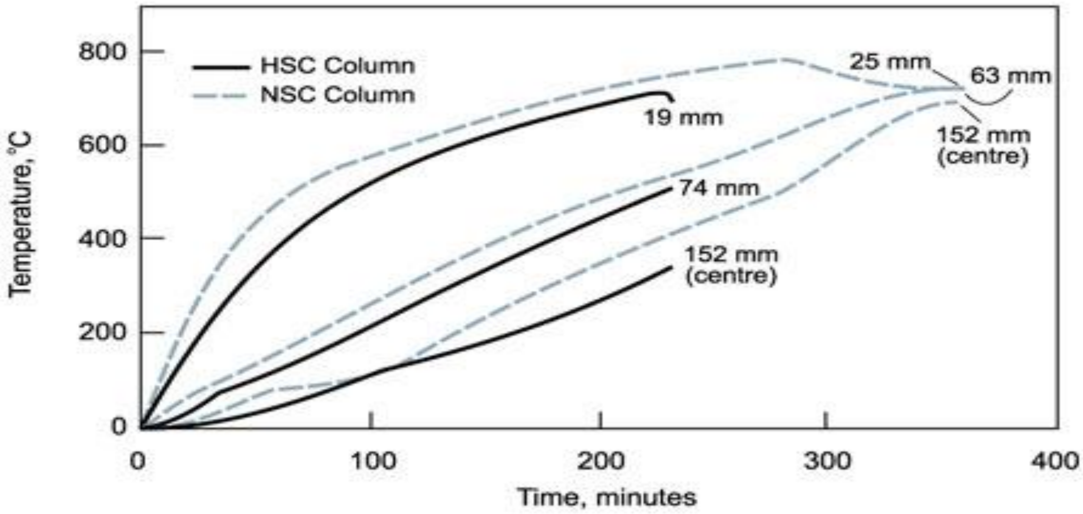
Aerated concrete



Aerated concrete is a lightweight, cellular material consisting of cement and/or lime and sand or other silica material. It is made by either a physical or a chemical process during which either air or gas is introduced into a slurry, which generally contains no coarse material. Aerated concrete used as a structural material is usually high-pressure steam-cured. It is thus factory-made and available to the user in precast units only, for floors, walls and roofs. Blocks for laying in mortar or glue are manufactured without any reinforcement. Larger units are reinforced with steel bars to resist damage through transport, handling and superimposed loads.

Autoclaved aerated concrete, which was originally developed in Sweden in 1929, is now manufactured all over the world.

High strength concrete (HSC)



In the early 1970s, experts predicted that the practical limit of ready-mixed concrete would be unlikely to exceed a compressive strength greater than 11,000 pounds square inch (psi). Over the past two decades, the development of high-strength concrete has enabled builders to easily meet and surpass this estimate. Two buildings in Seattle, Washington, contain concrete with a compressive strength of 19,000 psi.

The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute defines high-strength concrete as concrete with a compressive strength greater than 6,000 psi.

Likewise, there is not a precise point of separation between high-strength concrete and ultra-high performance concrete, which has greater compressive strength than high-strength concrete and other superior properties. See ultra high-performance concrete.

Manufacture of high-strength concrete involves making optimal use of the basic ingredients that constitute normal-strength concrete. Producers of high-strength concrete know what factors affect compressive strength and know how to manipulate those factors to achieve the required strength. In addition to selecting a high-quality portland cement, producers optimize aggregates, then optimize the combination of materials by varying the proportions of cement, water, aggregates, and admixtures.

When selecting aggregates for high-strength concrete, producers consider the strength of the aggregate, the optimum size of the aggregate, the bond between the cement paste and the aggregate, and the surface characteristics of the aggregate. Any of these properties could limit the ultimate strength of high-strength concrete.

Materials for HSC

Most modern HSC contain at least one supplementary cementation material. Fly ash, blast-furnace slag, or silica fume. Very often, fly ash or slag is used in conjuction with silica fume.

Fly ash

Fly ash is a by product from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash.

Fly ash is collected from the exhaust gases by electrostatic precipitators or bag filters. The fine powder does resemble portland cement but it is chemically different. Fly ash chemically reacts with the by product calcium hydroxide released by the chemical reaction between cement and water to form additional cementitious products that improve many desirable properties of concrete.

All fly ashes exhibit cementitious properties to varying degrees depending on the chemical and physical properties of both the fly ash and cement. Compared to cement and water, the chemical reaction between fly ash and calcium hydroxide typically is slower resulting in delayed hardening of the concrete. Delayed concrete hardening coupled with the variability of fly ash properties can create significant challenges for the concrete producer and finisher when placing steel-troweled floors.

Two types of fly ash are commonly used in concrete: Class C and Class F. Class C are often high-calcium fly ashes with carbon content less than 2%; whereas, Class F are generally low-calcium fly ashes with carbon contents less than 5% but sometimes as high as 10%. In general, Class C ashes are produced from burning sub-bituminous or lignite coals and Class F ashes bituminous or anthracite coals.

Performance properties between Class C and F ashes vary depending on the chemical and physical properties of the ash and how the ash interacts with cement in the concrete. Many Class C ashes when exposed to water will react and become hard just like cement, but not Class F ashes. Most, if not all, Class F ashes will only react with the byproducts formed when cement reacts with water

Silica fume

Silica fume, also known as microsilica, (CAS number 69012-64-2, EINECS number 273-761-1) is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete.

It is sometimes confused with fumed silica (also known as pyrogenic silica, CAS number 112945-52-5). However, the production process, particle characteristics and fields of application of fumed silica are all different from those of silica fume.

Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements stem from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste.

Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects therein forcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions and those of humid continental roadways and runways (because of the use of deicing salts) and saltwater bridges.

Super plasticizers

Super plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation(gravel, coarse and fine sands), and to improve the flow characteristics of suspensions such as in concrete applications.

Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste. The strength of concrete increases when the water to cement ratio decreases. However, their working mechanisms lack a full understanding, revealing in certain cases cement-super plasticizer incompatibilities.

The addition of super plasticizer in the truck during transit is a fairly new development within the industry.

Admixtures added in transit through automated slump management systems, such as allows concrete producers to maintain slump until discharge without reducing concrete quality.

Properties of HSC

- Higher flow ability
- Higher elastic modulus
- Higher flexural strength, low permeability,
- Improved abrasion resistance and
- Better durability

Advantages of HSC

- Reduction in member size, resulting in increase in plinth area/useable area and direct savings in the concrete volume saved.
- Reduction in the self-weight and super-imposed DL with the accompanying saving due to smaller foundations.
- Reduction in form-work area and cost with the accompanying reduction in shoring and stripping time due to high early-age gain in strength.
- Construction of High –rise buildings with the accompanying savings in real estate costs in congested areas.
- Longer spans and fewer beams for the same magnitude of loading.
- Reduced axial shortening of compression supporting members.
- Reduction in the number of supports and the supporting foundations due to the increase in spans.
- Reduction in the thickness of floor slabs and supporting beam sections which are a major component of the weight and cost of the majority of structures.
- Superior long term service performance under static, dynamic and fatigue loading.
- Low creep and shrinkage. 11.Greater stiffness as a result of a higher modulus Ec.
- Higher resistance to freezing and thawing, chemical attack, and significantly improved long-term durability and crack propagation.
- Reduced maintenance and repairs.
- Smaller depreciation as a fixed cost.
-

FIBRE REINFORCED CONCRETE (FRC)

Fibre-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres – each of which lend varying properties to the concrete. In addition, the character of fibre-reinforced concrete changes with varying concretes, fibre materials, geometries, distribution, orientation, and densities.

Fibres are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibres produce greater impact–, abrasion–, and shatter–resistance in concrete.

Generally fibres do not increase the flexural strength of concrete, and so cannot replace moment–resisting or structural steel reinforcement. Indeed, some fibres actually reduce the strength of concrete.

The amount of fibres added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibres), termed "volume fraction" (V_f). V_f typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d). Fibres with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fibre's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix. However, fibres that are too long tend to "ball" in the mix and create workability problems.

Some recent research indicated that using fibres in concrete has limited effect on the impact resistance of the materials. This finding is very important since traditionally, people think that ductility increases when concrete is reinforced with fibres. The results also indicated that the use of micro fibres offers better impact resistance to that of longer fibres.

The High Speed 1 tunnel linings incorporated concrete containing 1 kg/m³ of polypropylene fibres, of diameter 18 & 32 μm, giving the benefits noted below.

As for pavements, the most prevalent use for FRC is at toll plazas where non-metallic fibres are used in lieu of metallic reinforcement since they can disrupt electronic toll readers signals.

Basic requirements of fibre

- High tensile strength
- High modulus of elasticity
- Adequate extensibility
- Good bond at the interface
- Chemical stability
- Durability
- Energy absorption
- Resistance to shock and dynamic loading
- Impact and fatigue strength

Properties of FRC

- It has an ability to stop or delay the propagation of cracks
- It get stretched more than concrete under loading
- It has an ability to resist corrosion
- It enhances the tensile strength of concrete
- It enhances the shear strength of concrete
- It enhances the compressive strength of concrete etc.

Factors affecting FRC

Fibre reinforced concrete is the composite material containing fibres in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depends upon the efficient transfer of stress between matrix and the fibres. The factors are briefly discussed below:

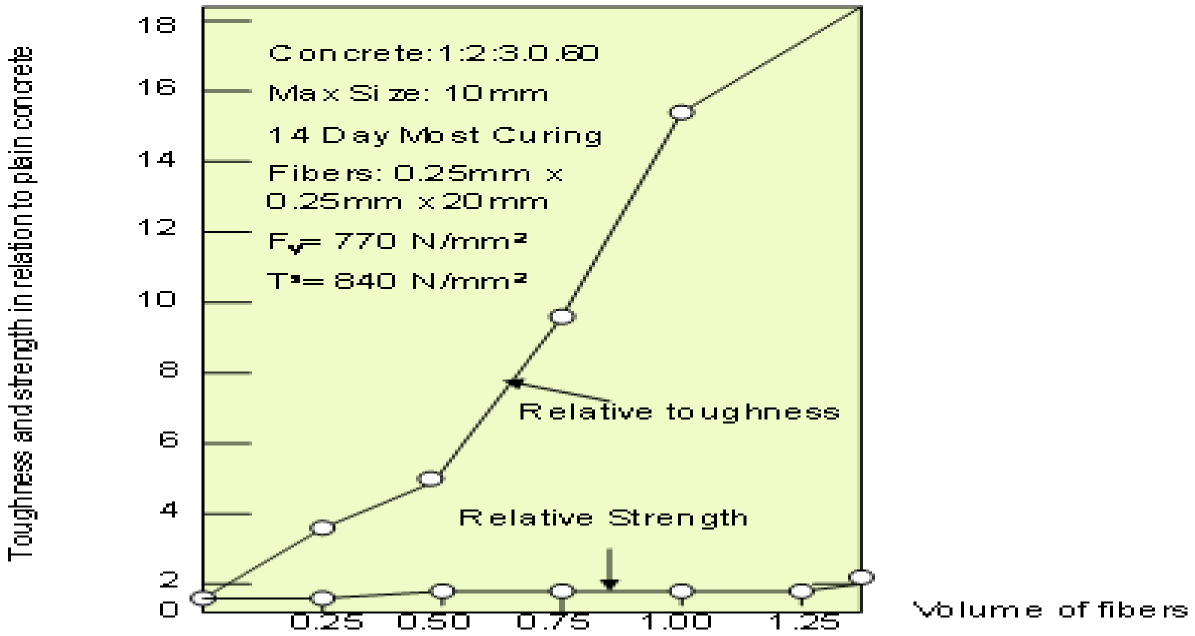
1. Relative Fibre Matrix Stiffness

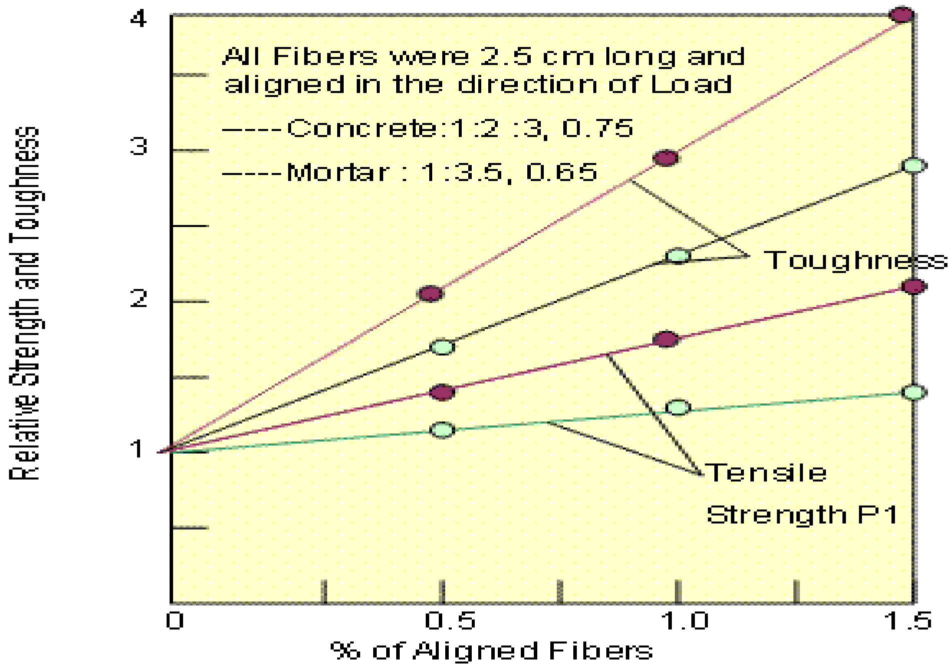
The modulus of elasticity of matrix must be much lower than that of fibre for efficient stress transfer. Low modulus of fibre such as nylons and polypropylene are, therefore, unlikely to give strength improvement, but the help in the absorbsion of large energy and therefore, impart greater degree of toughness and resistance to impart. High modulus fibres such as steel, glass and carbon impart strength and stiffness to the composite.

Interfacial bond between the matrix and the fibre also determine the effectiveness of stress transfer, from the matrix to the fibre. A good bond is essential for improving tensile strength of the composite.

2. Volume of Fibres

The strength of the composite largely depends on the quantity of fibres used in it. Fig 1.1 and 1.2 show the effect of volume on the toughness and strength. It can see from Fig 1.1 that the increase in the volume of fibres, increase approximately linearly, the tensile strength and toughness of the composite. Use of higher percentage of fibre is likely to cause segregation and harshness of concrete and mortar.





3. Aspect Ratio of the Fibre

Another important factor which influences the properties and behavior of the composite is the aspect ratio of the fibre. It has been reported that up to aspect ratio of 75, increase on the aspect ratio increases the ultimate concrete linearly. Beyond 75, relative strength and toughness is reduced.

4. Orientation of Fibres

One of the differences between conventional reinforcement and fibre reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibres are randomly oriented. To see the effect of randomness, mortar specimens reinforced with 0.5% volume of fibres were tested. In one set specimens, fibres were aligned in the direction of the load, in another in the direction perpendicular to that of the load, and in the third randomly distributed.

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

5. Workability and Compaction of Concrete

Incorporation of steel fibre decreases the workability considerably. This situation

adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete. The fibre volume at which this situation is reached depends on the length and diameter of the fibre.

Another consequence of poor workability is non-uniform distribution of the fibers. Generally, the workability and compaction standard of the mix is improved through increased water/ cement ratio or by the use of some kind of water reducing admixtures.

6. Size of Coarse Aggregate

Maximum size of the coarse aggregate should be restricted to 10mm, to avoid appreciable reduction in strength of the composite. Fibres also in effect, act as aggregate. Although they have a simple geometry, their influence on the properties of fresh concrete is complex. The inter-particle friction between fibres and between fibres and aggregates controls the orientation and distribution of the fibres and consequently the properties of the composite. Friction reducing admixtures and admixtures that improve the cohesiveness of the mix can significantly improve the mix.

7. Mixing

Mixing of fibre reinforced concrete needs careful conditions to avoid balling of fibres, segregation and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendency. Steel fibre content in excess of 2% by volume and aspect ratio of more than 100 are difficult to mix.

It is important that the fibres are dispersed uniformly through out the mix; this can be done by the addition of the fibres before the water is added. When mixing in a laboratory mixer, introducing the fibres through a wire mesh basket will help even distribution of fibres. For field use, other suitable methods must be adopted.

DIFFERENT TYPE OF FIBERS

Following are the different type of fibres genrally, used in the construction industries.

1. Steel Fibre Reinforced Concrete

2. Polypropylene Fibre Reinforced (PFR) cement mortar&concrete

3. Glass-Fibre Reinforced Concrete

4. Asbestos Fibres

5. Carbon Fibres

6. Organic Fibres

1. Steel Fibre Reinforced Concrete:-

A no of steel fibre types are available as reinforcement. Round steel fibre the commonly used type are produced by cutting round wire in to short length. The typical diameter lies in the range of 0.25 to 0.75mm. Steel fibres having a rectangular c/s are produced by silting the sheets about 0.25mm thick.

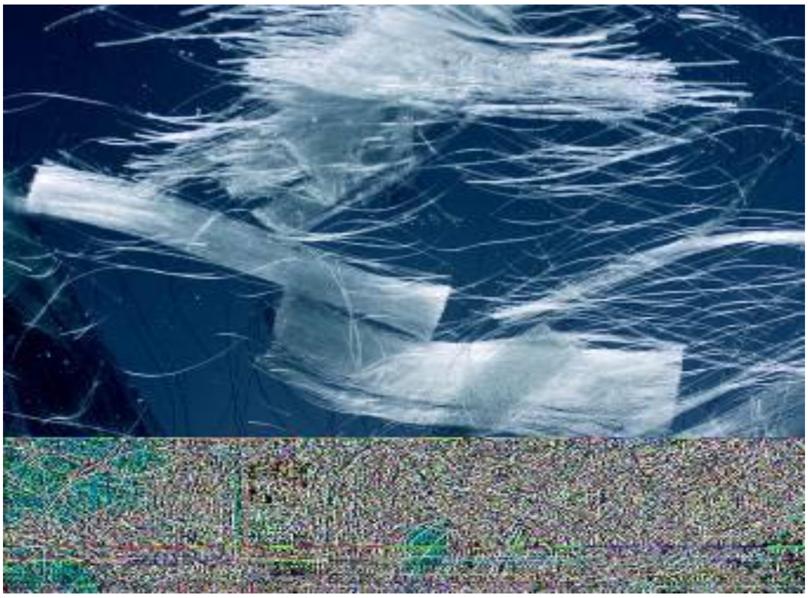
Fibre made from mild steel drawn wire. Conforming to IS:280-1976 with the diameter of wire varying from 0.3 to 0.5mm have been practically used in India. Round steel fibres are produced by cutting or chopping the wire, flat sheet fibres having a typical c/s ranging from 0.15 to 0.41mm in thickness and 0.25 to 0.90mm in width are produced by silting flat sheets. Deformed fibre, which are loosely bounded with water-soluble glue in the form of a bundle are also available. Since individual fibres tend to cluster together, their uniform distribution in the matrix is often difficult. This may be avoided by adding fibres bundles, which separate during the mixing process.

2 Polypropylene Fibre Reinforced (PFR) cement mortar&concrete.-

Polypropylene is one of the cheapest & abundantly available polymers polypropylene fibres are resistant to most chemical & it would be cementitious matrix which would deteriorate first under aggressive chemical attack. Its melting point is high (about 165 degrees centigrade). So that a working temp. As (100 degree centigrade) may be sustained for short periods without detriment to fibre properties.

Polypropylene fibres being hydrophobic can be easily mixed as they do not need lengthy contact during mixing and only need to be evenly distressed in the mix.

Polypropylene short fibres in small volume fractions between 0.5 to 15 commercially used in concrete.



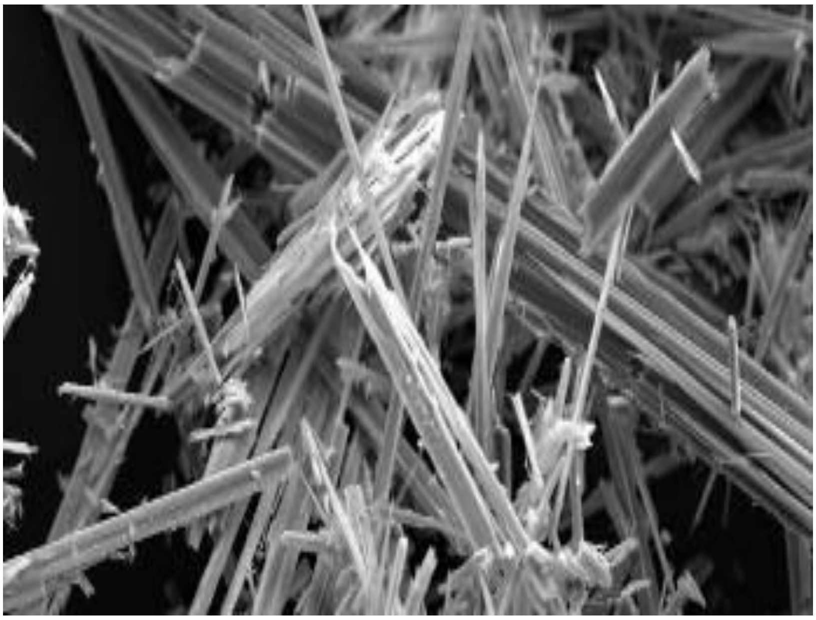
3. Glass-Fibre Reinforced Concrete:-

Glass fibre is made up from 200-400 individual filaments which are lightly bonded to make up a stand. These stands can be chopped into various lengths, or combined to make cloth mat or tape. Using the conventional mixing techniques for normal concrete it is not possible to mix more than about 2% (by volume) of fibres of a length of 25mm.

The major appliance of glass fibre has been in reinforcing the cement or mortar matrices used in the production of thin-sheet products. The commonly used verities of glass fibres are e-glass used. In the reinforced of plastics & AR glass E-glass has inadequate resistance to alkalis present in Portland cement where AR-glass has improved alkali resistant characteristics. Sometimes polymers are also added in the mixes to improve some physical properties such as moisture movement.

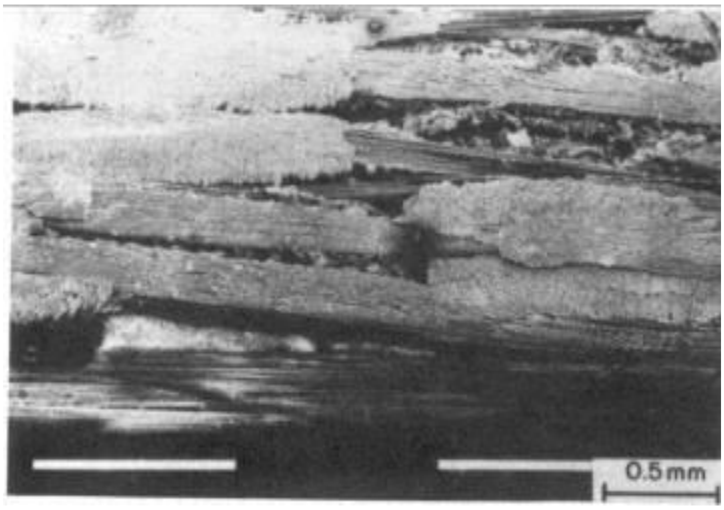
4. Asbestos Fibres:-

The naturally available inexpensive mineral fibre, asbestos, has been successfully combined with Portland cement paste to form a widely used product called asbestos cement. Asbestos fibres here thermal mechanical & chemical resistance making them suitable for sheet product pipes, tiles and corrugated roofing elements. Asbestos cement board is approximately two or four times that of unreinforced matrix. However, due to relatively short length (10mm) the fibre have low impact strength.



5. Carbon Fibres:-

Carbon fibres from the most recent & probability the most spectacular addition to the range of fibre available for commercial use. Carbon fibre comes under the very high modulus of elasticity and flexural strength. These are expansive. Their strength & stiffness characteristics have been found to be superior even to those of steel. But they are more vulnerable to damage than even glass fibre, and hence are generally treated with resign coating.



6. Organic Fibres:-

Organic fibre such as polypropylene or natural fibre may be chemically more inert than either steel or glass fibres. They are also cheaper, especially if natural. A large volume of vegetable fibre may be used to obtain a multiple cracking composite. The problem of mixing and uniform dispersion may be solved by adding a super plasticizer.

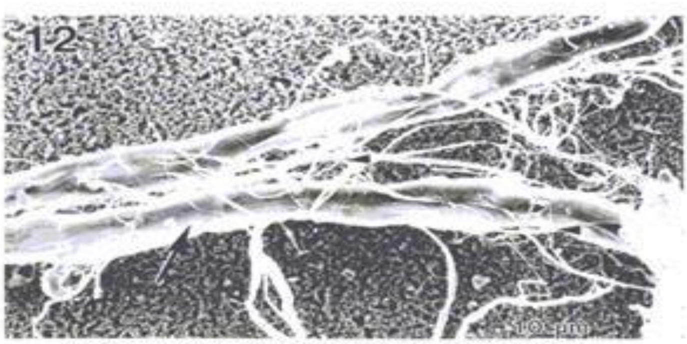


Fig. 1. Scanning electron micrograph of ultrafine Kevlar fibrils (arrowheads) caught on an aerosol filter used for fibre counting
(Warheit et al, 1992; with the permission of Academic Press, Orlando, Florida, USA)

Ready mix concrete

Ready-mix concrete is concrete that is manufactured in a factory or batching plant, according to a set recipe, and then delivered to a work site, by truck mounted in–transit mixers. This results in a precise mixture, allowing specialty concrete mixtures to be developed and implemented on construction sites. The first ready-mix factory was built in the 1930s, but the industry did not begin to expand significantly until the 1980s, and it has continued to grow since then.

Ready-mix concrete is sometimes preferred over on-site concrete mixing because of the precision of the mixture and reduced work site confusion. However, using a pre-determined concrete mixture reduces flexibility, both in the supply chain and in the actual components of the concrete.

Ready-mix concrete is also referred as the customized concrete products for commercial purpose. Ready-mix concrete, or RMC as it is popularly called, refers to concrete that is specifically manufactured for delivery to the customer's construction site in a freshly mixed and plastic or unhardened state. Concrete itself is a mixture of Portland cement, water and aggregates comprising sand and gravel or crushed stone. In traditional work sites, each of these materials is procured separately and mixed in specified proportions at site to make concrete. Read-mix concrete is bought and sold by volume - usually expressed in cubic meters (cubic yards in the US).

Ready-mix concrete is manufactured under controlled operations and transported and placed at site using sophisticated equipment and methods. In 2011, there were 2,223 companies employing 72,924 workers that produced RMC in the United States.

- The materials are batched at a central plant, and the mixing begins at that plant, so the traveling time from the plant to the site is critical over longer distances. Some sites are just too far away, though this is usually a commercial rather than a technical issue.
- Generation of additional road traffic. Furthermore, access roads and site access have to be able to carry the greater weight of the ready-mix truck plus load. (Green concrete is approx. 2.5 tonne per m^3.) This problem can be overcome by utilizing so-called 'mini mix' companies which use smaller $4m^3$ capacity mixers able to reach more-restricted sites.
- Concrete's limited time span between mixing and curing means that ready-mix should be placed within 210 minutes of batching at the plant. Modern admixtures can modify that time span precisely, however, so the amount and type of admixture added to the mix is very important.

  - **Shotcrete** is concrete conveyed through a hose and pneumatically projected at high velocity onto a surface, as a construction technique. It is reinforced by conventional steel rods, steel mesh, and/or fibers. Fiber reinforcement (steel or synthetic) is also used for stabilization in applications such as slopes or tunneling.
  - Shotcrete is usually an all-inclusive term for both the wet-mix and dry-mix versions. In pool construction, however, the term "shotcrete" refers to wet-mix and "gunite" to dry-mix. In this context, these terms are not interchangeable (see "Shotcrete vs. gunite" discussion below).
  - Shotcrete is placed and compacted at the same time, due to the force with the nozzle. It can be sprayed onto any type or shape of surface, including vertical or overhead areas.
  - Siffcon :
  - Slurry Infiltrated Fibrous Reinforced Concrete (SIFCON) is a relatively new high performance and advanced material and can be considered as a special type of Steel Fiber Reinforced Concrete (SFRC).The technique of infiltrated layers of steel fibers with Portland cement based materials was first proposed by Haynes (1968).Lankard (1979) modified the method used by Haynes and proved that if percentage of steel fibers in cement matrix could be increased, one could get a material with very high strength properties which he christened as SIFCON.
  - **SIFCON**
  - SIFCON is unique construction material possessing high strength as well as large ductility and far excellent potential for structural applications when accidental (or) abnormal loads are encountered during services SIFCON also exhibit new behavioral phenomenon, that of "Fiber lock" which believed to be responsible for its outstanding stress-strain properties
  - The matrix in SIFCON has no coarse aggregates, but a high cementitious content. However, it may contain fine (or) coarse sand and additives such as fly ash, micro silica and latex emulsions. The matrix fineness must be designed so as to properly infiltrate the fiber network placed in moulds, since otherwise, large pores may form leading to substantial reduction in properties
  - A controlled quantity of high range water reducing admixtures (super plasticizer) may be used for improving flowing characteristics of SIFCON. All steel fiber types namely straight, hooked and crimped can be used. The fibers are subjected to frictional and mechanical interlock in addition to the bond with the matrix. The matrix plays the role of transferring the forces between fibers by shear, but al so acts as bearing to keep fibers interlock.

- **COMPOSITION OF SIFCON**
- Proportions of cement and sand generally used for making SIFCON are 1:1, 1:1.5 (or) 1:2 cement slurry alone have some applications. Generally, fly ash (or) silica fume equal to 10 to 15% by weight of cement is used in mix. Water cement ratio varies between 0.3 to 0.4. Percentage of super plasticizers varies from 2 to 5% by weight of cement. The percentage of fibers by volume can be any where from 4 to 20% even though the current practical ranges from 4 to 12%.
- **FERROCEMENT :**
- Cement and concrete are used interchangeably but there are technical distinctions and the meaning of cement has changed since the mid-nineteenth century when ferrocementoriginated. Ferro- means iron although metal commonly used in ferro-cement is the iron alloy steel. Cement in the nineteenth century and earlier meant mortar or broken stone or tile mixed with lime and water to form a strong mortar. Today cement usually means Portland cement, Mortar is a paste of a binder (usually Portland cement), sand and water; and concrete is a fluid mixture of Portland cement, sand, water and crushed stone aggregate which is poured into formwork (shuttering). Ferro-concrete is the original name of reinforced concrete (armored concrete) known at least since the 1890s and in 1903 it was well described in London's Society of Engineer's Journal but is now widely confused with ferrocement.
- **Ferrocement** or **ferro-cement** (also called **thin-shell concrete** or **ferro-concrete**) is a system of reinforced mortar or plaster (lime or cement, sand and water) applied over layer of metal mesh, woven expanded-metal or metal-fibers and closely spaced thin steel rods such as rebar, metal commonly used is iron or some type of steel.
- It is used to construct relatively thin, hard, strong surfaces and structures in many shapes such as hulls for boats, shell roofs, and water tanks. Ferrocement originated in the 1840s in France and is the origin of reinforced concrete. It has a wide range of other uses including sculpture and prefabricated building components. The term "ferrocement" has been applied by extension to other composite materials, including some containing no cement and no ferrous material.

HIGH PERFORMANCE CONCRETE:

- 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 cementious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer. The term ‘high performance’ is somewhat pretentious because the essential feature of this concrete is that it’s ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence High performance concrete is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete. 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.

- High Performance concrete works out to be economical, even though it's initial cost is higher than that of conventional concrete because the use of High Performance concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs.
- Concrete is a durable and versatile construction material. It is not only
- Strong, economical and takes the shape of the form in which it is placed, but it is also aesthetically satisfying. However experience has shown that concrete is vulnerable to deterioration, unless precautionary measures are taken during the design and production. For this we need to understand the influence of components on the behavior of concrete and to produce a concrete mix within closely controlled tolerances.
- The conventional Portland cement concrete is found deficient in respect of :
- Durability in severe environs (shorter service life and frequent maintenance)
- Time of construction (slower gain of strength)
- Energy absorption capacity (for earthquake resistant structures)
- Repair and retrofitting jobs.

Hence it has been increasingly realized that besides strength, there are other equally important criteria such as durability, workability and toughness. And hence we talk about 'High performance concrete' where performance requirements can be different than high strength and can vary from application to application.

- High Performance Concrete can be designed to give optimized performance characteristics for a given set of load, usage and exposure conditions consistent with the requirements of cost, service life and durability. The high performance concrete does not require special ingredients or special equipments except careful design and production. High performance concrete has several advantages like improved durability characteristics and much lesser micro cracking than normal strength concrete.
- Any concrete which satisfies certain criteria proposed to overcome limitations of conventional concretes may be called 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. It may also include concrete, which significantly reduces construction time to permit rapid opening or reopening of roads to traffic, without compromising long-

term serviceability. Therefore it is not possible to provide a unique definition of High Performance Concrete without considering the performance requirements of the intended use of the concrete.

Geo polymer concrete

The cement industry is the India's second highest payer of Central Excise and Major contributor to GDP. With infrastructure development growing and the housing sector booming, the demand for cement is also bound to increase. However, the cement industry is extremely energy intensive. After aluminium and steel, the manufacturing of Portland cement is the most energy intensive process as it consumes 4GJ per tonne of energy. After thermal power plants and the iron and steel sector, the Indian cement industry is the third largest user of coal in the country. In 2003-04, 11,400 million kWh of power was consumed by the Indian cement industry. The cement industry comprises 130 large cement plants and more than 300 mini cement plants. The industry's capacity at the beginning of the year 2008-09 was about 198 million tones. The cement demand in India is expected to grow at 10% annually in the medium term buoyed by housing, infrastructure and corporate capital expenditures. Considering an expected production and consumption growth of 9 to 10 percent, the demand-supply position of the cement industry is expected to improve from 2008-09 onwards.

Coal-based thermal power installations in India contribute about 65% of the total installed capacity for electricity generation. In order to meet the growing energy demand of the country, coal-based thermal power generation is expected to play a dominant role in the future as well, since coal reserves in India are expected to last for more than 100 years. The ash content of coal used by thermal power plants in India varies between 25 and 45%. However, coal with an ash content of around 40% is predominantly used in India for thermal power generation. As a consequence, a huge amount of fly ash (FA) is generated in thermal power plants, causing several disposal-related problems. In spite of initiatives taken by the government, several non-governmental organizations and research and development organizations, the total utilization of FA is only about 50%. India produces 130 million tonne of FA annually which is expected to reach 175 million tonne by 2012. Disposal of FA is a growing problem as only 15% of FA is currently used for high value addition applications like concrete and building blocks, the remainder being used for land filling. Globally, less than 25% of the total annual FA produced in the world is utilized. In the USA and China, huge quantities of FA are produced (comparable to that in India) and its reported utilization levels were about 32% and 40%, respectively, during 1995. FA has been successfully used as a mineral admixture component of Portland pozzolan blended cement for nearly 60 years. There is effective utilization of FA in making cement concretes as it extends technical advantages as well as controls the environmental pollution.

Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. GGBS is a glassy, granular, non metallic material consisting essentially of silicates and aluminates of calcium and other bases. Slag when ground to less than 45 micron from coarser, popcorn like friable structure, will have a specific surface of about 400 to 600 m2/kg (Blaine). GGBS has almost the same particle size as cement. GGBS, often blended with Portland cement as low cost filler, enhances concrete workability, density, durability and resistance to alkali-silica reaction.

Alternative but promising gainful utility of FA and GGBS in construction industry that has emerged in recent years is in the form of Geopolymer cement concretes' (GPCCs), which by appropriate process technology utilize all classes and grades of FA and GGBS; therefore there is a great potential for reducing stockpiles of these waste materials.

Importance of Geopolymer Cement Concretes

Producing one tonne of cement requires about 2 tonnes of raw materials (shale and limestone) and releases 0.87 tonne (H" 1 tonne) of CO2, about 3 kg of Nitrogen Oxide (NOx), an air contaminant that contributes to ground level smog and 0.4 kg of PM10 (particulate matter of size 10 µm), an air borne particulate matter that is harmful to the respiratory tract when inhaled. The global release of CO2 from all sources is estimated at 23 billion tonnes a year and the Portland cement production accounts for about 7% of total CO2 emissions. The cement industry has been making significant progress in reducing CO2 emissions through improvements in process technology and enhancements in process efficiency, but further improvements are limited because CO2 production is inherent to the basic process of calcinations of limestone. Mining of limestone has impact on land-use patterns, local water regimes and ambient air quality and thus remains as one of the principal reasons for the high environmental impact of the industry. Dust emissions during cement manufacturing have long been accepted as one of the main issues facing the industry. The industry handles millions of tonnes of dry material. Even if 0.1 percent of this is lost to the atmosphere, it can cause havoc environmentally. Fugitive emissions are therefore a huge problem, compounded by the fact that there is neither an economic incentive nor regulatory pressure to prevent emissions.

The cement industry does not fit the contemporary picture of a sustainable industry because it uses raw materials and energy that are non-renewable; extracts its raw materials by mining and manufactures a product that cannot be recycled. Through waste management, by utilizing the waste by-products from thermal power plants, fertiliser units and steel factories, energy used in the production can be considerably reduced.This cuts energy bills, raw material costs as well as green house gas emissions. In the process, it can turn abundantly available wastes, such as fly ash and slag into valuable products, such as geopolymer concretes.

'Geopolymer cement concretes' (GPCC) are Inorganic polymer composites, which are prospective concretes with the potential to form a substantial element of an environmentally sustainable construction by replacing/supplementing the conventional concretes. GPCC have high strength, with good resistance to chloride penetration, acid attack, etc. These are commonly formed by alkali activation of industrial aluminosilicate waste materials such as FA and GGBS, and have a very small Greenhouse footprint when compared to traditional concretes.

Basics of Geopolymers

The term 'geopolymer' was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure. Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calcium- silicate-hydrates (CSHs) for matrix formation and strength, but utilise the polycondensation of silica and alumina precursors to attain structural strength. Two main constituents of geopolymers are: source materials and alkaline liquids. The source materials on alumino-silicate should be rich in silicon (Si) and aluminium (Al). They could be by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. Geopolymers are also unique in comparison to other aluminosilicate materials (e.g. aluminosilicate gels, glasses, and zeolites). The concentration of solids in geopolymerisation is higher than in aluminosilicate gel or zeolite synthesis.

Composition of Geopolymer Cement Concrete Mixes

Following materials are generally used to produce GPCCs:

- Fly ash,
- GGBS,
- Fine aggregates and
- Coarse aggregates
- Catalytic liquid system (CLS): It is an alkaline activator solution (AAS) for GPCC. It is a combination of solutions of alkali silicates and hydroxides, besides distilled water. The role of AAS is to activate the geopolymeric source materials (containing Si and Al) such as fly ash and GGBS.

Formulating the GPCC Mixes

Unlike conventional cement concretes, GPCCs are a new class of materials and hence, conventional mix design approaches are applicable. The formulation of the GPCC mixtures requires systematic numerous investigations on the materials available.

Preparation of GPCC Mixes

The mixing of ingredients of GPCCs can be carried out in mixers used for conventional cement concretes – such as pan mixer, drum mixer, etc

MECHANICAL PROPERTIES

Compressive Strength: With proper formulation of mix ingredients, 24 hour compressive strengths of 25 to 35 MPa can be easily achieved without any need for any special curing. Such mixes can be considered as self curing. However, GPCC mixes with 28 day strengths up to about 60-70 MPa have been developed at SERC.

Modulus of Elasticity The Young's modulus or modulus of elasticity (ME), Ec of GPCC is taken as tangent modulus measured at the stress level equal to 40 percent of the average compressive strength of concrete cylinders. The MEs of GPCCs are marginally lower than that of conventional cement concretes (CCs), at similar strength levels.

Stress Strain Curves The stress-strain relationship depends upon the ingredients of GPCCs and the curing period.

Rate of Development of Strength This is generally faster in GPCCs, as compared to CCs.

Reinforced GPCC Beams

Load carrying capacity of GPCC beams, are up to about 20% more of CC beams at similar concrete strength levels. Cracking of concrete occurs whenever the tensile strength of the concrete is exceeded. The cracking in reinforced concrete is attributable to various causes such as flexural tensile stresses, diagonal tension, lateral tensile strains, etc. The cracking moment increases as the compressive strength increases in both GPCC and CC beams.

Reinforced concrete structures are generally analyzed by the conventional elastic theory (Clause 22.1 of IS 456:2000) which is equivalent to assuming a linear moment-curvature relationship for flexural members. However, in actual behaviour of beams, non-linear moment curvature relationship is considered. The moment-curvature relation can be idealized to consist of three straight lines with different slopes. The slopes of these line changes as the behaviour of the beam is changed due to increasing load. Thus each straight line indicates different phases of beam history. The moment-curvature relations of GPCCs and CCs are essentially similar.

Ductility factor of the beams is considered as the ratio of deflection at ultimate moment (äU) to the deflection at yield moment (äY). The ductility factor decreases as the tensile reinforcement increased. The ductility factor of GPCC beams could be marginally less than CC beams indicating higher stiffness of GPCC beams. The crack patterns observed for GPCC beams are similar to the CC beams.

Reinforced GPCC Columns

The concrete compressive strength and longitudinal reinforcement ratio influence the load capacity of columns. The load carrying capacity increases with the increase in concrete compressive strength and longitudinal reinforcement ratio. Crack patterns and failure modes of GPCC columns are similar to those of CC columns.

Bond Strength of GPCC with Rebars

The bond strength of GPCCs with rebarsare higher compared to CC. Thus developmental length of steel bars in reinforced GPCC can be kept same, as in the case of reinforced CC. The bond strengths of GPCC and PPCC are significantly more and conservative than the design bond stress recommended in IS: 456-2000. The GPCCs possess satisfactory bond with embedded steel bars so that the conventional design process of reinforced structural components can be applied conservatively to GPCCs also.

Durability Aspects of GPCCS

The GPCC specimens have chloride permeability rating of ‘low’ to ‘very low’ as per ASTM 1202C. GPCCs offer generaly better protection to embedded steel from corrosion as compared to CC. The GPCC are found to possess very high acid resistance when tested under exposure to 2% and 10% sulphuric acids.

Concluding Remarks on GPCCS

From the test data generated at SERC, it can be concluded that GPCCs are good candidates materials of constructions from both strength and durability considerations. Geopolymer concrete shows significant potential to be a material for the future; because it is not only environmentally friendly but also possesses excellent mechanical properties. Practical recommendations on use of geopolymer concrete technology in practical applications such as precast concrete products and waste encapsulation need to be developed in Indian context.

Because of lower internal energy (almost 20% to 30 % less) and lower CO2 emission contents of ingredients of geopolymer based composites compared to those of conventional Portland cement concretes, the new composites can be considered to be more eco-friendly and hence their utility in practical applications needs to be developed and encouraged.