QUALITY CONTROL & MONITARING

Introduction

Quality is depending on planning, architectural dimensioning, structural design construction, material, etc. In different situation meaning of quality is different. Equality of product value is maximum or minimum which depends on user's need. There is a so many meaning of quality

For example

(1) Fitness for purpose
(2) Conformance to requirements
(3) Grade
    *appearance
    *performance
    *life
    *taste
    *odor

In short it means, what-ever purpose you may adopt for product that purpose can be maintained by

(1) Suitability

(2) Reliability

(3) Durability

(4) Safe

(5) Affordability

(6) Maintainability

(7) Economical

(8) Versatility

Building damaged due to poor materials

Poor cement

Poor steel

Chemical water

Inferior sand and other inferior materials of construction

We can assume from this photo that poor material play major role in building collapse

Building collapsed because of poor construction

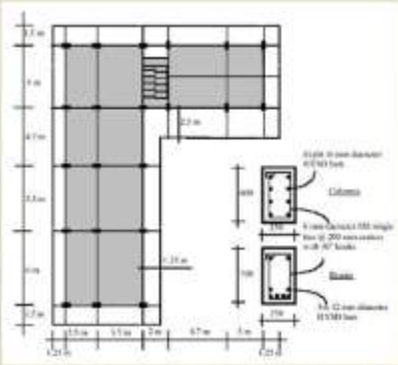
Poor workmanship

Poor supervision

Improper technology

Poor lay-out measurement

Improper Length, heights, depth and thickness Improper measurements of angles at corner



'L' Shaped School Building in Ahmedabad

Orientation of Columns in Longer Wing Was Detrimental

(iii) Vertical Layout of Building:

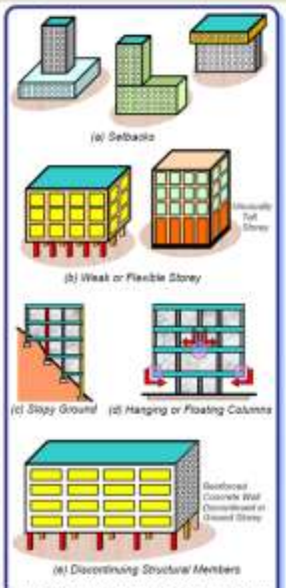


Figure 3: Sudden deviations in load transfer path along the height lead to poor performance of buildings.

- Continuous load path along the height of the building is required for good performance.
- Deviation or discontinuity in the load transfer path results in to poor performance.

(a) Buildings with vertical setbacks cause sudden rise in earth quake forces at the level of discontinuity (Fig 3a)

(b) Buildings with fewer columns or walls in a particular storey or unusually tall storey tend to initiate damage or collapse in that storey (Fig 3b) Many buildings with open parking collapsed during 2001 earthquake.

(c) Buildings on sloping ground tend to twist. (Fig 3c)

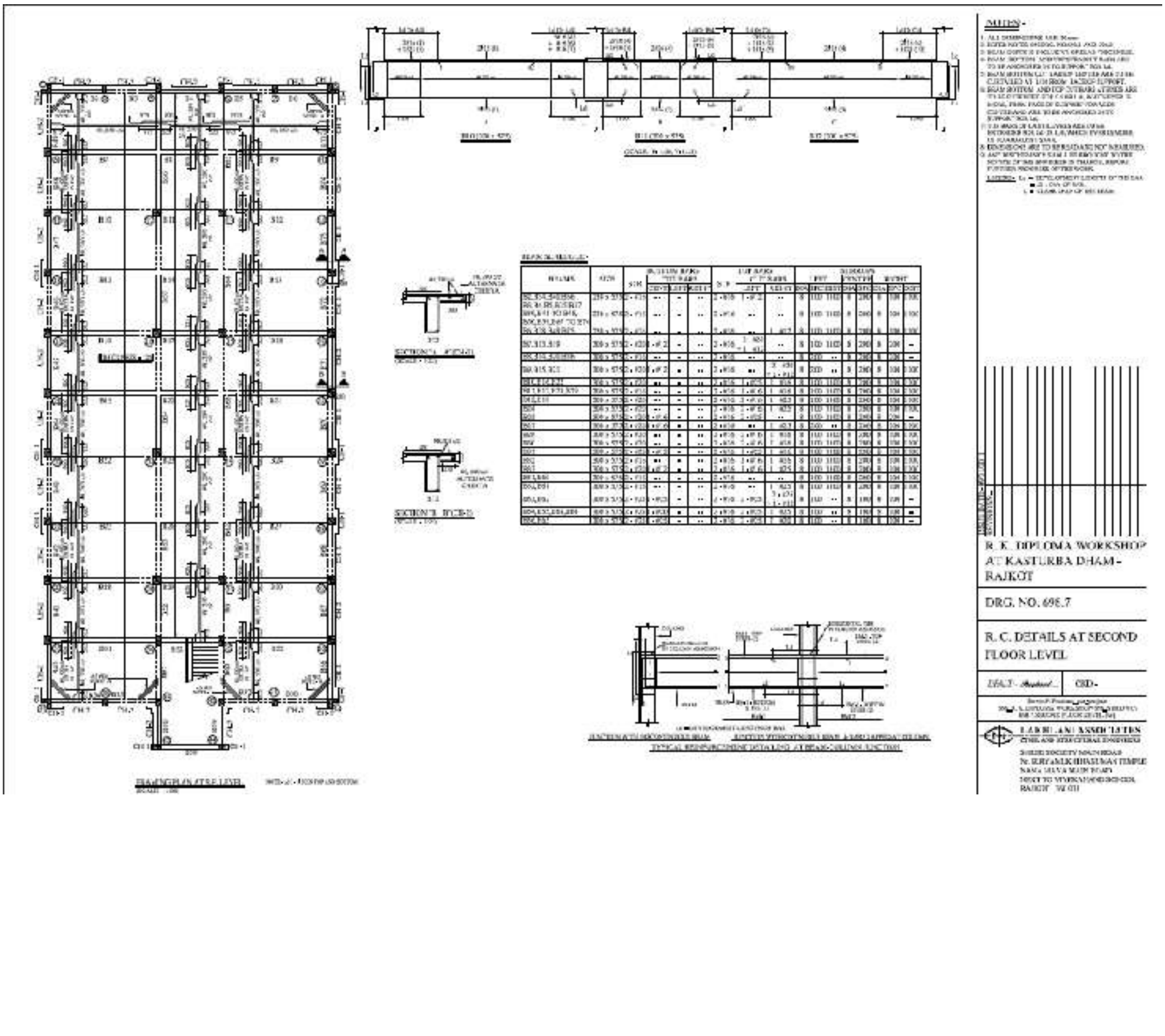
(d) Buildings with floating columns result in to discontinuity in load path (Fig 3d).

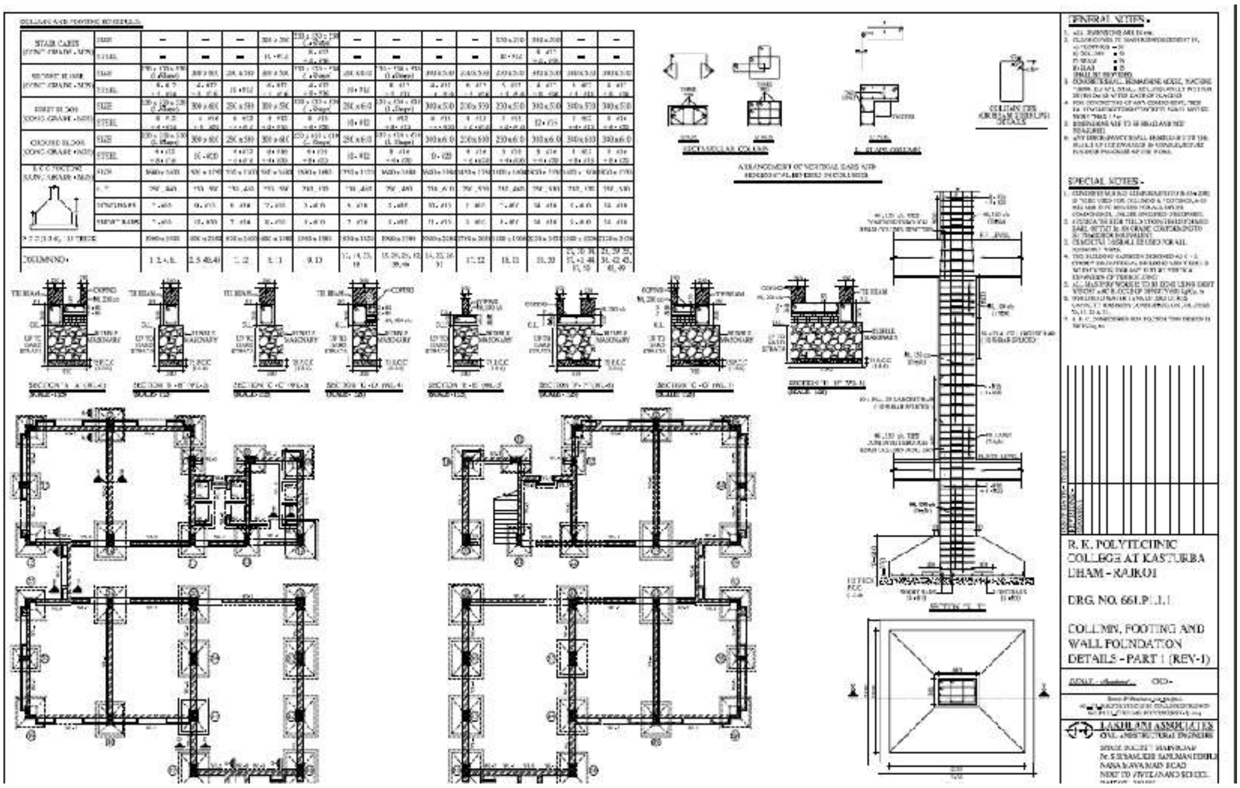
(e) Buildings with concrete walls not reaching up to ground are liable to get damaged. (Fig 3e)

- Architectural features that are detrimental to earthquake response of buildings should be avoided. If not, they must be minimized.

- When irregular features are included in buildings, a considerably higher level of engineering effort is required in the structural design and yet the building may not be as good as one with simple architectural features.

- This does not necessitate buildings with monotonous architectural features. Input from a structural engineer at earlier stage of planning can help to achieve a balance between desired architectural features and structural requirements for the building.





Effect of poor technique on quality of construction

(1) Cement , sand, water , steel, bricks etc quality
(2) Cement, sand , aggregate ratio
(3) Water/cement ratio
(4) Workability
(5) Machine use in construction
(6) Labor- skill & experience
(7) Design of construction material
(8) Supervision

New technique

As given in national building code

Indian standard code (is)

Concept of Ductile design

Concept of Earthquake resistant building

Utility of project: industrial / academic for

(1)Industrial

Industry may come to know about the Reasons of failure .

Quality of material and its measurement

Concept of planning , design, construction ,maintenanc etc

Industries may come to know about the research and development taking place and way of implementation

For example

Concept of architectural dimensioning

Concept structural design

Concept of Ductile design and such many other concepts

Example of architectural dimensions and structural design (concept of ductile desine)

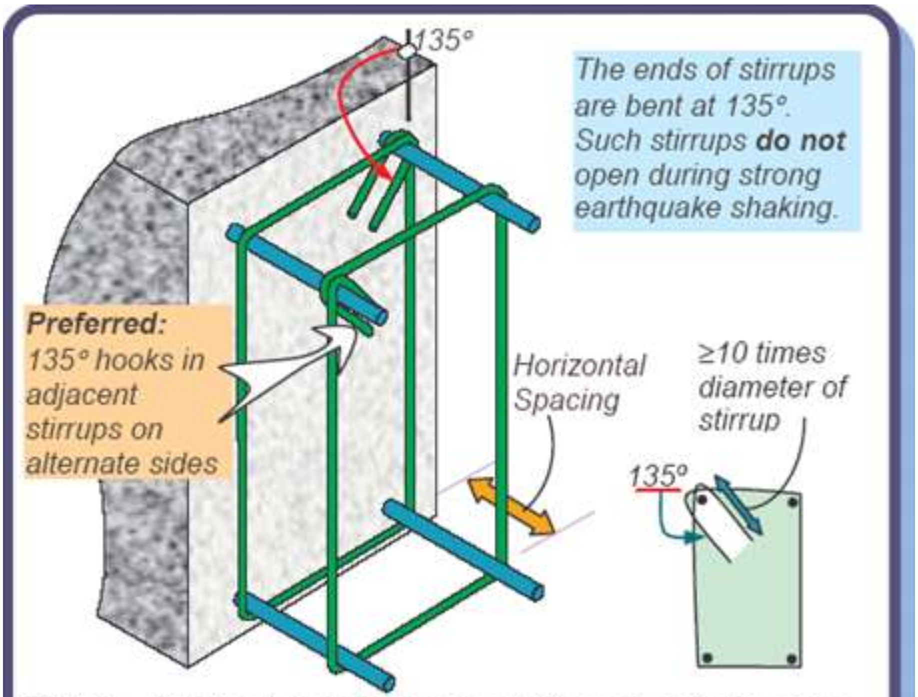


Figure 4: Steel reinforcement in seismic beams
- stirrups with 135° hooks at ends required as per IS:13920-1993.

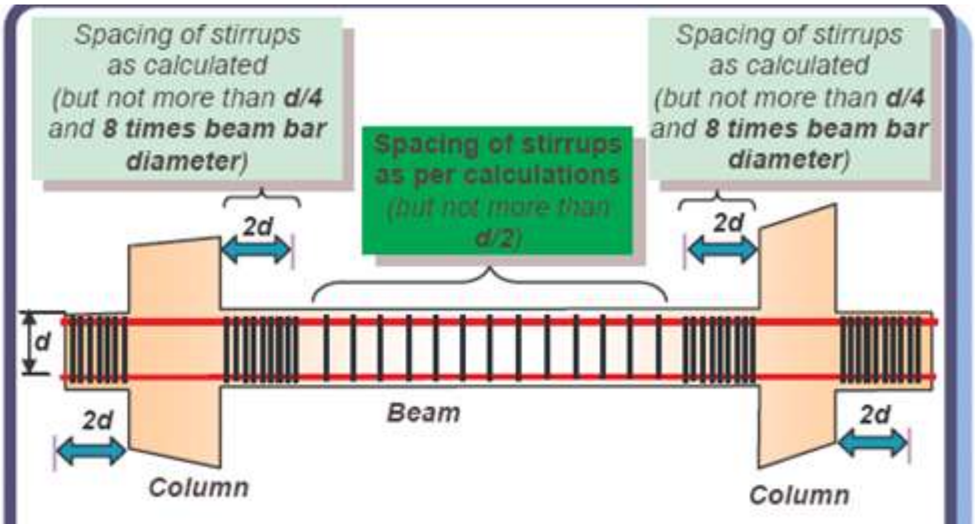
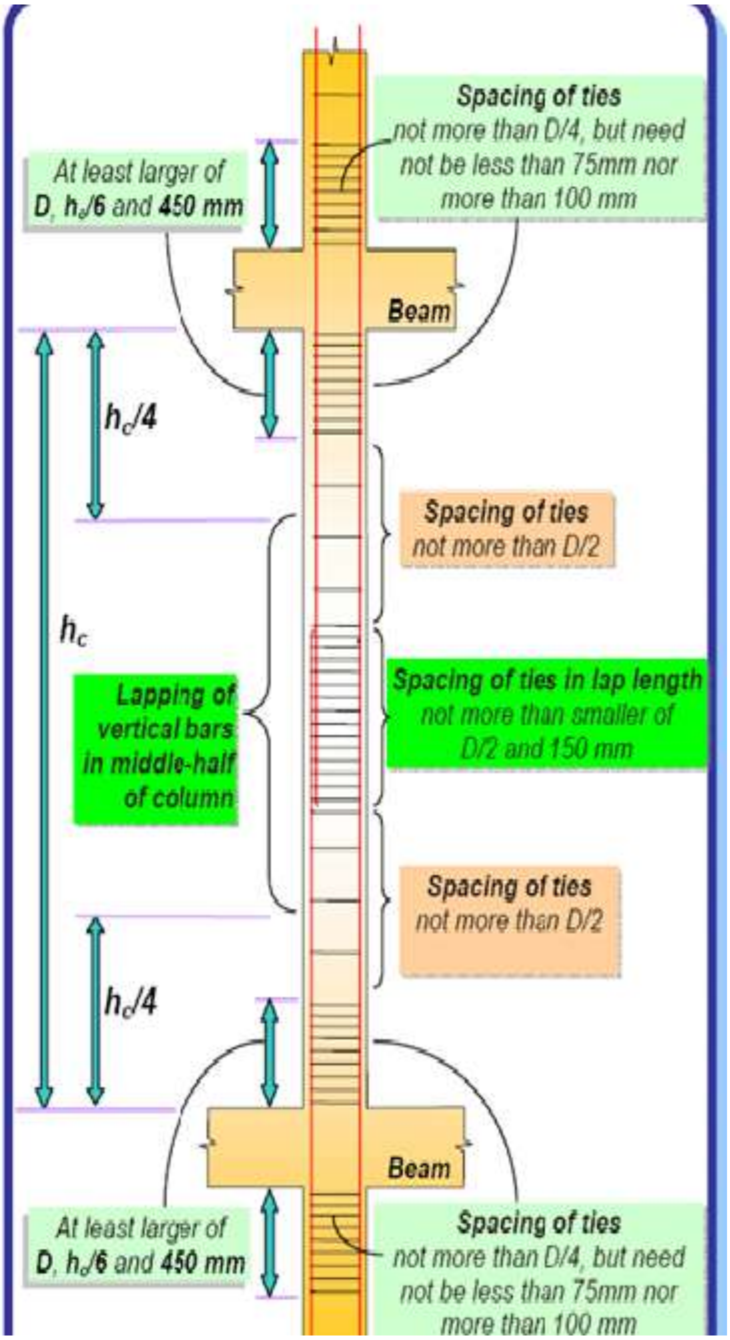


Figure 5: Location and amount of vertical stirrups in beams – *IS:13920-1993 limit on maximum spacing ensures good earthquake behaviour.*


Spacing of ties
not more than D/4, but need
not be less than 75mm nor
more than 100 mm
At least larger of
D, h_c/6 and 450 mm
Beam
h_c/4
Spacing of ties
not more than D/2
h_c
Lapping of
vertical bars
in middle-half
of column
Spacing of ties in lap length
not more than smaller of
D/2 and 150 mm
Spacing of ties
not more than D/2
h_c/4
Beam
At least larger of
D, h_c/6 and 450 mm
Spacing of ties
not more than D/4, but need
not be less than 75mm nor
more than 100 mm

(C) Construction Practices:

- Standard quality structural materials
  - ➢Design Mix Concrete
  - ➢Reinforcement with required strength and ductility
  - ➢Periodical testing of concrete and reinforcement in standard laboratory
- Proven practices for stringent quality control
- Post concreting care

Tools for Quality Control

Check Sheets

Pareto Charts

Why-Why Diagrams

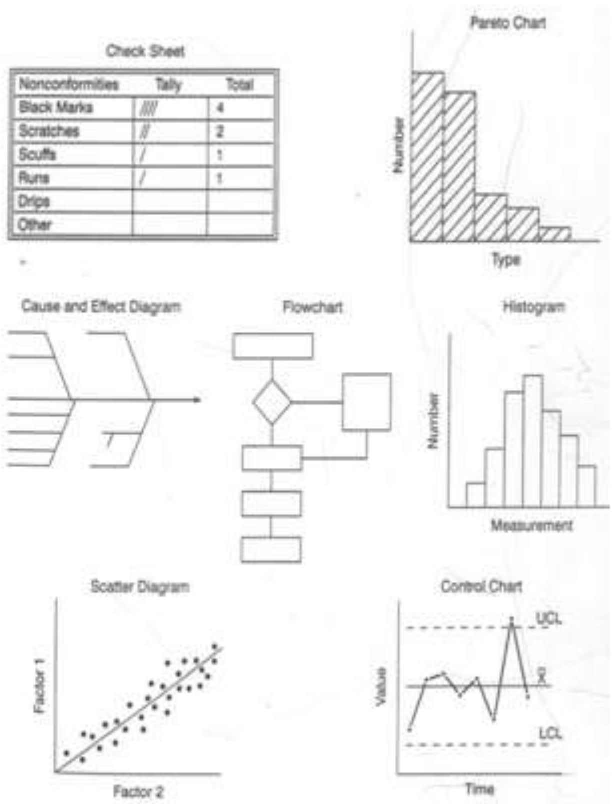
Cause & Effect Diagrams

Flowcharts

Histograms

Scatter Diagram

Control Charts



TypeTypes of Cement and Testing of Cement

I I I n the previous chapter we have discussed various properties of Portland cement in general. We have seen that cements exhibit different properties and characteristics depending upon their chemical compositions. By changing the fineness of grinding or the oxide composition, cement can be made to exhibit different properties. In the past continuous effort swarm dot oproduce different kinds of cement, suitable for different situations by changing oxide composition and fineness of ò

grinding. With the extensive use of cement, for widely varying conditions, the types of cement that could be made only by varying the relative proportions of the oxide compositions, were not found to be sufficient. Recourses have been taken to add one or two more new materials, known as additives, to the clinker at the time of grinding, or to the use of entirely different basic raw materials in the manufacture of cement.

The use of additives, changing chemical composition, and use of different raw materials have resulted in the availability of many types of cements to cater to the need of the construction industries for specific purposes. In this chapter we shall deal with the properties and use of various kinds of cement. These cements are classified as Portland cements and non-Portland cements. The distinction is mainly based on the methods of manufacture. The Portland and Non-Portland cements generally used are listed below: Indian standard specification number is also given against these elements.

Types of Cement

(*a*) Ordinary Portland Cement
(*b*) Rapid Hardening Cement
(*c*) Extra Rapid Hardening Cement
(*d*) Sulphate Resisting Cement
(*e*) Portland Slag Cement
(*f*) Quick Setting Cement
(*g*) Super Sulphated Cement
(*h*) Low Heat Cement

(*j*) Portland Pozzolana Cement

(*k*) Air Entraining Cement
(*l*) Coloured Cement: White Cement
(*m*) Hydrophobic Cement
(*n*) Masonry Cement
(*o*) Expansive Cement
(*p*) Oil Well Cement
(*q*) Rediset Cement
(*r*) Concrete Sleeper grade Cement
(*s*) High Alumina Cement

Ordinary Portland Cement

Ordinary Portland cement (OPC) is by far the most important type of cement. All the discussions that we have done in the previous chapter and most of the discussions that are going to be done in the coming chapters relate to OPC. Prior to 1987, there was only one grade of OPC which was governed by IS 269-1976. After 1987 higher grade cements were introduced in India. The OPC was classified into three grades, namely 33 grade, 43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. If the 28 days strength is not less than 33N/mm , it is called 33 grade cement, if the 2 strength is not less than 43N/mm , it is called 43 grade cement, and if the strength is not less 2 then 53 N/mm , it is called 53 grade cement. But the actual strength obtained by these 2 cements at the factory are much higher than the BIS specifications.

The physical and chemical properties of 33, 43 and 53 grade OPC are shown in Table 2.5 and 2.6.

It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, closer on line control of constituents, maintaining better particle size distribution, finer grinding and better packing. Generally use of high grade cements offer many advantages for making stronger concrete. Although they are little costlier than low grade cement, they offer 10-20% savings in cement consumption and also they offer many other hidden benefits. One of the most important benefits is the faster rate of development of strength. In the modern construction activities, higher grade cements have become so popular that 33 grade cement is almost out of the market. Table 2.9 shows the grades of cement manufactured in various countries of the world.

The manufacture of OPC is decreasing all over the world in view of the popularity of blended cement on account of lower energy consumption, environmental pollution, economic and other technical reasons. In advanced western countries the use of OPC has come down to about 40 per cent of the total cement production. In India for the year 1998-99 out of the total cement production *i.e.* , 79 million tons, the production of OPC in 57.00 million tons *i.e.* , 70%. The production of PPC is 16 million tone *i.e.* , 19% and slag cement is 8 million tons *i.e.* , 10%. In the years to come the use of OPC may still come down, but all the same the OPC will remain as an important type for general construction.

The detail testing methods of OPC is separately discribed at the end of this chapter.

Rapid Hardening Cement

This cement is similar to ordinary Portland cement. As the name indicates it develops strength rapidly and as such it may be more appropriate to call it as high early strength cement. It is pointed out that rapid hardening cement which develops higher rate of development of strength should not be confused with quick-setting cement which only sets quickly. Rapid hardening cement develops at the age of three days, the same strength as that is expected of ordinary Portland cement at seven days.

The rapid rate of development of strength is attributed to the higher fineness of grinding (specific surface not less than 3250 sq. cm per gram) and higher C_3S and lower C_2S content.

A higher fineness of cement particles expose greater surface area for action of water and also higher proportion of C_3S results in quicker hydration. Consequently, capid hardening cement gives out much greater heat of hydration during the early period. Therefore, rapid hardening cement should not be used in mass concrete construction.

The use of rapid heading cement is recommended in the following situations:

(*a*) In pre-fabricated concrete construction.

(*b*) Where formwork is required to be removed early for re-use elsewhere,

(*c*) Road repair works,

(*d*) In cold weather concrete where the rapid rate of development of strength reduces the vulnerability of concrete to the frost damage.

The physical and chemical requirements of rapid hardening cement are shown in Tables 2.5 and 2.6 respectively.

Extra Rapid Hardening Cement

Extra rapid hardening cement is obtained by intergrinding calcium chloride with rapid hardening Portland cement. The normal addition of calcium chloride should not exceed 2 per cent by weight of the rapid hardening cement. It is necessary that the concrete made by using extra rapid hardening cement should be transported, placed and compacted and finished within about 20 minutes. It is also necessary that this cement should not be stored for more than a month.

Extra rapid hardening cement accelerates the setting and hardening process. A large quantity of heat is evolved in a very short time after placing. The acceleration of setting, hardening and evolution of this large quantity of heat in the early period of hydration makes the cement very suitable for concreting in cold weather, The strength of extra rapid hardening .cement is about 25 per cent higher than that of rapid hardening cement at one or two days and 10–20 per cent higher at 7 days. The gain of strength will disappear with age and at 90 days the strength of extra rapid hardening cement or the ordinary portland cement may be nearly the same.

There is some evidence that there is small amount of initial corrosion of reinforcement when extra rapid hardening cement is used, but in general, this effect does not appear to be progressive and as such there is no harm in using extra rapid hardening cement in reinforced concrete work. However, its use in prestress concrete construction is prohibited.

In Russia, the attempt has been made to obtain the extra rapid hardening property by grinding the cement to a very fine degree to the extent of having a specific surface between 5000 to 6000 sq. cm/gm. The size of most of the particles are generally less than 3 microns It is found that this very finely ground cement is difficult to store as it is liable to air-set. It is not a common cement and hence it is not covered by Indian standard.

Sulphate Resisting Cement

Ordinary Portland cement is susceptible to the attack of sulphates, in particular to the action of magnesium sulphate. Sulphates react both with the free calcium hydroxide in set-cement to form calcium sulphate and with hydrate of calcium aluminate to form calcium sulphoaluminate, the volume of which is approximately 227% of the volume of the original aluminates. Their expansion within the frame work of hadened cement paste results in cracks and subsequent disruption. Solid sulphate do not attack the cement compound. Sulphates in solution permeate into hardened concrete and attack calcium hydroxide, hydrated calcium aluminate and even hydrated silicates.

The above is known as sulphate attack. Sulphate attack is greatly accelerated if accompanied by alternate wetting and drying which normally takes place in marine structures in the zone of tidal variations.

To remedy the sulphate attack, the use of cement with low C3A content is found to be effective. Such cement with low C3A and comparatively low C4AF content is known as Sulphate Resisting Cement. In other words, this cement has a high silicate content. The specification generally limits the C3A content to 5 per cent.

Tetracalcium Alumino Ferrite (C3AF) varies in Normal Portland Cement between to 6 to 12%. Since it is often not feasible to reduce the AlO2 3 content of the raw material, FeO2 3 may be added to the mix so that the C4AF content increases at the expense of C 3A. IS code limits the total content of C4AF and C3A, as follows.

2C 3A 4+ C3AF should not exceed 25%.

In many of its physical properties, sulphate resisting cement is similar to ordinary Portland cement. The use of sulphate resisting cement is recommended under the following conditions:

(*a*) Concrete to be used in marine condition;

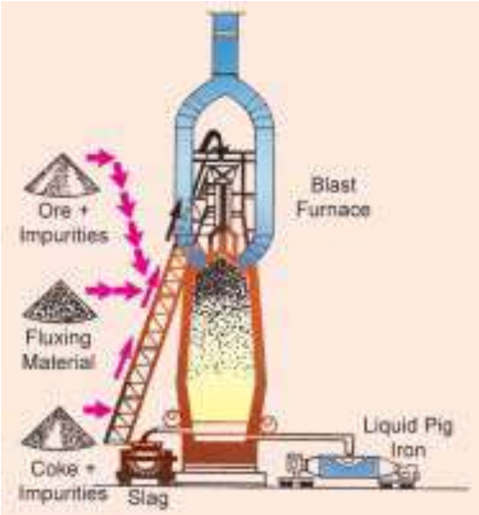
(*b*) Concrete to be used in foundation and basement, where soil is infested with sulphates;

(*c*) Concrete used for fabrication of pipes which are likely to be buried in marshy region or sulphate bearing soils;

(*d*) Concrete to be used in the construction of sewage treatment works.

Portland Slag Cement (PSC)

Portland slag cement is obtained by mixing Portland cement clinker, gypsum and granulated blast furnace slag in suitable proportions and grinding the mixture to get a thorough and intimate mixture between the constituents. It may also be manufactured by separately grinding Portland cement clinker, gypsum and ground granulated blast furnace slag
and later mixing them intimately. The resultant product is a cement which has physical properties similar to those of ordinary Portland cement. In addition, it has low heat of hydration and is relatively better resistant to chlorides, soils and water containing excessive
amount of sulphates or alkali metals, alumina and iron, as well as, to acidic waters, and therefore, this can be used for marine works with advantage.



The manufacture of blast furnace slag cement has been developed primarily to utilize blast furnace slag, a waste product from blast furnaces. The development of this type of cement has considerably increased the total output of cement production in India and has, in addition, provided a scope for profitable use for an otherwise waste product. During 98-99 India produced 10% slag cement out of 79 million tons.

The quantity of granulated slag mixed with portland clinker will range from 25-65 per cent. In different countries this cement is known in different names. The quantity of slag mixed also will vary from country to country strength is mainly due to the cement clinker fraction and later strength is that due to the slag fraction. Separate grinding is used as an easy
means of verying the slag clinker proportion in the finished cement to meet the market demand. Recently, under Bombay Sewage disposal project at Bandra, they have used 70%
ground granulated blast furnace slag (GGBS) and 30% cement for making grout to fill up the
trench around precast sewer 3.5 m dia embedded 40 m below MSL.

Portland blast furnace cement is similar to ordinary Portland cement with respect to fineness, setting time, soundness and strength. It is generally recognised that the rate of hardening of Portland blast furnace slag cement in mortar or concrete is somewhat slower than that of ordinary Portland cement during the first 28 days, but thereafter increases, so that
at 12 months the strength becomes close to or even exceeds those of Portland cement.

The heat of hydration of Portland blast furnace cement is lower than that of ordinary Portland cement. So this cement can be used in mass concrete structures with advantage. However, in cold weather the low heat of hydration of Portland blast furnace cement coupled with moderately low rate of strength development, can lead to frost damage.

Extensive research shows that the presence of GGBS leads to the enhancement of the intrinsic properties of the concrete both in fresh and hardened states. The major advantages currently recognised are:

(*a*) Reduced heat of hydration;
(*b*) Refinement of pore structure;
(*c*) Reduced permeability;
(*d*) Increased resistance to chemical attack.

It is seen that in India when the Portland blast furnace slag cement was first introduced it met with considerable suspicion and resistance by the users. This is just because some manufacturers did not use the right quality of slag. It has been pointed out that only glassy granulated slag could be used for the manufacture of slag cement. Air-cooled crystallined slag cannot be used for providing cementitious property. The slag which is used in the manufacture of various slag cement is chilled very rapidly either by pouring it into a large body of water or by subjecting the slag stream to jets of water, or of air and water. The purpose is to cool the slag quickly so that crystallisation is prevented and it solidifies as glass. The product is called granulated slag. Only in this form the slag should be used for slag cement. It the slag prepared in any other form is used, the required quality of the cement will not be obtained.

Portland slag cement exhibits very low diffusivity to chloride ions and such slag cement gives better resistance to corrosion of steel reinforcement.

Quick Setting Cement

This cement as the name indicates sets very early. The early setting property is brought out by reducing the gypsum content at the time of clinker grinding. This cement is required to be mixed, placed and compacted very early. It is used mostly in under water construction where pumping is involved. Use of quick setting cement in such conditions reduces the pumping time and makes it economical. Quick setting cement may also find its use in some typical grouting operations.

Super Sulphated Cement

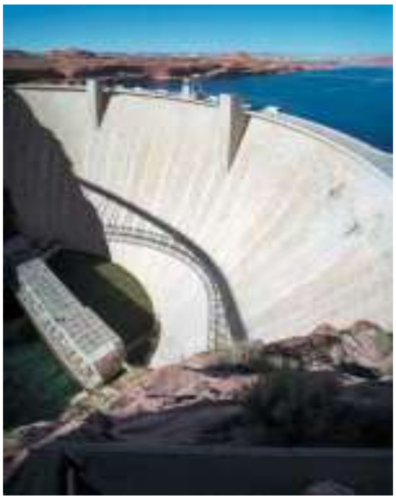
Super sulphated cement is manufactured by grinding together a mixture of 80-85 per cent granulated slag, 10-15 per cent hard burnt gypsum, and about 5 per cent Portland cement clinker. The product is ground finer than that of Portland cement. Specific surface must not be less than 4000 cm^2 per gm. The super-sulphated cement is extensively used in Belgium, where it is known as "ciment metallurgique sursulfate." In France, it is known as "ciment sursulfate".

This cement is rather more sensitive to deterioration during storage than Portland cement. Super-sulphated cement has a low heat of hydration of about 40-45 calories/gm at 7 days

and
45-50 at 28 days. This cement has high sulphate resistance. Because of this property this cement is particularly recommended for use in foundation, where chemically aggressive conditions exist. As super-sulphated cement has more resistance than Portland blast furnace
slag cement to attack by sea water, it is also used in the marine works. Other areas where super-sulphated cement is recommended include the fabrication of reinforced concrete pipes
which are likely to be buried in sulphate bearing soils. The substitution of granulated slag is
responsible for better resistance to sulphate attack.

Super-sulphated cement, like high alumina cement, combines with more water on hydration than Portland cements. Wet curing for not less than 3 days after casting is essential
as the premature drying out results in an undesirable or powdery surface layer. When we use super sulphated cement the water/cement ratio should not be less than 0.5. A mix leaner than about 1:6 is also not recommended.

Low Heat Cement



It is well known that hydration of cement is an exothermic action which produces large quantity of heat during hydration. This aspect has been discussed in detail in Chapter 1. Formation of cracks in large body of concrete due to heat of hydration has focussed the attention of the concrete technologists to produce a kind of cement which produces less heat or the same amount of heat, at a low rate during the hydration process. Cement having this property was developed in U.S.A. during 1930 for use in mass concrete construction, such as dams, where temperature rise by the heat of hydration can become excessively large. A low-heat evolution is achieved by reducing the contents of C3S and C3A which are the compounds evolving the maximum heat of hydration and increasing C S2. A reduction of temperature will retard the chemical action of hardening and so further restrict the rate of evolution of heat. The rate of evolution of heat will, therefore, be less and evolution of heat will extend over a longer period. Therefore, the feature of low-heat cement is a slow rate of gain of strength. But the ultimate strength of low-heat cement is the same as that of ordinary Portland cement. As per the Indian
Standard Specification the heat of hydration of low-heat Portland cement shall be as follows:

7 days — not more than 65 calories per gm.

28 days — not more than 75 calories per gm.

The specific surface of low heat cement as found out by air-permeability method is not
less than 3200 sq. cm/gm. The 7 days strength of low heat cement is not less than 16 MPa
in contrast to 22 MPa in the case of ordinary Portland cement. Other properties, such as setting time and soundness are same as that of ordinary Portland cement.

Portland Pozzolana Cement

The history of pozzolanic material goes back to Roman' s time. The descriptions and details
of pozzolanic material will be dealt separately under the chapter 'Admixtures'. However

a brief description is given below.

Portland Pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 10 to 25 per cent of pozzolanic material (as per the latest amendment, it is 15 to 35%). A pozzolanic material is essentially a silicious or aluminous material which while in itself possessing no cementitious properties, which will, in finely divided form and in the presence of water, react with calcium hydroxide, liberated in the hydration process, at ordinary temperature, to form compounds possessing cementitious properties. The pozzolanic materials generally used for manufacture of PPC are calcined clay (IS 1489 part 2 of 1991) or fly ash (IS 1489 part I of 1991). Fly ash is a waste material, generated in the thermal power station, when powdered coal is used as a fuel. These are collected in the electrostatic precipitator. (It is called pulverised fuel ash in UK). More information on fly ash as a mineral admixture is given in chapter 5.

It may be recalled that calcium silicates produce considerable quantities of calcium hydroxide, which is by and large a useless material from the point of view of strength or durability. If such useless mass could be converted into a useful cementitious product, it considerably improves quality of concrete. The use of fly ash performs such a role. The pozzolanic action is shown below:

Calcium hydroxide + Pozzolana + water   C – S – H (gel)

Portland pozzolana cement produces less heat of hydration and offers greater resistance to the attack of aggressive waters than ordinary Portland cement. Moreover, it reduces the leaching of calcium hydroxide when used in hydraulic structures. It is particularly useful in marine and hydraulic construction and other mass concrete constructions. Portland pozzolana cement can generally be used where ordinary Portland cement is usable. However, it is important to appreciate that the addition of pozzolana does not contribute to the strength at early ages. Strengths similar to those of ordinary Portland cement can be expected in general only at later ages provided the concrete is cured under moist conditions for a sufficient period.

In India there is apprehension in the minds of the user to use the Portland pozzolana cement for structural works. It can be said that this fear is not justified. If the Portland pozzolana cement is manufactured by using the right type of reactive pozzolanic material, the Portland pozzolanic cement will not be in any way inferior to ordinary Portland cement except for the rate of development of strength upto 7 days. It is only when inferior pozzolanic materials, which are not of reactive type and which do not satisfy the specifications limit for pozzolanic materials, are used the cement would be of doubtful quality. The advantages of PPC can be summerised as follows.

Technically PPC has considerable advantages over OPC when made by using optimum percentage of right quality of fly ash.

Air-Entraining Cement

Air-entraining cement is not covered by Indian Standard so far. This cement is made by mixing a small amount of an air-entraining agent with ordinary Portland cement clinker at the time of grinding. The following types of air-entraining agents could be used:

(*a*) Alkali salts of wood resins.

(*b*) Synthetic detergents of the alkyl-aryl sulphonate type.

(*c*) Calcium lignosulphate derived from the sulphite process in paper making.

(*d*) Calcium salts of glues and other proteins obtained in the treatment of animal hides.

These agents in powder, or in liquid forms are added to the extent of 0.025–0.1 per cent by weight of cement clinker. There are other additives including animal and vegetable fats, oil and their acids could be used. Wetting agents, aluminium powder, hydrogen peroxide could also be used. Air-entraining cement will produce at the time of mixing, tough, tiny, discrete non-coalesceing air bubbles in the body of the concrete which will modify the properties of plastic concrete with respect to workability, segregation and bleeding. It will modify the properties of hardened concrete with respect to its resistance to frost action. Air-entraining agent can also be added at the time of mixing ordinary Portland cement with rest of the ingredients. More about this will be dealt under the chapter "Admixtures."

Coloured Cement (White Cement)

For manufacturing various coloured cements either white cement or grey Portland cement is used as a base. The use of white cement as a base is costly. With the use of grey cement only red or brown cement can be produced.

Coloured cement consists of Portland cement with 5-10 per cent of pigment. The pigment cannot be satisfactorily distributed throughout the cement by mixing, and hence, it is usual to grind the cement and pigment together. The properties required of a pigment to be used for coloured cement are the durability of colour under exposure to light and weather, a fine state of division, a chemical composition such that the pigment is neither effected by the cement nor detrimental to it, and the absence of soluble salts.

The process of manufacture of white Portland cement is nearly same as OPC. As the raw materials, particularity the kind of limestone required for manufacturing white cement is only available around Jodhpur in Rajasthan, two famous brands of white cement namely Birla White and J.K. White Cements are manufactured near Jodhpur. The raw materials used are high purity limestone (96% CaCo and less than 0.07% iron oxide). The other raw materials

are china clay with iron content of about 0.72 to 0.8%, silica sand, flourspar as flux and selenite as retarder. The fuels used are refined furnace oil (RFO) or gas. Sea shells and coral can also be used as raw materials for production of white cement.

The properties of white cement is nearly same as OPC. Generally white cement is ground finer than grey cement. Whiteness of white cement as measured by ISI scale shall not be less than 70%. Whiteness can also be measured by Hunters Scale. The value as measured by Hunters scale is generally 90%. The strength of white cement is much higher than what is stated in IS code 8042 of 1989.

Hydrophobic cement

Hydrophobic cement is obtained by grinding ordinary Portland cement clinker with water repellant film-forming substance such as oleic acid, and stearic acid. The water-repellant film formed around each grain of cement, reduces the rate of deterioration of the cement during long storage, transport, or under unfavourable conditions. The film is broken out when the cement and aggregate are mixed together at the mixer exposing the cement particles for normal hydration. 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. In India certain places such as Assam, Shillong etc., get plenty of rainfall in the rainy season had have high humidity in other seasons. The transportation and storage of cement in such places cause deterioration in the quality of cement. In such far off places with poor communication system, cement perforce requires to be stored for long time. Ordinary cement gets deteriorated and loses some if its strength, whereas the hydrophobic cement which does not lose strength is an answer for such situations.

The properties of hydrophobic cement is nearly the same as that ordinary Portland cement except that it entrains a small quantity of air bubbles. The hydrophobic cement is made actually from ordinary Portland cement clinker. After grinding, the cement particle is sprayed in one direction and film forming materials such as oleic acid, or stearic acid, or pentachlorophenol, or calcium oleate are sprayed from another direction such that every particle of cement is coated with a very fine film of this water repellant material which protects them from the bad effect of moisture during storage and transportation. The cost of this cement is nominally higher than ordinary Portland cement.

Masonry Cement

Ordinary cement mortar, though good when compared to lime mortar with respect to strength and setting properties, is inferior to lime mortar with respect to workability, water-retentivity, shrinkage property and extensibility.

Masonry cement is a type of cement which is particularly made with such combination of materials, which when used for making mortar, incorporates all the good properties of lime mortar and discards all the not so ideal properties of cement mortar. This kind of cement is mostly used, as the name indicates, for masonry construction. It contains certain amount of air-entraining agent and mineral admixtures to improve the plasticity and water retentivity.

Expansive Cement

Concrete made with ordinary Portland cement shrinks while setting due to loss of free water. Concrete also shrinks continuously for long time. This is known as drying shrinkage. Cement used for grouting anchor bolts or grouting machine foundations or the cement used in grouting the prestress concrete ducts, if shrinks, the purpose for which the grout is used will be to some extent defeated. There has been a search for such type of cement which will not shrink while hardening and thereafter. As a matter of fact, a slight expansion with time will prove to be advantageous for grouting purpose. This type of cement which suffers no overall change in volume on drying is known as expansive cement. Cement of this type has been developed by using an expanding agent and a stabilizer very carefully. Proper material and controlled proportioning are necessary in order to obtain the desired expansion. Generally, about 8-20 parts of the sulphoaluminate clinker are mixed with 100 parts of the Portland cement and 15 parts of the stabilizer. Since expansion takes place only so long as concrete is moist, curing must be carefully controlled. The use of expanding cement requires skill and experience.

One type of expansive cement is known as shrinkage compensating cement. This cement when used in concrete, with restrained expansion, induces compressive stresses which approximately offset the tensile stress induced by shrinkage. Another similar type of cement is known as Self Stressing cement. This cement when used in concrete induces significant compressive stresses after the drying shrinkage has occurred. The induced compressive stresses not only compensate the shrinkage but also give some sort of prestressing effects in the tensile zone of a flexural member.

Oil-Well Cement

Oil-wells are drilled through stratified sedimentary rocks through a great depth in search of oil. It is likely that if oil is struck, oil or gas may escape through the space between the steel casing and rock formation. Cement slurry is used to seal off the annular space between steel casing and rock strata and also to seal off any other fissures or cavities in the sedimentary rock layer. The cement slurry has to be pumped into position, at considerable depth where the prevailing temperature may be upto 175°C. The pressure required may go upto 1300 kg/cm The slurry should remain sufficiently mobile to be able to flow under these conditions for periods upto several hours and then hardened fairly rapidly. It may also have to resist corrosive conditions from sulphur gases or waters containing dissolved salts. The type of cement suitable for the above conditions is known as Oil-well cement. The desired properties of Oil-well cement can be obtained in two ways: by adjusting the compound composition of cement or by adding retarders to ordinary Portland cement. Many admixtures have been patented as retarders. The commonest agents are starches or cellulose products or acids. These retarding agents prevent quick setting and retains the slurry in mobile condition to facilitate penetration to all fissures and cavities. Sometimes workability agents are also added to this cement to increase the mobility.

Rediset Cement

Acclerating the setting and hardening of concrete by the use of admixtures is a common knowledge. Calcium chloride, lignosulfonates, and cellulose products form the base of some of admixtures. The limitations on the use of admixtures and the factors influencing the end properties are also fairly well known.

High alumina cement, though good for early strengths, shows retrogression of strength when exposed to hot and humid conditions. A new product was needed for use in the precast concrete industry, for rapid repairs of concrete roads and pavements, and slip-forming. In brief, for all jobs where the time and strength relationship was important. In the PCA laboratories of USA, investigations were conducted for developing a cement which could yield high strengths in a matter of hours, without showing any retrogression. Regset cement was the result of investigation. Associated Cement Company of India have developed an equivalent cement by name “REDISET” Cement.

High Alumina Cement

High alumina cement is obtained by fusing or sintering a mixture, in suitable proportions, of alumina and calcareous materials and grinding the resultant product to a fine powder. The raw materials used for the manufacture of high alumina cement are limestone and bauxite.

These raw materials with the required proportion of coke were charged into the furnace. The
furnace is fired with pulverised coal or oil with a hot air blast. The fusion takes place at a temperature of about 1550-1600°C. The cement is maintained in a liquid state in the furnace.
Afterwards the molten cement is run into moulds and cooled. These castings are known as
pigs. After cooling the cement mass resembles a dark, fine gey compact rock resembling the
structure and hardeness of basalt rock.

The pigs of fused cement, after cooling are crushed and then ground in tube mills to a
finess of about 3000 sq. cm/gm.

Refractory Concrete

An important use of high alumina cement is for making refractory concrete to withstand
high temperatures in conjunction with aggregate having heat resisting properties. It is interesting to note that high alumina cement concrete loses considerable strength only when
subjected to humid condition and high temperature. Desiccated high alumina cement concrete on subjecting to the high temperature will undergo a little amount of conversion and
will still have a satisfactory residual strength. On complete desiccation the resistance of alumina
cement to dry heat is so high that the concrete made with this cement is considered as one of the refractory materials. At a very high temperature alumina cement concrete exhibits good
ceramic bond instead of hydraulic bond as usual with other cement concrete.

Crushed firebrick is one of the most commonly used aggregates for making refractory
concrete with high alumina cement. Such concrete can withstand temperature upto about 1350°C. Refractory concrete for withstanding temperature upto 1600°C can be produced by
using aggregates such as silimanite, carborundum, dead-burnt magnesite. The refractory concrete is used for foundations of furnaces, coke ovens, boiler settings. It is also used in fire
pits, construction of electric furnaces, ordinary furnaces and kilns. High alumina cement can
be used for making refractory mortars.

High alumina cement is a slow setting but rapid hardening cement.Its setting time can be reduced considerably by mixing it with certain proportions of ordinary Portland cement. In situations such as stopping of ingress of water or for construction between tides or for reducing pumping time in some underwater construction a particular mixture of high alumina cement and ordinary Portland cement is adopted. The values shown in the graph is only approximate. The actual proportioning and the resultant setting time are required to be actually found out by trial when such a combination is practised.

TESTING OF CEMENT

Testing of cement can be brought under two categories:

(*a*) Field testing

(*b*) Laboratory testing.

Field Testing

It is sufficient to subject the cement to field tests when it is used for minor works. The following are the field tests:

(*a*) Open the bag and take a good look at the cement. There should not be any visible lumps. The colour of the cement should normally be greenish grey.

(*b*) Thrust your hand into the cement bag. It must give you a cool feeling. There should not be any lump inside.

(*c*) Take a pinch of cement and feel-between the fingers. It should give a smooth and not a gritty feeling.

(*d*) Take a handful of cement and throw it on a bucket full of water, the particles should float for some time before they sink.

(*e*) Take about 100 grams of cement and a small quantity of water and make a stiff paste. From the stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of the bucket. After 24 hours the cake should retain its original shape and at the same time it should also set and attain some strength.

If a sample of cement satisfies the above field tests it may be concluded that the cement is not bad. The above tests do not really indicate that the cement is really good for important works. For using cement in important and major works it is incumbent on the part of the user to test the cement in the laboratory to confirm the requirements of the Indian Standard specifications with respect to its physical and chemical properties. No doubt, such confirmations will have been done at the factory laboratory before the production comes out from the factory. But the cement may go bad during transportation and storage prior to its use in works. The following tests are usually conducted in the laboratory.

(*a*) Fineness test. (*b*) Setting time test.

(*c*) Strength test. (*d*) Soundness test.

(*e*) Heat of hydration test. (*f*) Chemical composition test.

Fineness Test

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence faster the development of strength,

The fineness of grinding has increased over the years. But now it has got nearly stabilised. Different cements are ground to different fineness. The disadvantages of fine grinding is that it is susceptible to air-set and early deterioration. Maximum number of particles in a sample of cement should have a size less than about 100 microns. The smallest particle may have a size of about 1.5 microns. By and large an average size of the cement particles may be taken as about 10 micron. The particle size fraction below 3 microns has been found to have the predominant effect on the strength at one day while 3-25 micron fraction has a major influence on the 28 days strength. Increase in fineness of cement is also found to increase the drying shrinkage of concrete. In commercial cement it is suggested that there should be about 25-30 per cent of particles of less than 7 micron in size.

Fineness of cement is tested in two ways :

(*a*) By seiving.

(*b*) By determination of specific surface (total surface area of all the particles in one gram of cement) by air-premeability appartus. Expressed as cm/gm or m/kg. Generally 22
Blaine Airpermeability appartus is used.

Sieve Test

Weigh correctly 100 grams of cement and take it on a standard IS Sieve No. 9 (90 microns). Break down the air-set lumps in the sample with fingers. Continuously sieve the sample giving circular and vertical motion for a period of 15 minutes. Mechanical sieving devices may also be used. Weigh the residue left on the sieve. This weight shall not exceed 10% for ordinary cement. Sieve test is rarely used.

Air Permeability Method

This method of test covers the procedure for determining the fineness of cement as represented by specific surface expressed as total surface area in sq. cm/gm. of cement. It is also expressed in m /kg. Lea and Nurse Air Permeability Appartus is shown in Fig. 2.6. This 2 appartus can be used for measuring the specific surface of cement. The principle is based on the relation between the flow of air through the cement bed and the surface area of the particles comprising the cement bed. From this the surface area per unit weight of the body material can be related to the permeability of a bed of a given porosity. The cement bed in the permeability cell is 1 cm. high and 2.5 cm. in diameter. Knowing the density of cement the weight required to make a cement bed of porosity of 0.475 can be calculated. This quantity of cement is placed in the permeability cell in a standard manner. Slowly pass on air through the cement bed at a constant velocity. Adjust the rate of air flow until the flowmeter shows a difference in level of 30-50 cm. Read the difference in level (*h*) of the manometer 1 and the difference in level (*h*) of the flowmeter. Repeat these observations to ensure that 2 nsteady conditions have been obtained as shown by a constant value of *h* / *h* . Specific surface 1 2 *S* is calculated from the following formula: *w*

14 w *A* 3

S = and *K* = *Kh h* /

d () 1 - w *CL w* 1 2

where, = Porosity, *i.e.* , 0.475

A = Area of the cement bed

L = Length (cm) of the cement bed

d = Density of cement, and

C = Flowmeter constant.

The specific surface for various cements is shown in Table 2.5.

Fineness can also be measured by Blain Air Permeability apprartus. This method is more commonly employed in India. Fig. 2.7 shows the sketch of Blaine type Air Permeability appartus.

Standard Consistency Test

For finding out initial setting time, final setting time and soundness of cement, and strength a parameter known as standard consistency has to be used. It is pertinent at this stage to describe the procedure of conducting standard consistency test. The standard consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate to a depth of 33-35 mm from the top of

the mould shown in Fig. 2.8. The appartus is called Vicat Appartus. This appartus is used to
find out the percentage of water required to produce a cement paste of standard consistency.
The standard consistency of the cement paste is some time called normal consistency (CPNC).

The following procedures is adopted to find out standard consistency. Take about 500
gms of cement and prepare a paste with a weighed quantity of water (say 24 per cent by weight of cement) for the first trial. The paste must be prepared in a standard manner and filled into the Vicat mould within 3-5 minutes. After completely filling the mould, shake the
mould to expel air. A standard plunger, 10 mm diameter, 50 mm long is attached and brought
down to touch the surface of the paste in the test block and quickly released allowing it to sink into the paste by its own weight. Take the reading by noting the depth of penetration of the plunger. Conduct a 2nd trial (say with 25 per cent of water) and find out the depth of penetration of plunger. Similarly, conduct trials with higher and higher water/cement ratios
till such time the plunger penetrates for a depth of 33-35 mm from the top. That particular
percentage of water which allows the plunger to penetrate only to a depth of 33-35 mm from
the top is known as the percentage of water required to produce a cement paste of standard
consistency. This percentage is usually denoted as '*P*'. The test is required to be conducted in
a constant temperature (27° + 2°C) and constant humidity (90%).

Setting Time Test

An arbitraty division has been made for the setting time of cement as initial setting time
and final setting time. It is difficult to draw a rigid line between these two arbitrary divisions.

For convenience, initial setting time is regarded as the time elapsed between the moment that
the water is added to the cement, to the time that the paste starts losing its plasticity. The final
setting time is the time elapsed between the moment the water is added to the cement, and
the time when the paste has completely lost its plasticity and has attained sufficient firmness
to resist certain definite pressure.

In actual construction dealing with cement paste, mortar or concrete certain time is required for mixing, transporting, placing, compacting and finishing. During this time

cement
paste, mortar, or concrete should be in plastic condition. The time interval for which the cement products remain in plastic condition is known as the initial setting time. Normally a
minimum of 30 minutes is given for mixing and handling operations. The constituents and
fineness of cement is maintained in such a way that the concrete remains in plastic condition
for certain minimum time. Once the concrete is placed in the final position, compacted and
finished, it should lose its plasticity in the earliest possible time so that it is least vulnerable to
damages from external destructive agencies. This time should not be more than 10 hours which is often referred to as final setting time. Table 2.5 shows the setting time for different
cements.

The Vicat Appartus shown in Fig. 2.8 is used for setting time test also. The following
procedure is adopted. Take 500 gm. of cement sample and guage it with 0.85 times the water
required to produce cement paste of standard consistency (0.85 P). The paste shall be guaged
and filled into the Vicat mould in specified manner within 3-5 minutes. Start the stop watch
the moment water is added to the cement. The temperature of water and that of the test room, at the time of
gauging shall be within
27°C ± 2°C.

Initial Setting Time

Lower the needle (C) gently and bring it in contact with the surface of the test block and quickly release. Allow it to penetrate into the test block. In the beginning, the needle will completely pierce through the test block. But after some time when the paste starts
needly may penetrate only to a depth of 33-35 mm from the top. The period elapsing between the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 33-35 mm from the top is taken as initial setting
time.

Final Setting Time

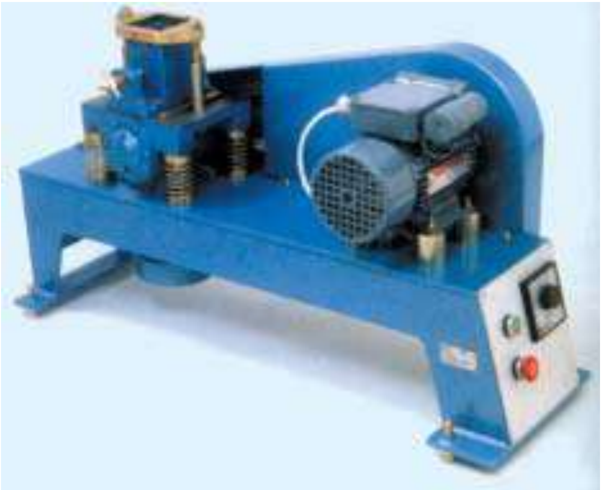
Replace the needle (C) of the Vicat appartus by a circular attachment (F) shown in the
Fig 2.8. The cement shall be considered as finally set when, upon, lowering the attachment
gently cover the surface of the test block, the centre needle makes an impression, while the
circular cutting edge of the attachment fails to do so. In other words the paste has attained such hardness that the centre needle does not pierce through the paste more than 0.5 mm.

Strength Test

The compressive strength of hardened cement is the most important of all the properties.

Therefore, it is not surprising that the cement is always tested for its strength at the laboratory before the cement is used in important works. Strength tests are not made on neat cement paste because of difficulties of excessive shrinkage and subsequent cracking of neat cement.

Strength of cement is indirectly found on cement sand mortar in specific proportions. The standard sand is used for finding the strength of cement. It shall conform to IS 650-1991. Take 555 gms of standard sand (Ennore sand), 185 gms of cement (*i.e.* , ratio of cement to sand is 1:3) in a non-porous enamel tray and mix them with a trowel for one minute, then add water of quantity $\frac{P}{4} + 3.0$ per cent of combined weight of cement and sand and mix the three ingredients thoroughly until the mixture is of uniform colour. The time of mixing should not be less than 3 minutes nor more than 4 minutes. Immediately after mixing, the mortar is filled into a cube mould of size 7.06 cm. The area of the face of the cube will be equal to 50 sq cm. Compact the mortar either by hand compaction in a standard specified manner or on the vibrating equipment (12000 RPM) for 2 minutes..



Keep the compacted cube in the mould at a temperature of 27°C ± 2°C and at least 90 per cent relative humidity for 24 hours. Where the facility of standard temperature and humidity room is not available, the cube may be kept under wet gunny bag to simulate 90 per cent relative humidity. After 24 hours the cubes are removed from the mould and immersed in clean fresh water until taken out for testing.

Soundness Test

It is very important that the cement after setting shall not undergo any appreciable change of volume. Certain cements have been found to undergo a large expansion after setting causing disruption of the set and hardened mass. This will cause serious difficulties for the durability of structures when such cement is used. The testing of soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion is of prime importance.

The unsoundness in cement is due to the presence of excess of lime than that could be combined with acidic oxide at the kiln. This is also due to inadequate burning or insufficiency in fineness of grinding or thorough mixing of raw materials. It is also likely that too high a proportion of magnesium content or calcium sulphate content may cause unsoundness in cement. For this reason the magnesia content allowed in cement is limited to 6 per cent. It can be recalled that, to prevent flash set, calcium sulphate is added to the clinker while grinding. The quantity of gypsum added will vary from 3 to 5 per cent depending upon C3A content. If the addition of gypsum is more than that could be combined with C3A, excess of gypsum will remain in the cement in free state. This excess of gypsum leads to an expansion and consequent disruption of the set cement paste.

Unsoundness in cement is due to excess of lime, excess of magnesia or excessive proportion of sulphates. Unsoundness in cement does not come to surface for a considarable period of time. Therefore, accelerated tests are required to detect it. There are number of such tests in common use. The appartus is shown in Fig. 2.9. It consists of a small split cylinder of spring brass or other suitable metal. It is 30 mm in diameter and 30 mm high. On either side of the split are attached two indicator arms 165 mm long with pointed ends. Cement is gauged with 0.78 times the water required for standard consistency (0.78 P), in a standard manner and filled into the mould kept on a glass plate. The mould is covered on the top with another glass plate. The whole assembly is immersed in water at a temperature of 27°C – 32°C and kept there for 24 hours.

Measure the distance between the indicator points. Submerge the mould again in water.

Heat the water and bring to boiling point in about 25-30 minutes and keep it boiling for 3 hours. Remove the mould from the water, allow it to cool and measure the distance between the indicator points. The difference between these two measurements represents the expansion of cement. This must not exceed 10 mm for ordinary, rapid hardening and low heat Portland cements. If in case the expansion is more than 10 mm as tested above, the cement is said to be unsound.

Automatic / Manual 5 litre Mortar Mixer.

The Le Chatelier test detects unsoundness due to free lime only. This method of testing does not indicate the presence and after effect of the excess of magnesia. Indian Standard Specification stipulates that a cement having a magnesia content of more than 3 per cent shall be tested for soundness by Autoclave test which is sensitive to both free magnesia and free lime. In this test a neat cement specimen 25 × 25 mm is placed in a standard autoclave and the steam pressure inside the autoclave is raised in such a rate as to bring the gauge pressure of the steam to 21 kg/sq cm in 1 – 1/4 hour from the time the heat is turned on. This pressure is maintained for 3 hours. The autoclave is cooled and the length measured again. The expansion permitted for all types of cements is given in Table 2.5. The high steam pressure accelerates the hydration of both magnesia and lime.

No satisfactory test is available for deduction of unsoundness due to an excess of calcium sulphate. But its content can be easily determined by chemical analysis.

Heat of Hydration

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This can be easily observed if a cement is gauged with water and placed in a thermos flask. Much attention has been paid to the heat evolved during the hydration of cement in the interior of mass concrete dams. It is estimated that about 120 calories of heat is generated in the hydration of 1 gm. of cement. From this it can be assessed the total quantum of heat produced in a conservative system such as the interior of a mass concrete dam. A temperature rise of about 50°C has been observed. This unduly high temperature developed at the interior of a concrete dam causes serious expansion of the body of the dam and with the subsequent cooling considerable shrinkage takes place resulting in serious cracking of concrete.

The use of lean mix, use of pozzolanic cement, artificial cooling of constituent materials and incorporation of pipe system in the body of the dam as the concrete work progresses for circulating cold brine solution through the pipe system to absorb the heat, are some of the methods adopted to offset the heat generation in the body of dams due to heat of hydration of cement.

Test for heat of hydration is essentially required to be carried out for low heat cement only. This test is carried out over a few days by vaccum flask methods, or over a longer period in an adiabatic calorimeter. When tested in a standard manner the heat of hydration of low heat Portland cement shall not be more than 65 cal/gm. at 7 days and 75 cal/g, at 28 days.

Chemical Composition Test

A fairly detailed discussion has been given earlier regarding the chemical composition of cement. Both oxide composition and compound composition of cement have been discussed. At this stage it is sufficient to give the limits of chemical requirements. The Table 2.6 shows the various chemical compositions of all types of cements.

Ratio of percentage of lime to percentage of silica, alumina and iron oxide, when calculated by the formulae,

$$\frac{CaO - 0.7SO_3}{2.8\,SiO_2 + 1.2\,Al_2O_3 + 0.65\,Fe_2O_3} \text{ : Not greater than 1.02 and not less than 0.66}$$

The above is called lime saturation factor per cent.

Table 2.5 gives the consolidated physical requirements of various types of cement.

Table 2.6 gives the chemical requirements of various types of cement.

Aggregates and Testing of Aggregates

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Earlier, aggregates ,were considerd as chemically inert materials but now it has been recognised that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that the aggregates occupy 70–80 per cent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. To know more about the concrete it is very essential that one should know more about the aggregates which constitute major volume in concrete. Without the study of the aggregate in depth and range the study of the concrete is incomplete. Cement is the only factory made standard component in concrete. Other ingredients, namely, water and aggregates are natural materials and can vary to any extent in many of their properties. The depth and range of studies that are required to be made in respect of aggregates to understand their widely varying effects and influence on the properties of concrete cannot be underrated.

Concrete can be considered as two phase materials for convenience; paste phase and aggregate phase. Having studied the paste phase of concrete in the earlier chapters, we shall now study the aggregates and aggregate phase in concrete in this chapter. The study of aggregates can best be done under the following sub-headings:

(*a*) Classification
(*b*) Source
(*c*) Size
(*d*) Shape
(*e*) Texture
(*f*) Strength
(*g*) Specific gravity and bulk density
(*h*) Moisture content
(*i*) Bulking factor
(*j*) Cleanliness
(*k*) Soundness
(*l*) Chemical properties
(*m*) Thermal properties
(*n*) Durability
(*o*) Sieve analysis
(*p*) Grading

Classification

Aggregates can be classified as (*i*) Normal weight aggregates, (*ii*) Light weight aggregates and (*iii*) Heary weight aggregates. Light weight aggregate and heavy weight aggregate will be discussed elsewhere under appropriate topics. In this chapter the properties of normal weight aggregates will only be discussed.

Normal weight aggregates can be further classified as natural aggregates and artificial aggregates.

Sand, Gravel, Crushed Broken Brick,
Rock such as Granite, Air-cooled Slag.
Quartzite, Basalt, Sintered fly ash
Sandstone Bloated clay

Aggregates can also be classified on the basis of the size of the aggregates as coarse aggregate and fine aggregate.

Source

Almost all natural aggregate materials originate from bed rocks. There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of rocks. It may be recalled that igneous rocks are formed by the cooling of molten magma or lava at the surface of the crest (trap and basalt) or deep beneath the crest (granite). The sedimentary rocks are formed originally below the sea bed and subsequently lifted up. Metamorphic rocks are originally either igneous or sedimentary rocks which are subsequently metamorphosed due to extreme heat and pressure. The concrete making properties of aggregate are influenced to some extent on the basis of geological formation of the parent rocks together with the subsequent processes of weathering and alteration. Within the main rock group, say granite group, the quality of aggregate may vary to a very great extent owing to changes in the structure and texture of the main parent rock from place to place.

Aggregates from Igneous Rocks

Most igneous rocks make highly satisfactory concrete aggregates because they are normally hard, tough and dense. The igneous rocks have massive structure, entirely crystalline or wholly glassy or in combination in between, depending upon the rate at which they were cooled during formation. They may be acidic or basic depending upon the percentage of silica content. They may occur light coloured or dark coloured. The igneous rocks as a class are the most chemically active concrete aggregate and show a tendency to react with the alkalies in cement. This aspect will be discussed later. As the igneous rock is one of the widely occurring type of rocks on the face of the earth, bulk of the concrete aggregates, that are derived, are of igneous origin

Aggregates from Sedimentary Rocks

Igneous rocks or metamorphic rocks are subjected to weathering agencies such as sun, rain and wind. These weathering agencies decompose, fragmantise, transport and deposit the particles of rock, deep beneath the ocean bed where they are cemented together by some of the cementing materials. The cementing materials could be carbonaceous, siliceous or argillaceous in nature. At the same time the deposited and cemented material gets subjected to static pressure of water and becomes compact sedimentary rock layer.

The deposition, cementation and consolidation takes place layer by layer beneath the ocean bed. These sedimentary rock formations subsequently get lifted up and becomes continent. The sedimentary rocks with the stratified structure are quarried and concrete aggregates are derived from it. The quality of aggregates derived from sedimentary rocks will vary in quality depending upon the cementing material and the pressure under which these rocks are originally compacted. Some siliceous sand stones have proved to be good concrete aggregate. Similarly, the limestone also can yield good concrete aggregate.

The thickness of the stratification of sedimentary rocks may vary from a fraction of a centimetre to many centimetres. If the stratification thickness of the parent rock is less, it is likely to show up even in an individual aggregate and thereby it may impair the strength of the aggregate. Such rocks may also yield flaky aggregates. Sedimentary rocks vary from soft to hard, porous to dense and light to heavy. The degree of consolidation, the type of cementation, the thickness of layers and contamination, are all important factors in determining the suitability of sedimentary rock for concrete aggregates.

Aggregates from Metamorphic Rocks

Both igneous rocks and sedimentary rocks may be subjected to high temperature and pressure which causes metamorphism which changes the structure and texture of rocks. Metamorphic rocks show foliated structure. The thickness of this foliation may vary from a few centimetres to many metres. If the thickness of this foliation is less, then individual aggregate may exhibit foliation which is not a desirable characteristic in aggregate. However, many metamorphic rocks particularly quartizite and gneiss have been used for production of good concrete aggregates.

It may be mentioned that many properties of aggregates namely, chemical and mineral composition, petro-graphic description, specific gravity, hardness, strength, physical and chemical stability, pore structure etc. depend mostly on the quality of parent rock. But there are some properties possessed by the aggregates which are important so far as concrete making is concerned which have no relation with the parent rock, particularly, the shape and size. While it is to be admitted that good aggregates from good parent rocks can make good concrete, it may be wrong to conclude that good concrete cannot be made from slightly inferior aggregates obtained from not so good parent rocks. Aggregates which are not so good can be used for making satisfactory concrete owing to the fact that a coating of cement paste on aggregates bring about improvement in respect of durability and strength characteristics. Therefore, selection of aggregates is required to be done judiciously taking the economic factor into consideration. Several factors may be considered in making the final selection of aggregates where more than one source is available. The relative cost of material in the several sources is the most important consideration that should weigh in making a choice. Records of use of aggregate from a particular source, and examination of concrete made with such aggregates, if such cases are there, provide valuable information.

The study will include appraisal of location and the amount of processing which each source may require. The aggregate which can be delivered to the mixing plant directly may not be the most economical one. It may require a cement content more than that of another source. Also very often the cost of some processing, such as correction of aggregate, may be fully recovered, when the processing accomplishes the reduction in cement content of the concrete. In general, that aggregate which will bring about the desired quality in the concrete with least overall expense, should be selected.

Size

The largest maximum size of aggregate practicable to handle under a given set of conditions should be used. Perhaps, 80 mm size is the maximum size that could be conveniently used for concrete making. Using the largest possible maximum size will result in (*i*) reduction of the cement content (*ii*) reduction in water requirement (*iii*) reduction of drying shrinkage. However, the maximum size of aggregate that can be used in any given condition may be limited by the following conditions:

(*i*) Thickness of section; (*ii*) Spacing of reinforcement;
(*iii*) Clear cover; (*iv*) Mixing, handling and placing techniques.

Generally, the maximum size of aggregate should be as large as possible within the limits specified, but in any case not greater than one-fourth of the minimum thickness of the member. Rubbles 160 mm size or upto any reasonable size may be used in plain concrete. In such concrete, called plum concrete, the quantity of rubble up to a maximum limit of 20 per cent by volume of the concrete, is used when specially permitted. The rubbles are placed on about 60 cm thick plastic concrete at certain distance apart and then the plastic concrete is vibrated by powerful internal vibrators. The rubbles sink into the concrete. This method of incorporating large boulders in the concrete is also called displacement concrete. This method is adopted in the construction of Koyna dam in Maharashtra. For heavily reinforced concrete member the nominal maximum size of aggregate should usually be restricted to 5 mm less than the minimum clear distance between the main bars or 5 mm less than the minimum cover to the reinforcement, whichever is smaller. But from various other practical considerations, for reinforced concrete work, aggregates having a maximum size of 20 mm are generally considered satisfactory.

Aggregates are divided into two categories from the consideration of size (*i*) Coarse aggregate and (*ii*) Fine aggregate. The size of aggregate bigger than 4.75 mm is considered as coarse aggregate and aggregate whose size is 4.75 mm and less is considered as fine aggregate.

Shape

The shape of aggregates is an important characteristic since it affects the workability of concrete. It is difficult to really measure the shape of irregular body like concrete aggregate which are derived from various rocks. Not only the characteristic of the parent rock, but also the type of crusher used will influence the shape of aggregates, *e.g.* , the rocks available round about Pune region are found to yield slightly flaky aggregates, whereas, good granite rock as found in Banglore will yield cubical aggregate. The shape of the aggregate is very much influenced by the type of crusher and the reduction ratio *i.e.* , the ratio of size of material fed into crusher to the size of the finished product. Many rocks contain planes of parting or jointing which is characteristic of its formation. It also reflects the internal petrographic structure. As a consequence of these tendencies, schists, slates and shales commonly produce flaky forms, whereas, granite, basalt and quartzite usually yield more or less equidimensional particles. Similarly, quartzite which does not posses cleavage planes produces cubical shape aggregates.

From the standpoint of economy in cement requirement for a given water/cement ratio, rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregate is offset to some extent by the higher strengths and sometimes by greater durability as a result of the interlocking texture of the hardened concrete and higher bond characteristic between aggregate and cement paste.

Flat particles in concrete aggregates will have particularly objectionable influence on the workability, cement requirement, strength and durability. In general, excessively flaky aggregate makes very poor concrete. Classification of particles on the basis of shape of the aggregate is shown in Table 3.1. One of the methods of expressing the angularity qualitatively is by a figure called A

N umber, as suggested by Shergold . This is based on the percentage voids in the 3. 1 aggregate after compaction in a specified manner. The test gives a value termed the angularity number. The method of determination is described in IS: 2386 (Part I) 1963.

Table 3.1 Shape of Particle

Classification	*Description*	*Examples*
Rounded	Fully water worn or completely shaped by attrition	River or seashore gravels; desert, seashore and wind-blown sands
Irregular or Partly rounded	Naturally irregular or partly shaped by attrition, having rounded edges	Pit sands and gravels; land or dug flints; cuboid rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; screes
Flaky	Material, usually angular, of which the thickness is small relative to the width and/or length	Laminated rocks

Round (spherical) concrete aggregate. Flaky concrete aggregate. Crushed concrete aggregate.

A quantity of single sized aggregate is filled into metal cylinder of three litre capacity. The aggregates are compacted in a standard manner and the percentage of void is found out. The void can be found out by knowing the specific gravity of aggregate and bulk density or by pouring water to the cylinder to bring the level of water upto the brim. If the void is 33 per cent the angularity of such aggregate is considered zero. If the void is 44 per cent the angularity number of such aggregate is considered 11. In other words, if the angularity number is zero, the solid volume of the aggregate is 67 per cent and if angularity number is

Poorly shapped crushed aggregate. It will make poor concrete. Barmac crushed 20 mm cubical aggregate. It will make good concrete.

Good aggregate resulted from Barmac crusher. 20 mm crushed angular aggregates not so good for concrete.

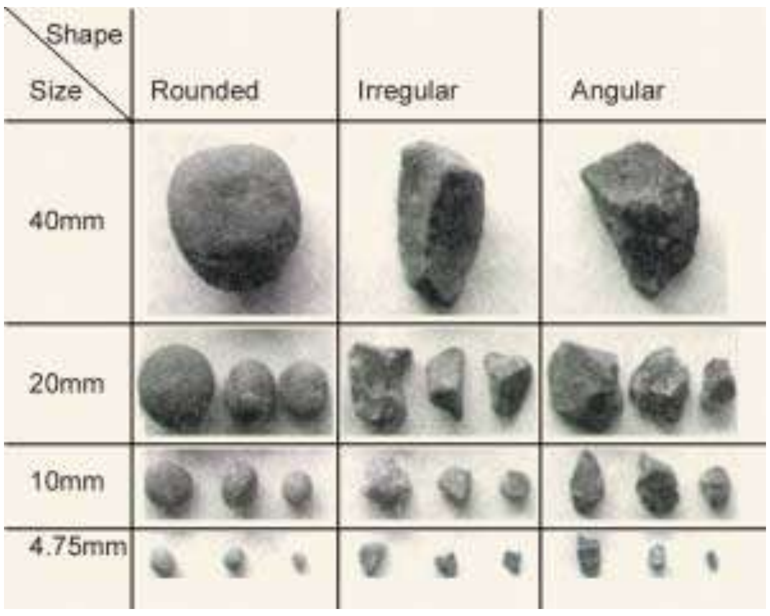
Courtesy : Durocrete Pune

11, the solid volume of the aggregate is 56 per cent. The normal aggregates which are suitable for making the concrete may have angularity number anything from zero to 11. Angularity number zero represents the most practicable rounded aggregates and the angularity number 11 indicates the most angular aggregates that could be tolerated for making concrete not so unduly harsh and uneconomical.

Murdock suggested a different method for expressing the shape of aggregate by a parameter called Angularity Index ‘ f_A ’. 3. 2

$$\text{Angularity Index } f_A = \frac{3 f_H}{20} + 1.0$$ where f_H is the Angularity number.

There has been a lot of controversy on the subject whether the angular aggregate or rounded aggregate will make better concrete. While discussing the shape of aggregate, the texture of the aggregate also enters the discussion because of its close association with the shape. Generally, rounded aggregates are smooth textured and angular aggregates are rough textured. Some engineers, prohibit the use of rounded aggregate on the plea that it yields poor concrete, due to lack of bond between the smooth surface of the aggregate and cement paste. They suggest that if at all the rounded aggregate is required to be used for economical reason, it should be broken and then used. This concept is not fully justified for the reason that even the so called, the smooth surface of rounded aggregates is rough enough for developing a reasonably good bond between the surface and the submicroscopic cement gel. But the angular aggregates are superior to rounded aggregates from the following two points of view:



Shape and size of aggregates

(*a*) Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for roads and pavements.

(*b*) The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume. By having greater surface area, the angular aggregate may show higher bond strength than rounded aggregates.

The higher surface area of angular aggregate with rough texture requires more water for a given workability than rounded aggregates. This means that for a given set of conditions from the point of view of water/cement ratio and the consequent strength, rounded aggregate gives higher strength. Superimposing plus and minus points in favour and against these two kinds of aggregates it can be summed up as

For water/cement ratio below 0.4 the use of crushed aggregate has resulted in strength up to 38 per cent higher than the rounded aggregate. With an increase in water/cement ratio the influence of roughness of surface of the aggregate gets reduced, presumably because the strength of the paste itself becomes paramount, and at a water/cement ratio of 0.65, no difference in strength of concrete made with angular aggregate or rounded aggregate has been observed.

The shape of the aggregates becomes all the more important in case of high strength and high performance concrete where very low water/cement ratio is required to be used. In such cases cubical shaped aggregates are required for better workability. To produce mostly cubical shaped aggregate and reduce flaky aggregate, improved versions of crushers are employed, such as Hydrocone crushers, Barmac rock on rock VSI crusher etc. Sometimes ordinarily crushed aggregates are further processed to convert them to well graded cubical aggregates.

In the years to come natural sand will not be available in large quantity for big infrastructural projects. One has to go for manufactured sand. When rock is crushed in the normal way it is likely to yield flaky fine aggregate. Improved version of crushers are used to produce cubical shaped well graded fine aggregate. This method of production of good fine aggregate is being practised for high rise building projects at Mumbai and for construction of Mumbai-Pune express highway. On realising the importance of shape of aggregates for producing high strength concrete the improved version of crushers are being extinsively employed in India.

Texture

Surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough. Surface texture depends on hardness, grain size, pore structure, structure of the rock, and the degree to which forces acting on the particle surface have smoothed or roughend it. Hard, dense, fine-grained materials will generally have smooth fracture surfaces. Experience and laboratory experiments have shown that the adhesion between cement paste and aggregate is influenced by several complex factors in addition to the physical and mechanical properties.

As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume. A smooth particle, however, will require a thinner layer of paste to lubricate its movements with respect to other aggregate particles. It will, therefore, permit denser packing for equal workability and hence, will require lower paste content than rough particles. It has been also shown by experiments that rough textured aggregate develops higher bond strength in tension than smooth textured aggregate. The beneficial effects of surface texture of aggregate on flexural strength.

Measurement of Surface Texture

A large number of possible methods are available and this may be divided broadly into direct and indirect methods. Direct methods include (*i*) making a cast of the surface and magnifying a section of this, (*ii*) Tracing the irregularities by drawing a fine point over the surface and drawing a trace magnified by mechanical, optical, or electrical means, (*iii*) getting a section through the aggregates and examining a magnified image. Indirect methods include: (*i*) measurement of the degree of dispersion of light falling on the surface, (*ii*) determining the weight of a fine powder required to fill up the interstices of the surface to a truly smooth surface, (*iii*) the rock surface is held against rubber surface at a standard pressure and the resistance to the flow of air between the two surfaces is measured.

Strength

When we talk of strength we do not imply the strength of the parent rock from which the aggregates are produced, because the strength of the rock does not exactly represent the strength of the aggregate in concrete. Since concrete is an assemblage of individual pieces of aggregate bound together by cementing material, its properties are based primarily on the quality of the cement paste. This strength is dependant also on the bond between the cement paste and the aggregate. If either the strength of the paste or the bond between the paste and aggregate is low, a concrete of poor quality will be obtained irrespective of the strength of the rock or aggregate. But when cement paste of good quality is provided and its bond with the aggregate is satisfactory, then the mechanical properties of the rock or aggregate will influence the strength of concrete. From the above it can be concluded that while strong aggregates cannot make strong concrete, for making strong concrete, strong aggregates are an essential requirement. In other words, from a weak rock or aggregate strong concrete cannot be made. By and large naturally available mineral aggregates are strong enough for making normal strength concrete. The test for strength of aggregate is required to be made in the following situations:

(*i*) For production of high strength and ultra high strength concrete.
(*ii*) When contemplating to use aggregates manufactured from weathered rocks.
(*iii*) Aggregate manufactured by industrial process.

Aggregatte Crushing Value

Strength of rock is found out by making a test specimen of cylindrical shape of size 25 mm diameter and 25 mm height. This cylinder is subjected to compressive stress. Different rock samples are found to give different compressive strength varying from a minimum of about 45 MPa to a maximum of 545 MPa. As said earlier, the compressive strength of parent rock does not exactly indicate the strength of aggregate in concrete. For this reason assessment of strength of the aggregate is made by using a sample of bulk aggregate in a standardised manner. This test is known as aggregate crushing value test. Aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load. Generally, this test is made on single sized aggregate passing 12.5 mm and retained on 10 mm sieve. The aggregate is placed in a cylindrical mould and a load of 40 ton is applied through a plunger. The material crushed to finer than 2.36 mm is separated and expressed as a percentage of the original weight taken in the mould. This percentage is referred as aggregate crushing value. The crushing value of aggregate is restricted to 30 per cent for concrete used for roads and pavements and 45 per cent may be permitted for other structures.

The crushing value of aggregate is rather insensitive to the variation in strength of weaker aggregate. This is so because having been crushed before the application of the full load of 40 tons, the weaker materials become compacted, so that the amount of crushing during later stages of the test is reduced. For this reason a simple test known as "10 per cent fines value" is introduced. When the aggregate crushing value become 30 or higher, the result is likely to be inaccurate, in which case the aggregate should be subjected to "10 per cent fines value" test which gives a better picture about the strength of such aggregates.

This test is also done on a single sized aggregate as mentioned above. Load required to produce 10 per cent fines (particles finer than 2.36 mm) is found out by observing the penetration of plunger. The 10 per cent fines value test shows a good correlation with the standard crushing value test for strong aggregates while for weaker aggregates this test is more sensitive and gives a truer picture of the differences between more or less weak samples.

It should be noted that in the 10 per cent fines value test unlike the crushing value test, a higher numerical result denotes a higher strength of the aggregate. The detail of this test is given at the end of this chapter under testing of aggregate.

Aggregate Impact Value

With respect to concrete aggregates, toughness is usually considered the resistance of the material to failure by impact. Several attempts to develop a method of test for aggregates impact value have been made. The most successful is the one in which a sample of standard aggregate kept in a mould is subjected to fifteen blows of a metal hammer of weight 14 Kgs. falling from a height of 38 cms. The quantity of finer material (passing through 2.36 mm) resulting from pounding will indicate the toughness of the sample of aggregate. The ratio of the weight of the fines (finer than 2.36 mm size) formed, to the weight of the total sample taken is expressed as a percentage. This is known as aggregate impact value IS 283-1970 specifies that aggregate impact value shall not exceed 45 per cent by weight for aggregate used for concrete other than wearing surface and 30 per cent by weight, for concrete for wearing surfaces, such as run ways, roads and pavements.

Aggregate Abrasion Value

Apart from testing aggregate with respect to its crushing value, impact resistance, testing the aggregate with respect to its resistance to wear is an important test for aggregate to be used for road constructions, ware house floors and pavement construction. Three tests are in common use to test aggregate for its abrasion resistance. (*i*) Deval attrition test (*ii*) Dorry abrasion test (*iii*) Los Angels test.

Deval Attrition Test

In the Deval attrition test, particles of known weight are subjected to wear in an iron cylinder rotated 10000 times at certain speed. The proportion of material crushed finer than 1.7 mm size is expressed as a percentage of the original material taken. This percentage is taken as the attrition value of the aggregate. This test has been covered by IS 2386 (Part IV) – 1963. But it is pointed out that wherever possible Los Angeles test should be used.

Dorry Abrasion Test

This test is not covered by Indian Standard Specification. The test involves in subjecting a cylindrical specimen of 25 cm height and 25 cm diameter to the abrasion against rotating metal disk sprinkled with quartz sand. The loss in weight of the cylinder after 1000 revolutions of the table is determined. The hardeness of the rock sample is expressed in an empirical formula

$$\text{Hardness} = 20 - \frac{\text{Loss in Grams}}{3}$$

Good rock should show an abrasion value of not less than 17. A rock sample with a value of less than 14 would be considered poor.

Los Angeles Test

Los Angeles test was developed to overcome some of the defects found in Deval test. Los Angeles test is characterised by the quickness with which a sample of aggregate may be tested. The applicability of the method to all types of commonly used aggregate makes this method popular. The test involves taking specified quantity of standard size material along with specified number of abrasive charge in a standard cylinder and revolving if for certain specified revolutions. The particles smaller than 1.7 mm size is separated out. The loss in weight expressed as percentage of the original weight taken gives the abrasion value of the aggregate. The abrasion value should not be more than 30 per cent for wearing surfaces and not more than 50 per cent for concrete other than wearing surface. Table 3.4 gives average values of crushing strength of rocks, aggregate crushing value, abrasion value, impact value and attrition value for different rock groups.

Modulus of Elasticity

Modulus of elasticity of aggregate depends on its composition, texture and structure. The modulus of elasticity of aggregate will influence the properties of concrete with respect to shrinkage and elastic behaviour and to very small extent creep of concrete. Many studies have been conducted to investigate the influence of modulus of elasticity of aggregate on the properties of concrete. One of the studies indicated that the '*E*' of aggregate has a decided effect on the elastic property of concrete and that the relation of '*E*' of aggregate to that of the concrete is not a linear function, but may be expressed as an equation of exponential type.[3.4]

Bulk Density

The bulk density or unit weight of an aggregate gives valuable informations regarding the shape and grading of the aggregate. For a given specific gravity the angular aggregates show a lower bulk density. The bulk density of aggregate is measured by filling a container of known volume in a standard manner and weighing it. Bulk density shows how densely the aggregate is packed when filled in a standard manner. The bulk density depends on the particle size distribution and shape of the particles. One of the early methods of mix design make use of this parameter bulk density in proportioning of concrete mix. The higher the bulk density, the lower is the void content to be filled by sand and cement. The sample which gives the minimum voids or the one which gives maximum bulk density is taken as the right sample of aggregate for making economical mix. The method of determining bulk density also gives the method for finding out void content in the sample of aggregate.

For determination of bulk density the aggregates are filled in the container and then they are compacted in a standard manner. The weight of the aggregate gives the bulk density calculated in kg/litre or kg/m^3. Knowing the specific gravity of the aggregate in saturated and surface-dry condition, the void ratio can also be calculated.

$$\text{Percentage voids} = \frac{G_s - f}{G_s} \times 100$$

where G_s = specific gravity of the aggregate and = bulk density in kg/litre.

Bulk density of aggregate is of interest when we deal with light weight aggregate and heavy weight aggregate. The parameter of bulk density is also used in concrete mix design for converting the proportions by weight into proportions by volume when weigh batching equipments is not available at the site.

Specific Gravity

In concrete technology, specific gravity of aggregates is made use of in design calculations of concrete mixes. With the specific gravity of each constituent known, its weight can be converted into solid volume and hence a theoretical yield of concrete per unit volume can be calculated. Specific gravity of aggregate is also required in calculating the compacting factor in connection with the workability measurements. Similarly, specific gravity of aggregate is required to be considered when we deal with light weight and heavy weight concrete. Average specific gravity of the rocks vary from 2.6 to 2.8.

Absorption and Moisture Content

Some of the aggregates are porous and absorptive. Porosity and absorption of aggregate will affect the water/cement ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

The water absorption of aggregate is determined by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. The ratio of the increase in weight to the weight of the dry sample expressed as percentage is known as absorption of aggregate. But when we deal with aggregates in concrete the 24 hours absorption may not be of much significance, on the other hand, the percentage of water absorption during the time interval equal of final set of cement may be of more significance. The aggregate absorbs water in concrete and thus affects the workability and final volume of concrete. The rate and amount of absorption within a time interval equal to the final set of the cement will only be a significant factor rather than the 24 hours absorption of the aggregate. It may be more realistic to consider that absorption capacity of the aggregates which is going to be still less owing to the sealing of pores by coating of cement particle particularly in rich mixes. In allowing for extra water to be added to a concrete mix to compensate for the loss of water due to absorption, proper appreciation of the absorption in particular time interval must be made rather than estimating on the basis of 24 hours absorption.

In proportioning the materials for concrete, it is always taken for granted that the aggregates are saturated and surface dry. In mix design calculation the relative weight of the aggregates are based on the condition that the aggregates are saturated and surface dry. But in practice, aggregates in such ideal condition is rarely met with. Aggregates are either dry and absorptive to various degrees or they have surface moisture. The aggregates may have been exposed to rain or may have been washed in which case they may contain surface moisture or the aggregates may have been exposed to the sun for a long time in which case they are absorptive. Fine aggregates dredged from river bed usually contains surface moisture. When stacked in heap the top portion of the heap may be comparatively dry, but the lower portion of the heap usually contains certain amount of free moisture. It should be noted that if the aggregates are dry they absorb water from the mixing water and thereby affect the workability and, on the other hand, if the aggregates contain surface moisture they contribute extra water to the mix and there by increase the water/cement ratio. Both these conditions are harmful for the quality of concrete. In making quality concrete, it is very essential that corrective measures should be taken both for absorption and for free moisture so that the water/cement ratio is kept exactly as per the design.

Very often at the site of concrete work we may meet dry coarse aggregate and moist fine aggregate. The absorption capacity of the coarse aggregate is of the order of about 0.5 to 1 per cent by weight of aggregate. A higher absorption value may be met with aggregates derived from sand stone or other soft and porous rocks. Recently it was observed that the rocks excavated in the cuttings of Pune-Mumbai express highway, showed absorption of around 4% unusualy high for rock of the type Deccan trap. The high absorption characteristic has presented plenty of problems for using such stone aggregate for 40 MPa Pavement Quality Concrete (PQC). The natural fine aggregates often contain free moisture anything from one to ten per cent or more. Fig. 3.1 shows a diagrammatic representation of moisture in aggregates.

Bulking of Aggregates

The free moisture content in fine aggregate results in bulking of volume. Bulking phenomenon can be explained as follows:

Free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighbouring particles away from it. Similarly, the force exerted by surface tension keeps every particle away from each other. Therefore, no point contact is possible between the particles. This causes bulking of the volume. The extent of surface tension and consequently how far the adjacent particles are kept away will depend upon the percentage of moisture content and the particle size of the fine aggregate. It is interesting to note that the bulking increases with the increase in moisture content upto a certain limit and beyond that the further increase in the moisture content results in the decrease in the volume and at a moisture content representing saturation point, the fine aggregate shows no bulking. It can be seen from Fig. 3.2 that fine sand bulks more and coarse sand bulks less. From this it follows that the coarse aggregate also bulks but the bulking is so little that it is always neglected. Extremely fine sand and particularly the manufactured fine aggregate bulks as much as about 40 per cent.

Due to the bulking, fine aggregate shows completely unrealistic volume. Therefore, it is absolutely necessary that consideration must be given to the effect of bulking in proportioning the concrete by volume. If cognisance is not given to the effect of bulking, in case of volume batching, the resulting concrete is likely to be undersanded and harsh. It will also affect the yield of concrete for a given cement content.

The extent of bulking can be estimated by a simple field test. A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner. Note down the level, say h_1. Pour water into the measuring cylinder and completely inundate the sand and shake it. Since the volume of the saturated sand is the same as that of the dry sand, the inundated sand completely offsets the bulking effect. Note down the level of the sand say, h_2. Then $h_1 - h_2$ shows the bulking of the sample of sand under test.

$$\text{Percentage of bulking} = \frac{h_1 - h_2}{h_2} \times 100$$

In a similar way the bulking factor can be found out by filling the wet sand in a water tight measuring box (farma) up to the top and then pour water to inundate the sand. Then measure the subsidence of sand and express it as a percentage. This gives a more realistic picture of the bulking factor.

The field test to find out the percentage of bulking is so simple that this could be conducted in a very short time interval and the percentage of bulking so found out could be employed for correcting the volume of fine aggregate to be used. This can be considered as one of the important methods of field control to produce quality concrete. Since volume batching is not adopted for controlled concrete, the determination of the percentage of moisture content is not normally required. The quantity of water could be controlled by visual examination of the mix and by experience. The percentage of free moisture content is required to be determined and correction made only when weigh batching is adopted for production of quality concrete.

Measurement of Moisture Content of Aggregates

Determination of moisture content in aggregate is of vital importance in the control of the quality of concrete particularly with respect to workability and strength. The measurement of the moisture content of aggregates is basically a very simple operation. But it is complicated by several factors. The aggregate will absorb a certain quantity of water depending on its porosity. The water content can be expressed in terms of the weight of the aggregate when absolutely dry, surface dry or when wet. Water content means the free water, or that held on the surface of the aggregate or the total water content which includes the absorbed water plus the free water, or the water held in the interior portion of aggregate particles.

The measurement of the moisture content of aggregate in the field must be quick, reasonably accurate and must require only simple appartus which can be easily handled and used in the field. Some of the methods that are being used for determination of moisture content of aggregate are given below:

(*i*) Drying Method
(*ii*) Displacement Method
(*iii*) Calcium Carbide Method
(*iv*) Measurement by electrical meter.
(*v*) Automatic measurement

Drying Method

The application of drying method is fairly simple. Drying is carried out in a oven and the loss in weight before and after drying will give the moisture content of the aggregate. If the drying is done completely at a high temperature for a long time, the loss in weight will include not only the surface water but also some absorbed water. Appropriate corrections may be made for the saturated and surface dry condition. The oven drying method is too slow for field use. A fairly quick result can be obtained by heating the aggregate quickly in an open pan. The process can also be speeded up by pouring inflammable liquid such as methylated spirit or acetone over the aggregate and igniting it.

Displacement Method

In the laboratory the moisture content of aggregate can be determined by means of pycnometer or by using Siphon-Can Method. The principle made use of is that the specific gravity of normal aggregate is higher than that of water and that a given weight of wet aggregate will occupy a greater volume than the same weight of the aggregate when dry. By knowing the specific gravity of the dry aggregate, the specific gravity of the wet aggregate can be calculated. From the difference between the specific gravities of the dry and wet aggregates, the moisture content of the aggregate can be calculated.

Calcium Carbide Method

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

Electrical Meter Method

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

Automatic Measurement

In modern batching plants surface moisture in aggregates is automatically recorded by means of some kind of sensor arrangement. The arrangement is made in such a way that the quantity of free water going with aggregate is automatically recorded and simultaneously that

much quantity of water is reduced. This sophisticated method results in an accuracy of ± 0.2 to 0.6%.

Cleanliness

The concrete aggregates should be free from impurities and deletrious substances which are likely to interfere with the process of hydration, prevention of effective bond between the aggregates and matrix. The impurities sometimes reduce the durability of the aggregate.

Generally, the fine aggregate obtained from natural sources is likely to contain organic impurities in the form of silt and clay. The manufactured fine aggregate does not normally contain organic materials. But it may contain excess of fine crushed stone dust. Coarse aggregate stacked in the open and unused for long time may contain moss and mud in the lower level of the stack.

Sand is normally dredged from river beds and streams in the dry season when the river bed is dry or when there is not much flow in the river. Under such situation along with the sand, decayed vegetable matter, humus, organic matter and other impurities are likely to settle down. But if sand is dredged when there is a good flow of water from very deep bed, the organic matters are likely to get washed away at the time of dredging. The organic matters will interfere with the setting action of cement and also interfere with the bond characteristics with the aggregates. The presence of moss or algae will also result in entrainment of air in the concrete which reduces its strength.

To ascertain whether a sample of fine aggregate contains permissible quantity of organic impurities or not, a simple test known as colorimetric test is made. The sample of sand is mixed with a liquid containing 3 per cent solution of sodium hydroxide in water. It is kept for 24 hours and the colour developed is compared with a standard colour card. If the colour of the sample is darker than the standard colour card, it is inferred that the content of the organic impurities in the sand is more than the permissible limit. In that case either the sand is rejected or is used after washing.

Sometimes excessive silt and clay contained in the fine or coarse aggregate may result in increased shrinkage or increased permeability in addition to poor bond characteristics. The excessive silt and clay may also necessitate greater water requirements for given workability.

The quantity of clay, fine silt and fine dust are determined by sedimentation method. In this method, a sample of aggregate is poured into a graduated measuring jar and the aggregate is nicely rodded to dislodge particles of clay and silt adhering to the aggregate particles. The jar with the liquid is completely shaken so that all the clay and silt particles get mixed with water and then the whole jar is kept in an undisturbed condition. After a certain time interval, the thickness of the layer of clay and silt standing over the fine aggregate particles will give a fair idea of the percentage of clay and silt content in the sample of aggregate under test. The limits of deleterious materials as given in IS 383-1970 are shown in Table 3.5.

Fine aggregate from tidal river or from pits near sea shore will generally contain some percentage of salt. The contamination of aggregates by salt will affect the setting properties and ultimate strength of concrete. Salt being hygroscopic, will also cause efflorescence and unsightly appearance. Opinions are divided on the question whether the salt contained in aggregates would cause corrosion of reinforcement. But studies have indicated that the usual percentage of salt generally contained in the fine aggregate will not cause corrosion in any appreciable manner. However, it is a good practice to wash sand containing salt more than 3 per cent.

Soundness of Aggregate

Soundness refers to the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions. These physical conditions that affect the soundness of aggregate are the freezing the thawing, variation in temperature, alternate wetting and drying under normal conditions and wetting and drying in salt water. Aggregates which are porous, weak and containing any undesirable extraneous matters undergo excessive volume change when subjected to the above conditions. Aggregates which undergo more than the specified amount of volume change is said to be unsound aggregates. If concrete is liable to be exposed to the action of frost, the coarse and fine aggregate which are going to be used should be subjected to soundness test.

The soundness test consists of alternative immersion of carefully graded and weighed test sample in a solution of sodium or magnesium sulphate and oven drying it under specified conditions. The accumulation and growth of salt crystals in the pores of the particles is thought to produce disruptive internal forces similar to the action of freezing of water or crystallisation of salt. Loss in weight, is measured for a specified number of cycles. Soundness test is specified in IS 2386 (Part V). As a general guide, it can be taken that the average loss of weight after 10 cycles should not exceed 12 per cent and 18 per cent when tested with sodium sulphate and magnesium sulphate respectively.

It may be pointed out that the sulphate soundness test might be used to accept aggregates but not to reject them, the assumption being that aggregates which will satisfactorily withstand the test are good while those which breakdown may or may not be bad. Unfortunately, the test is not reliable. Certain aggregates with extremely fine pore structure show almost no loss of weight. Conversely, certain aggregates that disintegrate readily in the sulphate test but produce concrete of high resistance to freezing and thawing. A low loss of weight usually. but not always, an evidence of good durability, whereas a high loss of weight places the aggregate in questionable category.

Alkali Aggregate Reaction

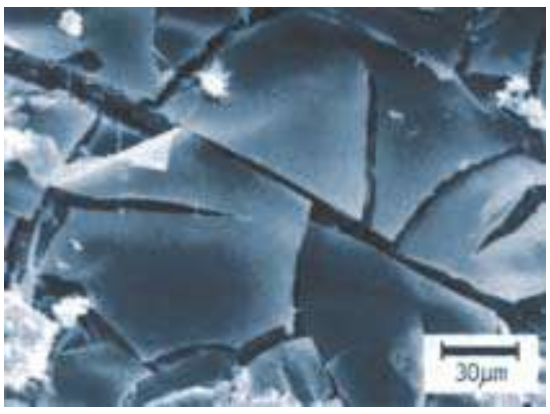
For a long time aggregates have been considered as inert materials but later on, particularly, after 1940' s it was clearly brought out that the aggregates are not fully inert. Some of the aggregates contain reactive silica, which reacts with alkalies present in cement *i.e.*, sodium oxide and potassium oxide.

In the United States of America it was found for the first time that many failures of concrete structures like pavement, piers and sea walls could be attributed to the alkali-aggregate reaction. Since then a systematic study has been made in this regard and now it is proved beyond doubt that certain types of reactive aggregates are responsible for promoting alkali-aggregate reaction.

The types of rocks which contain reactive constituents include traps, andesites, rhyolites, siliceous limestones and certain types of sandstones. The reactive constituents may be in the form of opals, cherts, chalcedony, volcanic glass, zeolites etc. The reaction starts with attack on the reactive siliceous minerals in the aggregate by the alkaline hydroxide derived from the alkalies in cement. As a result, the alkali silicate gels of unlimited swelling type are formed. When the conditions are congenial, progressive manifestation by swelling takes place, which results in disruption of concrete with the spreading of pattern cracks and eventual failure of concrete structures. The rate of deterioration may be slow or fast depending upon the conditions. There were cases where concrete has become unserviceable in about a year's time. In India, the basalt rocks occurring in the Deccan plateau, Madhya Pradesh, Kathiawar, Hyderabad, Punchal Hill (Jammu and Kashmir), Bengal and Bihar should be viewed with caution. 3 . 6

Similarly, limestones and dolomites containing chert nodules would be highly reactive. Indian limestones of Bijawar series are known to be highly cherty. Regions of occurrence include Madhya Pradesh, Rajasthan, Punjab and Assam.

Sandstones containing silica minerals like chalcedony, crypto to microcrystalline quartz or opal are found to be reactive. Regions of occurrence include Madhya Pradesh, Bengal, Bihar and Delhi. Some of the samples obtained from Madhya Pradesh, West Bengal and Kashmir were found to be containing reactive constituents which could be identified by visual examination. These contain substantial quantities of minerals like opals, chalcedony and amorphous silica. Quartzite samples of rock obtained from Kashmir were also found to be highly reactive.



Geographically India has a very extensive deposit of volcanic rocks. The Deccan traps covering the western part of Maharashtra and Madhya Pradesh, the dolomites of Madhya Pradesh, Punjab and Rajasthan, limestones of Jammu and Kashmir would form extensive source of for concrete construction. The aggregates from these rocks should be studied cautiously to see how far reactive are they. It is interesting to note that only such aggregates which contain reactive silica in particular proportion and in particular fineness are found to exhibit tendencies for alkali-aggregates reaction. It is possible to reduce its tendency by altering either the proportion of reactive silica or its fineness.

Factors Promoting the Alkali-Aggreate Reaction

(*i*) Reactive type of aggregate; (*ii*) High alkali content in cement;
(*iii*) Availability of moisture; (*iv*) Optimum temperature conditions.

It is not easy to determine the potential reactivity of the aggregates. The case history of aggregates may be of value in judging whether a particular source of aggregate is deleterious or harmless. The petrographic examination of thin rock sections may also immensely help to asses the potential reactivity of the aggregate. This test often requires to be supplemented by other tests.

Mortar Bar Expansion Test devised by Stanton has proved to be a very reliable test in assessing the reactivity or otherwise of the aggregate. A specimen of size 25 mm x 25 mm and 250 mm length is cast, cured and stored in a standard manner as specified in IS : 2386 (Part VII 1963). Measure the length of the specimen periodically, at the ages of 1, 2, 3, 6, 9, and 12 months. Find out the difference in the length of the specimen to the nearest 0.001 per cent and record the expansion of the specimen. The aggregate under test is considered harmful if it expands more than 0.05 per cent after 3 months or more than 0.1 per cent after six months.

The potential reactivity of aggregate can also be found out by chemical method. In this method the potential reactivity of an aggregate with alkalies in Portland cement is indicated by the amount of reaction taking place during 24 hours at 80°C between sodium hydroxide solution and the aggregate that has been crushed and sieved to pass a 300 micron IS Sieve and retained on 150 micron IS Sieve. The solution after 24 hours is analysed for silica dissolved and reduction in alkalinity, both expressed as millimoles per litre. The values are plotted as shown in Fig 3.3 reproduced from IS : 2386 (Part VII 1963). Generally, a potentially deleterious reaction is indicated if the plotted test result falls to the right of the boundary line of Fig. 3.3 and if plotted result falls to the left side of the boundary line, the aggregate may be considered as innocuous. The above chemical test may also be employed for finding out the effectiveness of adding a particular proportion of pozzolanic material to offset the alkali-aggregate reaction. Table 3.6 shows dissolved silica and reduction in alkalinity of some Indian aggregates.

High Alkali Content in Cement

The high alkali content in cement is one of the most important factors contributing to the alkali-aggregate reaction. Since the time of recognition to the importance of alkali-aggregate reaction phenomena, a serious view has been taken on the alkali content of cement. Many specifications restrict the alkali content to less than 0.6 per cent. Their total amount, expressed as Na_2O equivalent ($Na_2O + 0.658\ K_2O$). A cement, meeting this specification is designated as a low alkali cement. Field experience has never detected serious deterioration of concrete through the process of alkali-aggregate reaction when cement contained alkalies less than 0.6 per cent. In exceptional cases, however, cement with even lower alkali content have caused objectionable expansion. Generally, Indian cements do not contain high alkalies as in U.S.A. and U.K. The result of investigations done to find out the alkali content in the sample of Indian cement is shown in Table 3.7. Table 3.7 shows that 11 out of 26 Indian cement samples have total alkali content higher than 0.6 per cent. This is the statistics of cement manufactured prior to 1975. The present day cement manufactured by modern sophisticated methods will have lower alkali content than what is shown in Table 3.7.

Availability of Moisture

Progress of chemical reactions involving alkali-aggregate reaction in concrete requires the presence of water. It has been seen in the field and laboratory that lack of water greatly reduces this kind of deterioration. Therefore, it is pertinent to note that deterioration due to alkali-aggregate reaction will not occur in the interior of mass concrete. The deterioration will be more on the surface. It is suggested that reduction in deterioration due to alkali-aggregate reaction can be achieved by the application of waterproofing agents to the surface of the concrete with a view to preventing additional penetration of water into the structure.

Temperature Condition

The ideal temperature for the promotion of alkali-aggregate reaction is in the range of 10 to 38°C. If the temperatures condition is more than or less than the above, it may not provide an ideal situation for the alkali-aggregate reaction.

Mechanism of Deterioration of Concrete Through the Alkali-Aggregate Reaction

The mechanism of alkali aggregate reaction has not been perfectly understood. However, from the known information, the mechanism of deterioration is explained as follows:

The mixing water turns to be a strongly caustic solution due to solubility of alkalies from the cement. This caustic liquid attacks reactive silica to form alkali-silica gel of unlimited swelling type. The reaction proceeds more rapidly for highly reactive substances. If continuous supply of water and correct temperature is available, the formation of silica gel continues unabated. This silica gels grow in size. The continuous growth of silica gel exerts osmotic pressure to cause pattern cracking particularly in thinner sections of concrete like pavements. Conspicuous effect may not be seen in mass concrete sections.

The formation of pattern cracks due to the stress induced by the growth of silica gel results in subsequent loss in strength and elasticity. Alkali-aggregate reaction also accelerates other process of deterioration of concrete due to the formation of cracks. Solution of dissolved carbon dioxide, converts calcium hydroxide to calcium carbonate with consequent increase in volume. Many destructive forces become operative on the concrete disrupted by alkali-aggregate reaction which will further hasten the total disintegration of concrete.

Control of Alkali-Aggregate Reaction

From the foregoing discussion it is apparent that alkali-aggregate reaction can be controlled by the following methods:

(*i*) Selection of non-reactive aggregates;
(*ii*) By the use of low alkali cement;
(*iii*) By the use of corrective admixtures such as pozzolanas;
(*iv*) By controlling the void space in concrete;
(*v*) By controlling moisture condition and temperature.

It has been discussed that it is possible to identify potentially reactive aggregate by petrographic examination, mortar bar test or by chemical method. Avoiding the use of the reactive aggregate is one of the sure methods to inhibit the alkali-aggregate reaction in concrete.

In case avoidance of suspicious reactive aggregate is not possible due to economic reasons, the possibility of alkali-aggregate reaction can be avoided by the use of low alkali cement. restricting the alkali content in cement to less than 0.6 per cent or possibly less than 0.4 per cent, is another good step.

In the construction of nuclear power project at Kaiga in Karnataka, initially, they did not make proper investigation about the coarse aggregate they are likely to use in the power project. When they investigated, they found that the coarse aggregate was showing a tendency for alkali-aggregate reaction. They could not change the source for economical reason. Therefore, they have gone for using, special low-alkali cement. with alkali content less than 0.4 per cent.

It has been pointed out earlier that generally the aggregate is found to be reactive when it contains silica in a particular proportion and in particular fineness. It has been seen in the laboratory that if this optimium condition of silica being in particular proportion and fineness is disturbed, the aggregate will turn to be innocuous. This disturbance of optimum content and fineness of silica can be disturbed by the addition of pozzolanic materials such as crushed stone dust, diatomaceous earth, fly ash or surkhi. The use of pozzolanic mixture has been found to be one of practical solutions for inhibiting alkali-aggregate reaction.

It has been said that development of osmotic pressure on the set-cement gel by the subsequently formed alkali-silica gel is responsible for the disruption of concrete. If a system is introduced to absorb this osmotic pressure, it is probable that the disruption could be reduced. The use of air-entraining agent has frequently been recommended as a means of absorbing the osmotic pressure and controlling expansion due to alkali-aggregate reaction in mortar and concrete.

For the growth of silica gel a continuous availability of water is one of the requirements. If such continuous supply is not made available, the growth of silica gel is reduced. Similarly, if the correct range of temperature is not provided, the extent of expansion is also reduced.

Thermal Properties

Rock and aggregate possesses three thermal properties which are significant in establishing the quality of aggregate for concrete constructions. They are:

(*i*) Coefficient of expansion; (*ii*) Specific heat; (*iii*) Thermal conductivity.

Out of these, specific heat and conductivity are found to be important only in mass concrete construction where rigorous control of temperature is necessary. Also these properties are of consequence in case of light weight concrete used for insulation purpose. When we are dealing with the aggregate in general it will be sufficient at this stage to deal with only the coefficient of expansion of the aggregate, since it interacts with the coefficient of thermal expansion of cement paste in the body of the set-concrete.

depending upon the type and quantities of the aggregates, the mix proportions and other factors. The range of coefficient of thermal expansion for hydrated cement paste may vary from 10.8×10^{-6} Per °C to 16.2×10^{-6} per °C. Similarly, for mortar it may range from 7.9×10^{-6} per °C to 12.6×10^{-6} per °C.

The linear thermal coefficient of expansion of common rocks ranges from about 0.9×10^{-6} per °C to 16×10^{-6} per °C. From the above it could be seen that while there is thermal compatibility between the aggregate and concrete or aggregate and paste at higher range, there exists thermal incompatibility between aggregate and concrete or aggregate and paste at the lower range. This thermal incompatibility between the aggregate and concrete at the lower range causes severe stress which has got damaging effect on the durability and integrity of concrete structures.

Many research workers have studied the interaction of aggregates with different coefficient of thermal expansion with that of concrete. The result of the experiments does not present a very clear cut picture of the effects that may be expected, and some aspects of the problem are controversial. However, there seems to be a fairly general agreement that the thermal expansion of the aggregate has an effect on the durability of concrete, particularly under severe exposure conditions or under rapid temperature changes. Generally, it can be taken that, where the difference between coefficient of expansion of coarse aggregate and mortar is larger, the durability of the concrete may be considerably lower than would be predicted from the results of the usual acceptance tests. Where the difference between these coefficients exceeds 5.4×10^{-6} per °C caution should be taken in the selection of the aggregate for highly durable concrete.

If a particular concrete is subjected to normal variation of atmospheric temperature, the thermal incompatibility between the aggregates and paste or between the aggregate and matrix may not introduce serious differential movement and break the bond at the interface of aggregate and paste or aggregate and matrix. But if a concrete is subjected to high range of temperature difference the adverse effect will become acute. If quartz is used as aggregate for concrete that is going to be subjected to high temperature the concrete is sure to undergo disruption as quartz changes state and suddenly expands 0.85 per cent at a temperature of 572.7°C. It is also necessary to take care of the peculiar anisotropic behavior *i.e.*, the property of expanding more in one direction or parallel to one crystallographic axis than another. The most notable example is calcite which has a linear thermal coefficient expansion of 25.8×10^{-6} per °C parallel to its axis and -4.7×10^{-6} per °C perpendicular to this direction[3.7].

Potash feldspars are another group of minerals exhibiting anisotropic behaviour.

Therefore, in estimating the cubical expansion of concrete, care must be taken to this aspect of anisotropic behaviour of some of the aggregates. The study of coefficient of thermal expansion of aggregate is also important, in dealing with the fire resistance of concrete.

Grading of Aggregates

Aggregate comprises about 55 per cent of the volume of mortar and about 85 per cent volume of mass concrete. Mortar contains aggregate of size of 4.75 mm and concrete contains aggregate upto a maximum size of 150 mm.

Thus it is not surprising that the way particles of aggregate fit together in the mix, as influenced by the gradation, shape, and surface texture, has an important effect on the workability and finishing characteristic of fresh concrete, consequently on the properties of hardened concrete. Volumes have been written on the effects of the aggregate grading on the properties of concrete and many so called "ideal" grading curves have been proposed. In spite of this extensive study, we still do not have a clear picture of the influence of different types of aggregates on the plastic properties of concrete. It has been this much understood that there is nothing like "ideal" aggregate grading, because satisfactory concrete can be made with various aggregate gradings within certain limits.

It is well known that the strength of concrete is dependent upon water/cement ratio provided the concrete is workable. In this statement, the qualifying clause "provided the concrete is workable" assumes full importance. One of the most important factors for producing workable concrete is good gradation of aggregates. Good grading implies that a sample of aggregates contains all standard fractions of aggregate in required proportion such that the sample contains minimum voids. A sample of the well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. Minimum paste will mean less quantity of cement and less quantity of water, which will further mean increased economy, higher strength, lower-shrinkage and greater durability.

The advantages due to good grading of aggregates can also be viewed from another angle. If concrete is viewed as a two phase material, paste phase and aggregate phase, it is the paste phase which is vulnerable to all ills of concrete. Paste is weaker than average aggregate in normal concrete with rare exceptions when very soft aggregates are used. The paste is more permeable than many of the mineral aggregates. It is the paste that is susceptible to deterioration by the attack of aggressive chemicals. In short, it is the paste which is a weak link in a mass of concrete. The lesser the quantity of such weak material, the better will be the concrete. This objective can be achieved by having well graded aggregates. Hence the importance of good grading.

Many research workers in the field of concrete technology, having fully understood the importance of good grading in making quality concrete in consistent with economy, have directed their studies to achieve good grading of aggregate at the construction site.

Fuller and Thompson concluded that grading for maximum density gives the highest 3 . 8 strength, and that the grading curve of the best mixture resembles a parabola. Talbot and Richart from their works found that aggregate graded to produce maximum density gave a harsh mixture that is very difficult to place in ordinary concreting operations. Edwards and Young proposed a method of proportioning based on the surface area of aggregate to be wetted. Other things being equal, it was concluded that the concrete made from aggregate grading having least surface area will require least water which will consequently be the strongest.

Abrams and others in course of their investigations have also found that the surface area of the aggregate may vary widely without causing much appreciable difference in the concrete strength, and that water required to produce a given consistency is dependent more on other characteristics of aggregate than on surface area. Therefore, Abrams introduced a parameter known as "fineness modulus" for arriving at satisfactory gradings. He found that any sieve analysis curve of aggregate that will give the same fineness modulus will require the same quantity of water to produce a mix of the same plasticity and gives concrete of the same strength, so long as it is not too coarse for the quantity of cement used. The fineness modulus is an index of the coarseness or fineness of an aggregate sample, but, because different grading can give the same fineness modulus, it does not define the grading.

Waymouth introduced his theory of satisfactory grading on the basis of "particle interference" considerations . He found out the volume relationships between successive size 3 . 9 groups of particles based on the assumption that particles of each group are distributed throughout the concrete mass in such a way that the distance between them is equal to the mean diameter of the particles of the next smaller size group plus the thickness of the cement film between them. He stated that particle interference occurred between two successive sizes when the distance between particles is not sufficient to allow free passage of the smaller particles. The determination of grading by Waymouth method usually results in finer gradings.

Many other methods have been suggested for arriving at an optimum grading. All these procedures, methods and formulae point to the fact that none is satisfactory and reliable for field application. At the site, a reliable satisfactory grading can only be decided by actual trial and error, which takes into consideration the characteristics of the local materials with respect to size fraction, shape, surface texture, flakiness index and elongation index. The widely varying peculiarities of coarse and fine aggregates cannot be brought under formulae and set procedure for practical application.

One of the practical methods of arriving at the practical grading by trial and error method is to mix aggregates of different size fractions in different percentages and to choose the one sample which gives maximum weight or minimum voids per unit volume, out of all the alternative samples. Fractions which are actually available in the field, or which could be made available in the field including that of the fine aggregate will be used in making samples.

Sieve Analysis

This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call gradation.

A convenient system of expressing the gradation of aggregate is one which the consecutive sieve openings are constantly doubled, such as 10 mm, 20 mm, 40 mm etc. Under such a system, employing a logarithmic scale, lines can be spaced at equal intervals to represent the successive sizes.

The aggregates used for making concrete are normally of the maximum size 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600 micron, 300 micron and 150 micron. The aggregate fraction from 80 mm to 4.75 mm are termed as coarse aggregate and those fraction from 4.75 mm to 150 micron are termed as fine aggregate. The size 4.75 mm is a common fraction appearing both in coarse aggregate and fine aggregate (C.A. and F.A.).

Grading pattern of a sample of C.A. or F.A. is assessed by sieving a sample successively through all the sieves mounted one over the other in order of size, with larger sieve on the top. The material fraction of aggregate coarser than the sieve in question and finer than the sieve above. Sieving can be done either manually or mechanically. In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve. Operation should be continued till such time that almost no particle is passing through. Mechanical devices are actually designed to give motion in all possible direction, and as such, it is more systematic and efficient than hand-sieving. For assessing the gradation by sieve analysis, the quantity of materials to be taken on the sieve is given

From the sieve analysis the particle size distribution in a sample of aggregate is found out. In this connection a term known as "Fineness Modulus" (F.M.) is being used. F.M. is a ready index of coarseness or fineness of the material. Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100. The larger the figure, the coarser is the material. Table No. 3.9 shows the typical example of the sieve analysis, conducted on a sample of coarse aggregate and fine aggregate to find out the fineness modulus.

Many a time, fine aggregates are designated as coarse sand, medium sand and fine sand. These classifications do not give any precise meaning. What the supplier terms as fine sand may be really medium or even coarse sand. To avoid this ambiguity fineness modulus could be used as a yard stick to indicate the fineness of sand.

The following limits may be taken as guidance:

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

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

Combining Aggregates to Obtain Specified Gradings

Sometimes aggregates available at sites may not be of specified or desirable grading. In such cases two or more aggregates from different sources may be combined to get the desired grading. Often, mixing of available fine aggregate with available coarse aggregate in appropriate percentages may produce desirable gradings. But sometimes two or more fractions of coarse aggregate is mixed first and then the combined coarse aggregate is mixed with fine aggregate to obtain the desired gradings. Knowing the grading of available aggregates, proportions of mixing different sizes can be calculated, either graphically or arithmetically. This aspect will be dealt in more detail under the chapter Mix Design. At this stage a simple trial and error arithmetical method of combining coarse and fine aggregate is illustrated. Table 3.10 shows the grading pattern of the available coarse and fine aggregate at site. This table also shows the specified combined grading.

Table 3.11 shows the grading of different combination of fine and coarse aggregate for first trial and second trial. The combined grading of first trial and second trial is compared with the specified combined grading. Whichever trial gives the combined aggregate grading equal or nearly equal to the specified grading is adopted.

Specific Sur face and Surface Index

The importance of a good grading of the coarse and fine aggregate has already been discussed. The quantity of water required to produce a given workability depends to a large extent on the surface area of the aggregate.

The surface area per unit weight of the material is termed as specific surface. This is an indirect measure of the aggregate grading. Specific surface increases with the reduction in the size of aggregate particle so that fine aggregate contributes very much more to the surface area than does the coarse aggregate. Greater surface area requires more water for lubricating the mix to give workability. The workability of a mix is, therefore, influenced more by finer fraction than the coarser particles in a sample of aggregates.

The foregoing paragraph gives the impression that smaller particles of aggregate contribute more surface area and hence require more water for wetting the surface of aggregates; and for a given quantity of water, the presence of smaller particles reduces the workability. This impression is correct upto a certain extent of the finer fraction. This will not hold good for very fine particles in F.A. The every fine particles in F.A. *i.e.*, 300 micron and 150 micron particles, being so fine, contribute more towards workability. Their over-riding influence in contributing to the better workability by acting like ball bearings to reduce the internal friction between coarse particles, far out-weigh the reduction in workability owing to the consumption of mixing water for wetting greater surface area.

Consideration of specific surface gives a somewhat misleading picture of the workability to be expected. To overcome this difficulty Murdock has suggested the use of "Surface Index" which is an empirical number related to the specific surface of the particle with more weightage given to the finer fractions. The empirical numbers representing the surface index of aggregate particles within the set of sieve size are given in Table 3.12.

The total surface index (*fx*) of a mixture of aggregate is calculated by multiplying the percentage of material retained on its sieve by the corresponding surface index and to their sum is added a constant of 330 and the result is divided by 1000.

Standard Grading Curve

The grading patterns of aggregate can be shown in tables or charts. Expressing grading limits by means of a chart gives a good pictorial view. The comparison of grading pattern of a number of samples can be made at one glance. For this reason, often grading of aggregates is shown by means of grading curves. One of the most commonly referred practical grading curves are those produced by Road Research Laboratory (U.K.). On the basis of large 3 . 1 0 number of experiments in connection with bringing out mix design procedure, Road Research Laboratory has prepared a set of type grading curve for all-in aggregates graded down from 20 mm and 40 mm. They are shown in figure 3.4 and Fig 3.5 respectively. Similar curves for aggregate with maximum size of 10 mm and downward have been prepared by McIntosh and Erntory. It is shown in Fig. 3.6. Fig. 3.7 shows the desirable grading limit for 80 mm aggregate.

Four curves are shown for each maximum size of aggregate except 80 mm size. From values of percentage passing it can be seen that the lowest curve *i.e.*, curve No. 1 is the coarsest grading and curve No. 4 at the top represents the finest grading. Between the curves No. 1 to 4 there are three zones: A, B, C. In practice the coarse and fine aggregates are supplied separately. Knowing their gradation it will be possible to mix them up to get type grading conforming to any one of the four grading curv

In practice, it is difficult to get the aggregate to conform to any one particular standard curve exactly. If the user insists on a particular pattern of grading, the supplier may quote very high rates. At the same time the user also cannot accept absolutely poor grading pattern of aggregates. As a via media, grading limits are laid down in various specifications rather than to conform exactly to a particular grading curve. Table 3.14 shows the grading limits of coarse aggregates.

Table 3.15 shows the grading limits of fine aggregates. Table 3.16 shows the grading limits of all-in-aggregate.

It should be noted that for crushed stone sands, the permissible limit on 150 micron I.S. Sieve is increased to 20 per cent. Figs. 3.8 *a*, *b*, *c* and *d* show the grading limits of F.A.

Fine aggregate complying with the requirements of any grading zone in Table 3.15 is suitable for concrete but the quality of concrete produced will depend upon a number of factors including proportions.

Where concrete of high strength and good durability is required, fine aggregate conforming to any one of the four grading zones may be used, but the concrete mix should be properly designed. As the fine aggregate grading becomes progressively finer, that is from Grading Zones I to IV, the ratio of the fine aggregate to coarse aggregate should be progressively reduced. The most suitable fine to coarse ratio to be used for any particular mix will, however, depend upon the actual grading, particle shape and surface texture of both fine and coarse aggregates.

It is recommended that fine aggregate conforming to Grading Zone IV should not be used in reinforced concrete unless tests have been made to ascertain the suitability of proposed mix proportions.

It must be remembered that the grading of fine aggregates has much greater effect on workability of concrete than does the grading of coarse aggregate. Experience has shown that usually very coarse sand or very fine sand is unsatisfactory for concrete making. The coarse sand results in harshness bleeding and segregation, and the fine sand requires a comparatively greater amount of water to produce the necessary fluidity. For fine aggregates, a total departure of 5 per cent from zone limits may be allowed. But this relaxation is not permitted beyond the coarser limit of zone I or the finer limit of zone IV.

Crushed Sand

All along in India, we have been using natural sand. The volume of concrete manufactured in India has not been much, when compared to some advanced countries. The infrastructure development such as express highway projects, power projects and industrial developments have started now. Availability of natural sand is getting depleted and also it is becoming costly. Concrete industry now will have to go for crushed sand or what is called manufactured sand.

Advantages of natural sand is that the particles are cubical or rounded with smooth surface texture. The grading of natural F.A. is not always ideal. It depends on place to place. Being cubical, rounded and smooth textured it gives good workability.

So far, crushed sand has not been used much in India for the reason that ordinarily crushed sand is flaky, badly graded rough textured and hence they result in production of harsh concrete for the given design parameters. We have been also not using superplasticizer widely in our concreting operations to improve the workability of harsh mix. For the last about 4–5 years the old methods of manufacturing ordinary crushed sand have been replaced by modern crushers specially designed for producing, cubical, comparatively smooth textured, well graded sand, good enough to replace natural sand.

Many patented equipments are set up in India to produce crushed sand of acceptable quality at project site. Pune-Mumbai express highway is one of the biggest projects undertaken in India recently. Enough quantities of natural sand is not available in this region. The total quantity of concrete involved is more than 20,000,00 m of concrete. The authorities have 3 decided to use crushed sand.

A company by name Svedala is one of the concrete aggregate manufacturers who have been in the forefront for supplying crusher equipments by trade name Jaw master crusher, or Barmac Rock on Rock VSI crushers incorporating rock-on-rock crushing technology that has revolutionised the art of making concrete aggregates. This imported technology has been used for producing coarse and fine aggregates of desired quality in terms of shape, texture and grading.

Dust is a nuisance and technically undesirable in both coarse aggregate and more so in fine aggregate. Maximum permissible particles of size finer than 75 µ is 15% in fine aggregate and 3% in coarse aggregate. There are provision available in these equipments to control and seal the dust

In one of the high rise building sites in western suburb of Mumbai, M 60 concrete was specified. The required slump could not be achieved by natural sand with the given parameter of mix design. But with the use of manufactured sand with proper shape, surface texture, desirable grading to minimise void content, a highly workable mix with the given parameter of mix design, was achieved.

The following is the grading pattern of a sample collected from a sand crushing plant on a particular date and time at Pune-Mumbai Road Project:

The introduction of modern scientifically operated crushers which are operating all over the world, will go a long way for making quality aggregates in all cities in India. Ordinary crushers cannot give the desired shape, surface texture or grading of both coarse and fine aggregate.

Gap grading

So far we discussed the grading pattern of aggregates in which all particle size are present in certain proportion in a sample of aggregate. Such pattern of particle size distribution is also referred to as continuous grading.

Originally in the theory of continuous grading, it was assumed that the voids present in the higher size of the aggregate are filled up by the next lower size of aggregate, and similarly, voids created by the lower size are filled up by one size lower than those particle and so on. It was realised later that the voids created by a particular fraction are too small to accommodate the very next lower size. The next lower size being itself bigger than the size of the voids, it will create what is known as "particle size interference", which prevents the large aggregates compacting to their maximum density.

It has been seen that the size of voids existing between a particular size of aggregate is of the order of 2 or 3 size lower than that fraction. In other words, the void size existing between 40 mm aggregate is of the size equal to 10 mm or possibly 4.75 mm or the size of voids occurring when 20 mm aggregate is used will be in the order of say 1.18 mm or so. Therefore, along with 20 mm aggregate, only when 1.18 mm aggregate size is used, the sample will contain least voids and concrete requires least matrix. The following advantages are claimed for gap graded concrete:

(*i*) Sand required will be of the order of about 26 per cent as against about 40 per cent in the case of continuous grading.

(*ii*) Specific surface area of the gap graded aggregate will be low, because of high percentage of C.A. and low percentage of F.A.

(*iii*) Requires less cement and lower water/cement ratio.

(*iv*) Because of point contact between C.A. to C.A. and also on account of lower cement and matrix content, the drying shrinkage is reduced.

It was also observed that gap graded concrete needs close supervision, as it shows greater proneness to segregation and change in the anticipated workability. In spite of many claims of the superior properties of gap graded concrete, this method of grading has not become more popular than conventional continuous grading.

TESTING OF AGGREGATES

Test for Determination of Flakiness Index

The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm.

This test is conducted by using a metal thickness gauge, of the description shown in Fig. 3.9. A sufficient quantity of aggregate is taken such that a minimum number of 200 pieces of any fraction can be tested. Each fraction is gauged in turn for thickness on the metal gauge. The total amount passing in the guage is weighed to an accuracy of 0.1 per cent of the weight of the samples taken. The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken. Table 3.18 shows the standard dimensions of thickness and length gauges.

Test for Determination of Elongation Index

The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension. The elongation index is not applicable to sizes smaller than 6.3 mm.

This test is conducted by using metal length guage of the description shown in Fig. 3.10. A sufficient quantity of aggregate is taken to provide a minimum number of 200 pieces of any fraction to be tested. Each fraction shall be gauged individually for length on the metal guage. The guage length used shall be that specified in column of 4 of Table 3.18 for the appropriate size of material. The total amount retained by the guage length shall be weighed to an accuracy of at least 0.1 per cent of the weight of the test samples taken. The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged. The presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable, but no recoganised limits are laid down.

Indian standard explain only the method of calculating both Flakiness Index and Elongation Index. But the specifications do not specify the limits. British Standard BS 882 of 1992 limits the flakiness index of the coarse aggregate to 50 for natural gravel and to 40 for crushed corase aggregate However, for wearing surfaces a lower values of flakiness index are required

Test for Determination of clay, fine silt and fine dust

This is a gravimetric method for determining the clay, fine silt and fine dust which includes particles upto 20 microns.

The sample for test is prepared from the main sample, taking particular care that the test sample contains a correct proportion of the finer material. The amount of sample taken for the test is in accordance with Table 3.19.

Sedimentation pipette of the description shown in Fig. 3.11 is used for determination of clay and silt content. In the case of fine aggregate, approximately 300 gm. of samples in the air-dry condition, passing the 4.75 mm IS Sieve, is weighed and placed in the screw topped glass jar, together with 300 ml of diluted sodium oxalate solution. The rubber washer and cap are fixed. Care is taken to ensure water tightness. The jar is then rotated about its long axis, with this axis horizontal, at a speed of 80 ± 20 revolutions per minute for a period of 15 minutes. At the end of 15 minutes the suspension is poured into 1000 ml measuring cylinder and the residue washed by gentle swirling and decantation of successive 150 ml portions of sodium oxalate solution, the washings being added to the cylinder until the volume is made upto 1000 ml.

In the case of coarse aggregate the weighed sample is placed in a suitable container, covered with a measured volume of sodium oxalate solution (0.8 gm per litre), agitated vigorously to remove all fine material adhered and the liquid suspension transferred to the 1000 ml measuring cylinder. This process is repeated till all clay material has been transferred to the cylinder. The volume is made upto 1000 ml with sodium oxalate solution.

The suspension in the measuring cylinder is thoroughly mixed. The pipette A is then gently lowered until the pipette touches the surface of the liquid, and then lowered a further 10 cm into the liquid. Three minutes after placing the tube in position, the pipette A and the bore of tap B is filled by opening B and applying gentle suction at C. A small surplus may be drawn up into the bulb between tap B and tube C, but this is allowed to run away and any solid matter is washed out with distilled water from E. The pipette is then removed from the measuring cylinder and its contents run into a weighed container. The contents of the container is dried at 100°C to 110°C to constant weight, cooled and weighed.

The percentage of the fine slit and clay or fine dust is calculated from the formula.

$$\frac{100}{W_1}\left(\frac{1000\,W_2}{V} - 0.8\right)$$

where W_1 = weight in gm of the original sample.

W_2 = weight in gm of the dried residue

V = volume in ml of the pipette and

0.8 = weight in gm of sodium oxalate in one litre of diluted solution.

Test for Determination of Organic Impurities

This test is an approximate method for estimating whether organic compounds are present in the natural sand in an objectionable quantity or within the permissible limit. The sand from the natural source is tested as delivered and without drying. A 350 ml graduated clear glass bottle is filled to the 75 ml mark with 3 per cent solution of sodium hydroxide in water. The sand is added gradually until the volume measured by the sand layer is 125 ml. The volume is then made up to 200 ml by adding more solution. The bottle is then stoppered and shaken vigorously. Roding also may be permitted to dislodge any organic matter adhering to the natural sand by using glass rod. The liquid is then allowed to stand for 24 hours. The colour of this liquid after 24 hours is compared with a standard solution freshly prepared, as follows:

Add 2.5 ml of 2 per cent solution of tannic acid in 10 per cent alcohol, to 97.5 ml of a 3 per cent sodium hydroxide solution. Place in a 350 ml. bottle, stopper, shake vigorously and allow to stand for 24 hours before comparison with the solution above and described in the preceding paragraph. Alternatively, an instrument or coloured acetate sheets for making the comparison can be obtained, but it is desirable that these should be verified on receipt by comparison with the standard solution.

Test for Determination of Specific Gravity

Indian Standard Specification IS : 2386 (Part III) of 1963 gives various procedures to find out the specific gravity of different sizes of aggregates. The following procedure is applicable to aggregate size larger than 10 mm.

A sample of aggregate not less than 2 kg is taken. It is thoroughly washed to remove the finer particles and dust adhering to the aggregate. It is then placed in a wire basket and immersed in distilled water at a temperature between 22° to 32°C. Immediately after immersion, the entrapped air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per sec. During the operation, care is taken that the basket and aggregate remain completely immersed in water. They are kept in water for a period of 24 ± 1/2 hours afterwards. The basket and aggregate are then jolted and weighed (weight A_1) in water at a temperature 22° to 32° C. The basket and the aggregate are then removed from water and allowed to drain for a few minutes and then the aggregate is taken out from the basket and placed on dry cloth and the surface is gently dried with the cloth. The aggregate is transferred to the second dry cloth and further dried. The empty basket is again immersed in water, jolted 25 times and weighed in water (weight A_2). The aggregate is exposed to atmosphere away from direct sunlight for not less than 10 minutes until it appears completely surface dry. Then the aggregate is weighed in air (weight B). Then the aggregate is kept in the oven at a temperature of 100 to 110°C and maintained at this temperature for 24 ± 1/2 hours. It is then cooled in the air-tight container, and weighed (weight C).

$$\text{Specific Gravity} = \frac{C}{B-A}\;; \quad \text{Apparent Sp. Gravity} = \frac{C}{C-A}$$

$$\text{Water absorption} = \frac{100\,(B-C)}{C}$$

Where, A = the weight in gm of the saturated aggregate in water ($A_1 - A_2$),

B = the weight in gm of the saturated surface-dry aggregate in air, and

C = the weight in gm of oven-dried aggregate in air.

Test for Determination of Bulk Density and Voids

Bulk density is the weight of material in a given volume. It is normally expressed in kg per litre. A cylindrical measure preferably machined to accurate internal dimensions is used for measuring bulk density.

The cylindrical measure is filled about 1/3 each time with thoroughly mixed aggregate and tamped with 25 strokes by a bullet ended tamping rod, 16 mm diameter and 60 cm long. The measure is carefully struck off level using tamping rod as a straight edge. The net weight of the aggregate in the measure is determined and the bulk density is calculated in kg/litre.

$$\text{Bulk dinsity} = \frac{\text{net weight of the aggregate in kg}}{\text{capacity of the container in litre}}\;; \quad \text{Percentage of voids} = \frac{G_s - \gamma}{G_s} \times 100$$

where, G_s = specific gravity of aggregate and γ = bulk dinsity in kg/litre.

Mechanical Properties of Aggregates

IS: 2386 Part IV – 1963

Test for determination of aggregate crushing value

The "aggregate crushing value" gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. With aggregates of 'aggregate crushing value' 30 or higher, the result may be anomalous and in such cases the "ten per cent fines value" should be determined and used instead.

The standard aggregate crushing test is made on aggregate passing a 12.5 mm I.S. Sieve and retained on 10 mm I.S. Sieve. If required, or if the standard size is not available, other sizes upto 25 mm may be tested. But owing to the nonhomogeneity of aggregates the results will not be comparable with those obtained in the standard test.

About 6.5 kg material consisting of aggregates passing 12.5 mm and retained on 10 mm sieve is taken. The aggregate in a surface dry condition is filled into the standard cylindrical measure in three layers approximately of equal depth. Each layer is tamped 25 times with the tamping ord and finally levelled off using the tamping rod as straight edge. The weight of the sample contained in the cylinder measure is taken (A). The same weight of the sample is taken for the subsequent repeat test.

The cylinder of the test appartus with aggregate filled in a standard manner is put in position on the base-plate and the aggregate is carefully levelled and the plunger inserted horizontally on this surface. The plunger should not jam in the cylinder.

The appartus, with the test sample and plunger in position, is placed on the compression testing machine and is loaded uniformly upto a total load of 40 tons in 10 minutes time. The load is then released and the whole of the material removed from the cylinder and sieved on a 2.36 mm I.S. Sieve. The fraction passing the sieve is weighed (B),

$$\text{The aggregate crushing value} = \frac{B}{A} \times 100$$

where, B = weight of fraction passing 2.36 mm sieve,

A = weight of surface-dry sample taken in mould.

The aggregate crushing value should not be more than 45 per cent for aggregate used for concrete other than for wearing surfaces, and 30 per cent for concrete used for wearing surfaces such a runways, roads and air field pavements.

Test for determination of 'ten per cent fines value'

The sample of aggregate for this test is the same as that of the sample used for aggregate crushing value test. The test sample is prepared in the same way as described earlier. The cylinder of the test appartus is placed in position on the base plate and the test sample added in thirds, each third being subjected to 25 strokes by tamping rod. The surface of the aggregate is carefully levelled and the plunger inserted so that it rests horizontally on this surface.

The appartus, with the test sample and plunger in position is placed in the compression testing machine. The load is applied at a uniform rate so as to cause a total penetration of the plunger in 10 minutes of about:

15.00 mm for rounded or partially rounded aggregates (for example uncrushed gravels)

20.0 mm for normal crushed aggregates, and

24.0 mm for honeycombed aggregates (for example, expanded shales and slags).

These figure may be varied according to the extent of the rounding or honeycombing.

After reaching the required maximum penetration, the load is released and the whole of the material removed from the cylinder and sieved on a 2.36 mm I.S. Sieve. The fines passing the sieve is weighed and the weight is expressed as a percentage of the weight of the test sample. This percentage would fall within the range 7.5 to 12.6, but if it does not, a further test shall be made at a load adjusted as seems appropriate to bring the percentage fines with the range of 7.5 to 12.5 per cent. Repeat test is made and the load is found out which gives a percentage of fines within the range of 7.5 to 12.5

$$\text{Load required for 10 per cent fines} = \frac{14 \times X}{Y + 4}$$

where, X = load in tons, causing 7.5 to 12.5 per cent fines.

Y = mean percentage fines from two tests at X tons load.

Test for determination of aggregate impact value

The aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact. Which in some aggregates differs from its resistance to a slow compressive load.

The test sample consists of aggregate passing through 12.5 mm and retained on 10 mm I.S. Sieve. The aggregate shall be dried in an oven for a period of four hours at a temperature of 100°C to 110°C and cooled. The aggregate is filled about one-third full and tamped with 25 strokes by the tamping rod. A further similar quantity of aggregate is added and tamped in the standard manner. The measure is filled to over-flowing and then struck off level. The net weight of the aggregate in the measure is determined (weight A) and this weight of aggregate shall be used for the duplicate test on the same material.

The whole sample is filled into a cylindrical steel cup firmly fixed on the base of the machine. A hammer weighing about 14 kgs. is raised to a height of 380 mm above the upper surface of the aggregate in the cup and allowed to fall freely on the aggregate. The test sample shall be subjected to a total 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate is removed from the cup and the whole of it is sieved on 2.36 mm I.S. Sieve. The fraction passing the sieve is weighed to an accuracy of 0.1 gm. (weight B). The fraction retained on the sieve is also weighed (weight C). If the total weight ($B + C$) is less than the initial weight A by more than one gm the result shall be discarded and a fresh test made. Two tests are made.

The ratio of the weight of fines formed to the total sample weight in each test is expressed as percentage.

$$\text{Therefore, Aggregate Impact Value} = \frac{B}{A} \times 100$$

where, B = weight of fraction passing 2.36 mm I.S. Sieve.

A = weight of oven-dried sample.

The aggregate impact value should not be more than 45 per cent by weight for aggregates used for concrete other than wearing surfaces and 30 per cent by weight for concrete to be used as wearing surfaces, such as runways, roads and pavements.

Test for determination of aggregate abrasion value

Indian Standard 2386 (Part IV) of 1963 covers two methods for finding out the abrasion value of coarse aggregates: namely, by the use of Deval abrasion testing machine and by the use of Los Angeles abrasion testing machine. However, the use of Los Angeles abrasion testing machine gives a better realistic picture of the abrasion resistance of the aggregate. This method is only described herein.

Table 3.21 gives the detail of abrasive charge which consists of cast iron spheres or steel spheres approximately 48 mm in diameter and each weighing between 390 to 445 gm.

The test sample consist of clean aggregate which has ben dried in an oven at 105°C to 110°C and it should conform to one of the gradings shown in Table 3.22.

Test sample and abrasive charge are placed in the Los Angeles Abrasion testing machine and the machine is rotated at a speed of 20 to 33 rev/min. For gradings A, B, C and D, the machine is rotated for 500 revolutions. For gradings E, F and G, it is rotated 1000 revolutions. At the completion of the above number of revolution, the material is discharged from the machine and a preliminary separation of the sample made on a sieve coarser than 1.7 mm IS Sieve. Finer portion is then sieved on a 1.7 mm IS Sieve. The material coarser than 1.7 mm IS Sieved is washed, dried in an oven at 105° to 110°C to a substantially constant weight and accurately weighed to the nearest gram.

The difference between the original weight and the final weight of the test sample is expressed as a percentage of the original weight of the test sample. This value is reported as the percentage of wear. The percentage of wear should not be more than 16 per cent for concrete aggregates.

Typical properties of some of the Indian aggregate sample are shown in table 3.23.

Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. It has been discussed enough in chapter 1 about the quantity of mixing water but so far the quality of water has not been discussed. In practice, very often great control on properties of cement and aggregate is exercised, but the control on the quality of water is often neglected. Since quality of water affects the strength, it is necessary for us to go into the purity and quality of water.

Qualities of Water

A popular yard-stick to the suitability of water for mixing concrete is that, if water is fit for drinking it is fit for making concrete. This does not appear to be a true statement for all conditions. Some waters containing a small amount of sugar would be suitable for drinking but not for mixing concrete and conversely water suitable for making concrete may not necessarily be fit for drinking. Some specifications require that if the water is not obtained from source that has proved satisfactory, the strength of concrete or mortar made with questionable water should be compared with similar concrete or mortar made with pure water. Some specification also accept water for making concrete if the pH value of water lies between 6 and 8 and the water is free from organic matter. Instead of depending upon pH value and other chemical composition, the best course to find out whether a particular source of water is suitable for concrete making or not, is to make concrete with this water and compare its 7 days' and 28 days' strength with companion cubes made with distilled water. If the compressive strength is upto 90 per cent, the source of water may be accepted. This criteria may be safely adopted in places like coastal area of marshy area or in other places where the available water is brackish in nature and of doubtful quality. However, it is logical to know what harm the impurities in water do to the concrete and what degree of impurity is permissible is mixing concrete and curing concrete.

Underground water is sometime found unsuitable for mixing or even for curing concrete.

The quality of underground water is to be checked.

Carbonates and bi-carbonates of sodium and potassium effect the setting time of cement. While sodium carbonate may cause quick setting, the bi-carbonates may either accelerate or retard the setting. The other higher concentrations of these salts will materially reduce the concrete strength. If some of these salts exceeds 1,000 ppm, tests for setting time and 28 days strength should be carried out. In lower concentrations they may be accepted.

Brackish water contains chlorides and sulphates. When chloride does not exceed 10,000 ppm and sulphate does not exceed 3,000 ppm the water is harmless, but water with even higher salt content has been used satisfactorily.

Salts of Manganese, Tin, Zinc, Copper and Lead cause a marked reduction in strength of concrete. Sodium iodate, sodium phosphate, and sodium borate reduce the initial strength of concrete to an extra-ordinarily high degree. Another salt that is detrimental to concrete is sodium sulphide and even a sulphide content of 100 ppm warrants testing.

Silts and suspended particles are undesirable as they interfere with setting, hardening and bond characteristics. A turbidity limit of 2,000 ppm has been suggested. Table 4.1 shows the tolerable concentration of some impurities in mixing water.

The initial setting time of the test block made with a cement and the water proposed to be used shall not differ by ±30 minutes from the initial setting time of the test block made with same cement and distilled water.

Use of Sea Water for Mixing Concrete

Sea water has a salinity of about 3.5 per cent. In that about 78% is sodium chloride and 15% is chloride and sulphate of magnesium. Sea water also contain small quantities of sodium and potassium salts. This can react with reactive aggregates in the same manner as alkalies in cement. Therefore sea water should not be used even for PCC if aggregates are known to be potentially alkali reactive. It is reported that the use of sea water for mixing concrete does not appreciably reduce the strength of concrete although it may lead to corrosion of reinforcement in certain cases. Research workers are unanimous in their opinion, that sea water can be used in un-reinforced concrete or mass concrete. Sea water slightly accelerates the early strength of concrete. But it reduces the 28 days strength of concrete by about 10 to 15 per cent. However, this loss of strength could be made up by redesigning the mix. Water containing large quantities of chlorides in sea water may cause efflorescence and persistent dampness. When the appearance of concrete is important sea water may be avoided. The use of sea water is also not advisable for plastering purpose which is subsequently going to be painted.

Divergent opinion exists on the question of corrosion of reinforcement due to the use of sea water. Some research workers cautioned about the risk of corrosion of reinforcement particularly in tropical climatic regions, whereas some research workers did not find the risk of corrosion due to the use of sea water. Experiments have shown that corrosion of reinforcement occurred when concrete was made with pure water and immersed in pure water when the concrete was comparatively porous, whereas, no corrosion of reinforcement was found when sea water was used for mixing and the specimen was immersed in salt water when the concrete was dense and enough cover to the reinforcement was given. From this it could be inferred that the factor for corrosion is not the use of sea water or the quality of water where the concrete is placed. The factors effecting corrosion is permeability of concrete and lack of cover. However, since these factors cannot be adequately taken care of always at the site of work, it may be wise that sea water be avoided for making reinforced concrete. For

Sea water is not to be used for prestressed concrete or for reinforced concrete. If unavoidable, it could be used for plain cement concrete (PCC).

economical or other passing reasons, if sea water cannot be avoided for making reinforced concrete, particular precautions should be taken to make the concrete dense by using low water/cement ratio coupled with vibration and to give an adequate cover of at least 7.5 cm. The use of sea water must be avoided in prestressed concrete work because of stress corrosion and undue loss of cross section of small diameter wires. The latest Indian standard IS 456 of 2000 prohibits the use of Sea Water for mixing and curing of reinforced concrete and prestressed concrete work. This specification permits the use of Sea Water for mixing and curing of plain cement concrete (PCC) under unavoidable situation..

It is pertinent at this point to consider the suitability of water for curing. Water that contains impurities which caused staining, is objectionable for curing concrete members whose look is important. The most common cause of staining is usually high concentration of iron or organic matter in the water. Water that contains more than 0.08 ppm. of iron may be avoided for curing if the appearance of concrete is important. Similarly the use of sea water may also be avoided in such cases. In other cases, the water, normally fit for mixing can also be used for curing.

Admixtures and Construction Chemicals

Admixture is defined as a material, other than cement, water and aggregates, that is used as an ingredient of concrete and is added to the batch immediately before or during mixing. Additive is a material which is added at the time of grinding cement clinker at the cement factory.

These days concrete is being used for wide varieties of purposes to make it suitable in different conditions. In these conditions ordinary concrete may fail to exhibit the required 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.Until about 1930 additives and admixtures though used, were not considered an important part of concrete technology. Since then, there has been an increase in the use of admixtures. Though the use of admixtures and additives is being frowned upon or scorned by some technologists, there are many on the contrary, who highly commend and foster the use and development of admixtures as it imparts many desirable characteristics and effect economy in concrete construction. It should be remembered, however, that admixtures are no substitute for good concreting practices.

The history of admixtures is as old as the history of concrete. It embraces a very vast field as shown in table 5.22. But a few type of admixtures called Water Reducers or High Range Water Reducers, generally referred as plasticizers and superplasticizers, are of recent interest. They are specifically developed in Japan and Germany around 1970. Later on they were made popular in USA and Europe even in Middle East and Far East. Unfortunately, the use of plasticizers and superplasticizers have not become popular in India till recently (1985). There are many reasons for non acceptance for wider use of plasticizers in India: Ninety per cent of concreting activities are in the hands of common builders or Government departments who do not generally accept something new. Plasticizers were not manufactured in India and they were to be imported, and hence costly. Lack of education and awareness of the benefits accrued by the use of plasticizers, and we were used to making generally low strength concrete of the type M15 to M30, which do not really need the use of plasticizers.

Now, since early 1980’ s, some internationally renowned companies collaborated with Indian companies and have started manufacturing chemical admixtures in India. As a part of marketing they started educating consultants, architects, structural engineers and builders about the benefits of using admixtures. We, in India have also started using higher strength concrete for high rise buildings and bridges. Use of Ready mix concrete has really promoted the use of admixtures in India, in recent times.

It will be slightly difficult to predict the effect and the results of using admixtures because, many a time, the change in the brand of cement, aggregate grading, mix proportions and richness of mix alter the properties of concrete. Sometimes many admixtures affect more than one property of concrete. At times, they affect the desirable properties adversely. Sometimes, more than one admixture is used in the same mix. The effect of more than one admixture is difficult to predict. Therefore, one must be cautious in the selection of admixtures and in predicting the effect of the same in concrete.

As per the report of the ACI Committee 212, admixtures have been classified into 15 groups according to type of materials constituting the admixtures, or characteristic affect of the use. When ACI Committee 212 submitted the report in 1954, plasticizers and superplasticizers, as we know them today, were not existing. Therefore, in this grouping of admixtures, plasticizers and superplasticizers and a few variations in them have now been included under admixtures.

Classification of admixtures as given by M.R. Rixom (slightly modified to include a few new materials) is given in table 5.22.

In this chapter, the following admixtures and construction chemicals are dealt with.

Admixtures

- Plasticizers
- Superplasticizers
- Retarders and Retarding Plasticizers
- Accelerators and Accelerating Plasticizers
- Air-entraining Admixtures
- Pozzolanic or Mineral Admixtures
- Damp-proofing and Waterproofing Admixtures
- Gas forming Admixtures
- Air-detraining Admixtures
- Alkali-aggregate Expansion Inhibiting Admixtures
- Workability Admixtures
- Grouting Admixtures
- Corrosion Inhibiting Admixtures
- Bonding Admixtures
- Fungicidal, Germicidal, Insecticidal Admixtures
- Colouring Admixtures

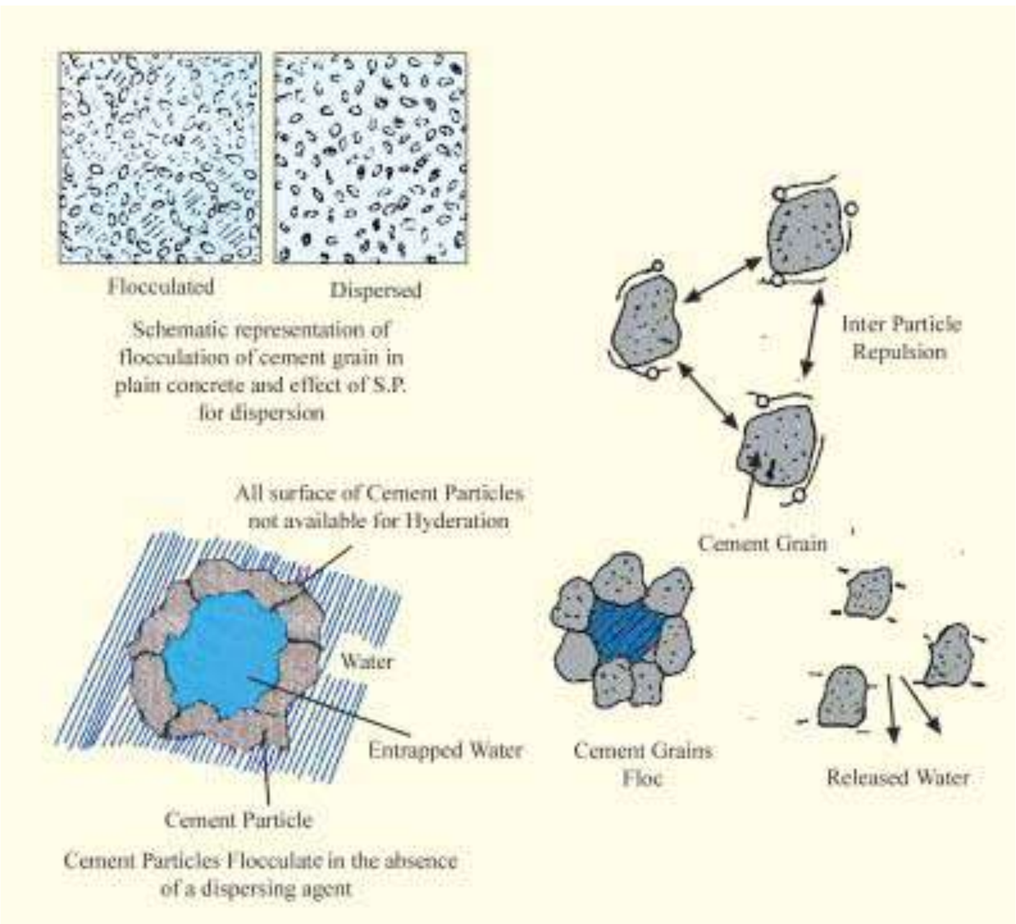
Construction Chemicals

- Concrete Curing Compounds
- Polymer Bonding Agents
- Polymer Modified Mortar for Repair and Maintenance
- Mould Releasing Agents
- Protective and Decorative Coatings
- Installation Aids
- Floor Hardeners and Dust-proofers
- Non-shrink High Strength Grout
- Surface Retarders
- Bond-aid for Plastering
- Ready to use Plaster
- Guniting Aid
- Construction Chemicals for Water-proofing

1. Integral Water-proofing Compounds
2. Membrane Forming Coatings
3. Polymer Modified Mineral Slurry Coatings
4. Protective and Decorative Coatings
5. Chemical DPC
6. Silicon Based Water-repellent Material
7. Waterproofing Adhesive for Tiles, Marble and Granite
8. Injection Grout for Cracks
9. Joint Sealants

Plasticizers (Water Reducers)

Requirement of right workability is the essence of good concrete. Concrete in different situations require different degree of workability. A high degree of workability is required in situations like deep beams, thin walls of water retaining structures with high percentage of steel reinforcement, column and beam junctions, tremie concreting, pumping of concrete, hot weather concreting, for concrete to be conveyed for considerable distance and in ready mixed concrete industries. The conventional methods followed for obtaining high workability is by improving the gradation, or by the use of relatively higher percentage of fine aggregate or by increasing the cement content. There are difficulties and limitations to obtain high workability in the field for a given set of conditions. The easy method generally followed at the site in most of the conditions is to use extra water unmindful of the harm it can do to the strength and durability of concrete. It has been stressed time and again in almost all the chapters of this book to the harmful effect of using extra water than necessary. It is an abuse, a criminal act, and unengineering to use too much water than necessary in concrete. At the same time, one must admit that getting required workability for the job in hand with set conditions and available materials is essential and is often difficult. Therefore, engineers at the site are generally placed in conflicting situations. Often he follows the easiest path and that is adding extra water to fluidise the mix. This addition of extra water to satisfy the need for workable concrete is amounting to sowing the seed of cancer in concrete. Today we have plasticizers and superplasticizers to help an engineer placed in intriguing situations. These plasticizers can help the difficult conditions for obtaining higher workability without using excess of water. One must remember that addition of excess water, will only 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. Whereas the plasticized concrete will improve the desirable qualities demanded of plastic concrete. The practice all over the world now is to use plasticizer or superplasticizer for almost all the reinforced concrete and even for mass concrete to reduce the water requirement for making concrete of higher workability or flowing concrete. The use of superplasticizer has become almost an universal practice to reduce water/cement ratio for the given workability, which naturally increases the strength. Moreover, the reduction in water/cement ratio improves the durability of concrete. Sometimes the use of plasticizers is employed to reduce the cement content and heat of hydration in mass concrete.



The organic substances or combinations of organic and inorganic substances, which allow a reduction in water content for the given workability, or give a higher workability at the same water content, are termed as plasticizing admixtures. The advantages are considerable in both cases : in the former, concretes are stronger, and in the latter they are more workable.

The basic products constituting plasticizers are as follows:

(*i*) Anionic surfactants such as lignosulphonates and their modifications and derivatives, salts of sulphonates hydrocarbons.

(*ii*) Nonionic surfactants, such as polyglycol esters, acid of hydroxylated carboxylic acids and their modifications and derivatives.

(*iii*) Other products, such as carbohydrates etc.

Among these, calcium, sodium and ammonium lignosulphonates are the most used. Plasticizers are used in the amount of 0.1% to 0.4% by weight of cement. At these doses, at constant workability the reduction in mixing water is expected to be of the order of 5% to 15%. This naturally increases the strength. The increase in workability that can be expected, at the same w/c ratio, may be anything from 30 mm to 150 mm slump, depending on the dosage, initial slump of concrete, cement content and type.

A good plasticizer fluidizes the mortar or concrete in a different manner than that of the air-entraining agents. Some of the plasticizers, while improving the workability, entrains air also. As the entrainment of air reduces the mechanical strength, a good plasticizer is one which does not cause air-entrainment in concrete more than 1 or 2%.

One of the common chemicals generally used, as mentioned above is Lignosulphonic acid in the form of either its calcium or sodium salt. This material is a natural product derived from wood processing industries. Admixtures based on lignosulphonate are formulated from purified product from which the bulk of the sugars and other interfering impurities are removed to low levels. Such a product would allow adsorption into cement particles without any significant interferences with the hydration process or hydrated products. Normal water reducing admixtures may also be formulated from wholly synthetic raw materials. It is also observed that at a recommended dose, it does not affect the setting time significantly. However, at higher dosages than prescribed, it may cause excessive retardation. It must be noted that if unrefined and not properly processed lignosulphonate is used as raw material, the behaviour of plasticizer would be unpredictable. It is some times seen that this type of admixture has resulted in some increase in air-entrainment. It is advised that users should follow the instructions of well established standard manufacturers of plasticizers regarding dosage.

Superplasticizers (High Range Water Reducers)

Superplasticizers constitute a relatively new category and improved version of plasticizer, the use of which was developed in Japan and Germany during 1960 and 1970 respectively. They are chemically different from normal plasticiszers. Use of superplasticizers permit the reduction of water to the extent upto 30 per cent without reducing workability in contrast to the possible reduction up to 15 per cent in case of plasticizers.

The use of superplasticizer is practiced for production of flowing, self levelling, self compacting and for the production of high strength and high performance concrete.

The mechanism of action of superplasticizers are more or less same as explained earlier in case of ordinary plasticizer. Only thing is that the superplasticizers are more powerful as dispersing agents and they are high range water reducers. They are called High Range Water Reducers in American literature. It is the use of superplasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 Mpa or more. It is the use of superplasticizer which has made it possible to use fly ash, slag and particularly silica fume to make high performance concrete.

The use of superplasticizer in concrete is an important milestone in the advancement of concrete technology. Since their introduction in the early 1960 in Japan and in the early 1970 in Germany, it is widely used all over the world. India is catching up with the use of superplasticizer in the construction of high rise buildings, long span bridges and the recently become popular Ready Mixed Concrete Industry. Common builders and Government departments are yet to take up the use of this useful material.

Superplasticizers can produce:

at the same w/c ratio much more workable concrete than the plain ones, ò

for the same workability, it permits the use of lower w/c ratio, ò

as a consequence of increased strength with lower w/c ratio, it also permits a ò reduction of cement content.

The superplasticizers also produce a homogeneous, cohesive concrete generally without any tendency for segregation and bleeding.

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 without the formation of cold joints. They are also used in grouting oil wells. Oil wells are sometimes taken upto a depth of about 6000 meter deep where the temperature may be about 200°C. The annular spacing between the steel tube and the wall of the well will have to be sealed with cement grout. Sometimes at that depth stratified or porous rockstrata may also require to be grouted to prevent the entry of gas or oil into some other strata. For all these works cement grout is required to be in mobile condition for about 3 to 4 hours, even at that high temperature without getting set. Use of retarding agent is often used for such requirements.

Sometimes concrete may have to be placed in difficult conditions and delay may occur in transporting and placing. In ready mixed concrete practices, concrete is manufactured in central batching plant and transported over a long distance to the job sites which may take considerable time. In the above cases the setting of concrete will have to be retarded, so that concrete when finally placed and compacted is in perfect plastic state.

Retarding admixtures are sometimes used to obtain exposed aggregate look in concrete. The retarder sprayed to the surface of the formwork, prevents the hardening of matrix at the interface of concrete and formwork, whereas the rest of the concrete gets hardened. On removing the formwork after one day or so, the unhardened matrix can be just washed off by a jet of water which will expose the aggregates. The above are some of the instances where a retarding agent is used.

Perhaps the most commonly known retarder is calcium sulphate. It is interground 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, sugars, acids or salts of acids. These chemicals may have variable action on different types of cement when used in different quantities. Unless experience has been had with a retarder, its use as an admixture should not be attempted without technical advice. Any mistake made in this respect may have disastrous consequences.

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 will cause indefinite delay in setting. At normal temperatures addition of sugar 0.05 to 0.10 per cent have little effect on the rate of hydration, but if the quantity is increased to 0.2 per cent, hydration can be retarded to such an extent that final set may not take place for 72 hours or more. Skimmed milk powder (casein) has a retarding effect mainly due to sugar content.

Other admixtures which have been successfully used as retarding agents are Ligno sulphonic acids and their salts, hydroxylated carboxylic acids and their salts which in addition to the retarding effect also reduce the quantity of water requirement for a given workability. This also increases 28 days compressive strength by 10 to 20 per cent. Materials like mucic acid, calcium acetate and a commercial products by name "Ray lig binder" are used for set retarding purposes. These days admixtures are manufactured to combine set retarding and water reducing properties. They are usually mixtures of conventional water reducing agents plus sugars or hydroxylated carboxylic acids or their salts. Both the setting time and the rate of strength build up are effected by these materials. This is shown in Table 5.4.

Retarding Plasticizers

It is mentioned earlier that all the plasticizers and superplasticizers by themselves show certain extent of retardation. Many a time this extent of retardation of setting time offered by admixtures will not be sufficient. Instead of adding retarders separately, retarders are mixed with plasticizers or superplasticizers at the time of commercial production. Such commercial brand is known as retarding plasticizers or retarding superplasticizers. ASTM type D is retarding plasticizers and ASTM type G is retarding superplasticizer. In the commercial formulation we have also retarding and slump retaining version.

Retarding plasticizers or superplasticizers are important category of admixtures often 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.

One must be careful in the selection of such ready made retarding admixtures. On account of heterogeneous nature and different molecular weight of retarders used with plasticizers, they tend to separate out. It happens when sugar solution is used as cheap retarders. When retarders like gluconate is used such separation or settlement of retarders do not happen. It is cautioned that such retarding plasticizers should always be shaken thoroughly or well stirred before use. There are cases that settlement of retarders from rest of the ingredients causing excessive retardation and failure of structures.

Accelerators

Accelerating admixtures 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.

In the past one of the commonly used materials as an accelerator was calcium chloride. But, now a days it is not used. Instead, some of the soluble carbonates, silicates fluosilicates and some of the organic compounds such as triethenolamine are used. Accelerators such as fluosilicates and triethenolamine are comparatively expensive.

The recent studies have shown that calcium chloride is harmful for reinforced concrete and prestressed concrete. It may be used for plain cement concrete in comparatively high dose. The limits of chloride content in concrete is given in chapter on Durability of Concrete.

Some of the accelerators produced 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 accelerator, the under water concreting has become easy. Similarly, the repair work that would be carried out to the waterfront structures in the region of tidal variations has become easy. The use of such powerful accelerators have facilitated, the basement waterproofing operations. In the field of prefabrication also it has become an invaluable material. As these materials could be used up to 10°C, they find an unquestionable use in cold weather concreting.

Some of the modern commercial accelerating materials are Mc-Schnell OC, Mc-Schnell SDS, Mc-Torkrethilfe BE, manufactured by Mc-Bauchemic (Ind) Pvt. Ltd. MC-Torkrethilfe BE is a material specially formulated to meet the demand for efficient and multifold properties desired for sprayed concrete and shotcreting operations. A field trial is essential to determine the dose for a given job and temperature conditions when the above materials are used.

Accelerating Plasticizers

Certain ingredients are added to accelerate the strength development of concrete to plasticizers or superplasticizers. Such accelerating superplasticizers, when added to concrete result in faster development of strength. The accelerating materials added to plasticizers or superplasticizers are triethenolamine chlorides, calcium nutrite, nitrates and flousilicates etc. The accelerating plasticizers or accelerating superplasticizers manufactured by well known companies are chloride free.

Table 5.5, Table 5.6, Table 5.7 and 5.8 shows the specification limits of IS 9103 of 1999, ASTM 494 of 1982, BS 5075 part I of 1982 and BS part 3 of 1985 respectively. Table 5.9 gives the list of some of the commercial plasticizers and superplasticizers manufactured in India.

Air-entraining Admixture

Perhaps one of the important advancements made in concrete technology was the discovery of air entrained concrete. Since 1930 there has been an ever increasing use of air entrained concrete all over the world especially, in the United States and Canada. Due to the recognition of the merits of air entrained concrete, about 85 per cent of concrete manufactured in America contains one or the other type of air entraining agent. So much so that air entraining agents have almost come to be considered a necessary 'fifth ingredient' in concrete making.

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 bearings and will modify the properties of plastic concrete regarding workability, segregation, bleeding and finishing quality of concrete. It also modifies the properties of hardened concrete regarding its resistance to frost action and permeability.

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 to 80 microns distributed evenly in the entire mass of concrete. The entrapped air is the voids present in the concrete due to insufficient compaction. These entrapped air voids may be of any shape and size normally embracing the contour of aggregate surfaces. Their size may range from 10 to 1000 microns or more and they are not uniformly distributed throughout the concrete mass.

Pozzolanic or Mineral Admixtures

The use of pozzolanic materials is as old as that of the art of concrete construction. It was recognised long time ago, that the suitable pozzolans used in appropriate amount, modify certain properties of fresh and hardened mortars and concretes.

when mixed with lime produced strong cementing material having hydraulic properties and such cementing materials were employed in the construction of acquaducts, arch, bridges etc. One such material was consolidated volcanic ash or tuff found near Pozzuoli (Italy) near Vesuvius. This came to be designated as Pozzuolana, a general term covering similar materials of volcanic origin found in other deposits in Italy, France and Spain. Later, the term pozzolan was employed throughout Europe to designate any materials irrespective of its origin which possessed similar properties.

Specimens of concrete made by lime and volcanic ash from Mount Vesuvius were used in the construction of Caligula Wharf built in the time of Julius Caesar nearly 2000 years ago is now existing in a fairly good condition. A number of structures stand today as evidence of the superiority of pozzolanic cement over lime. They also attest the fact that Greeks and Romans made real advance in the development of cementitious materials.

After the development of natural cement during the latter part of the 18th century, the Portland cement in the early 19th century, the practice of using pozzolans declined, but in more recent times, Pozzolans have been extensively used in Europe, USA and Japan, as an ingredient of Portland cement concrete particularly for marine and hydraulic structures.

It has been amply demonstrated that the best pozzolans in optimum proportions mixed with Portland cement improves many qualities of concrete, such as:

(*a*) Lower the heat of hydration and thermal shrinkage;
(*b*) Increase the watertightness;
(*c*) Reduce the alkali-aggregate reaction;
(*d*) Improve resistance to attack by sulphate soils and sea water;
(*e*) Improve extensibility;
(*f*) Lower susceptibility to dissolution and leaching;
(*g*) Improve workability;
(*h*) Lower costs.

In addition to these advantages, contrary to the general opinion, good pozzolans will not unduly increase water requirement or drying shrinkage.

Natural Pozzolans

Clay and Shales
Opalinc Cherts
Diatomaceous Earth
Volcanic Tuffs and Pumicites.

Artificial Pozzolans

Fly ash
Blast Furnace Slag
Silica Fume
Rice Husk ash
Metakaoline
Surkhi.

Bonding Admixture

Bonding admixtures are water emulsions of several organic materials that are mixed with cement or mortar grout for application to an old concrete surface just prior to patching with mortar or concrete. Sometimes they are mixed with the topping or patching material. Their function is to increase the bond strength between the old and new concrete. This procedure is used in patching of eroded or spalled concrete or to add relatively thin layers of resurfacing.

The commonly used bonding admixtures are made from natural rubber, synthetic rubber or from any organic polymers. The polymers include polyvinyl chloride, polyvinyl acetate etc.

Bonding admixtures fall into two general categories, namely, re-emulsifiable types and non-re-emulsifiable types. The latter is better suited for external application since it is resistant to water.

These emulsions are generally added to the mixture in proportions of 5 to 20 per cent by weight of cement. Bonding admixtures usually cause entrainment of air and a sticky consistency in a grout mixtures. They are effective only on clean and sound surfaces.

Fungicidal, Germicidal and Insecticidal Admixtures

It has been suggested that certain materials may either be ground into the cement or added as admixtures to impart fungicidal, germicidal or insecticidal properties to hardened cement pastes, mortars or concretes. These materials include polyhalogenated phenols, dieldren emulsion or copper compounds.

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 stability in the presence of alkalinity produced in the set cement (*c*) no adverse effect on setting time or strength development. Various metallic oxides and mineral pigments are used.

Pigments should preferably be thoroughly mixed or interground with the dry cement. They can also be mixed with dry concrete mixtures before the addition of mixing water.

RMC (India) Ltd., one of the Ready Mixed Concrete supplier markets ready mixed colour concrete for decorative pavements. Sometimes they make this colour concrete incorporating polypropelyne fibres to arrest possible cracks and craziness in the concrete floor.

Miscellaneous Admixtures

There are hundreds of commercial admixtures available in India. They effect more than one property of concrete. Sometimes they are ineffective and do not fulfil the claims of the manufacturers. It is not intended to deal in detail about these commercial admixtures. However, a few of the more important admixtures are briefly described and some of them are just named.

All these commercial admixtures can be roughly brought under two categories (*a*) Damp proofers (*b*) Surface hardeners, though there are other agents which will modify the properties like strength, setting time, workability etc.

Damp Proofers

(*a*) Accopr Accopr Accopr Accoproof: Accopr oof: oof: oof: oof: It is a white powder to be mixed with concrete at the rate of 1 kg per bag of cement for the purpose of increasing impermeability of concrete structures.

(*b*) Natson' Natson' Natson' Natson' Natson's Cement W s Cement W s Cement W s Cement W s Cement WaterPr aterPr aterPr aterPr aterProofer: oofer: oofer: oofer: oofer: As the name indicates, it is a waterproofing admixture to be admixed at the rate of 1.5 kg per bag of cement.

(*c*) T rip-L-Seal: rip-L-Seal: rip-L-Seal: rip-L-Seal: rip-L-Seal: It is a white powder, the addition of which is claimed to decrease permeability of concrete and mortars and produce rapid hardening effect.

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

(*e*) Feb-Mix-Admix: Feb-Mix-Admix: Feb-Mix-Admix: Feb-Mix-Admix: It is a light yellow coloured liquid claimed to impart waterproofing Feb-Mix-Admix: quality to concrete and increase workability and bond.

(*f*) Cemet: Cemet: Cemet: Cemet: Cemet: It is a waterproofing admixture. The recommended dose is 3 per cent by weight of cement. It is also claimed that its use in concrete will prevent efflorescence and growth of fungi.

In addition to the above the following are some of the commercial waterproofing admixtures:

(*a*) Arzok	(*b*) Bondex
(*c*) Impermo	(*d*) Luna-Ns-1
(*e*) Sigmet	(*f*) Arconate No. 2
(*g*) Swadco No. 1	(*h*) Rela
(*i*) Wet seal	(*j*) Water lock

Chemical DPC

Often old buildings are not provided with damp-proof course. The water from the ground rises by capillary action. This rising water brings with it the dissolved salts and chemicals which result in peeling of plaster affecting the durability of structure, and also make buildings unhygenic. Attempts were made to cut the wall thickness in stages and introduce new DPC, but this method was found to be not only cumbersome but also ineffective. Now we have materials that can be injected into the wall at appropriate level to seal the capillaries and thereby to stop the upward movement of water. The system involves a two component material called Samafit VK_1 and Samafit VK_2 manufactured by MC Bauchemie (Ind) Pvt. Ltd. Above the ground level and below the plinth level, holes are drilled in a particular system. Samafit VK_1 is injected into this hole till absorption stops. After another 1/2 to 1 hour's time the other fluid namely Samafit VK_2 is similarly introduced. These two liquids react with each other to form a kind of jelly like substance which block the capillary cavities in the brickwall and stops the capillary rise of water. In this way rising dampness in buildings, where damp proof course is not provided earlier, can be stopped.

Waterproofing Adhesives for Tiles, Marble and Granite

The normal practice followed for fixing glazed tiles in bathroom, lavatory, kitchen, and other places is the use of stiff neat cement paste. The existing practice, though somewhat satisfactory in the indoor conditions from the point of fixity, such practice is unsatisfactory when used in outdoor conditions and also from the point of view of waterproofing quality. The cement paste applied at the back of tiles do not often flow towards the edges of the tiles and as such water enter at the edges, particularly when white cement applied as joint filler become ineffective. In large number of cases it is seen that paintings and plaster gets affected behind these glazed tiles supposedly applied to prevent moisture movement from wet areas.

Waterproofing Adhesives for Tiles, Marble and Granite.

Cement paste is not the right material for fixing the glazed tiles. There are, polymer based, hydraulically setting, ready to use, waterproof tile adhesive available in the market. They offer many advantages over the conventional method of tile fixing such as better bond and adhesion, strengths, faster work, good waterproofing quality to the wall. They are also suitable for exterior and overhead surfaces. No curing of tile surface becomes necessary. If the wall and plastered surface is done to good plumb, a screeding of only 1 – 2 mm thickness of this modern material will be sufficient to fix the tiles in which case, the adoption of this material will also become economical. The modern tile adhesive material offers special advantages for fixing glazed tiles in swimming pools both on floor and at side walls. It provides one more barrier for the purpose of waterproofing.

Many a time, the glazed tiles fixed on the kitchen platform or bathroom floor gets dirty or damaged. It requires to be replaced. Normal practice is to chip off the old tile, screed cement paste or mortar and then lay the new tiles. With modern tile adhesive, it is not necessary to remove the old tile. Tile adhesive can be screeded on the existing tiles and new tiles are laid over the old tiles. The bonding quality is such that good adherence takes place tile over tile. This saves considerable cost and time and the operation becomes simple.

Marble and granite are increasingly used for cladding wall surfaces both internally and externally. Marble and granite have become the most common treatment for external cladding of prestigious buildings. They are used in the form of tiles or large panels. In the past for fixing thin marble and granite tiles cement paste was used and for fixing large slabs and panels, epoxy and dowel pins were used. Now there are specially made ready to use high strength polymer bonding materials available which can be used with confidence both for internal and external use. Requirement of dowels are eliminated in most of the cases except for cladding of large panels at very high level for extra safety. Marble and granite can even be fixed on boards, inclined surface underside of beams and in ceilings by the use of this new powerful adhesives.

Zentrival PL for fixing glazed tiles and ceramic tiles and Zentrival HS for marble, granite and stones are the materials manufactured by Mc-Bauchemie (India) Pvt. Ltd., Nitobond EP, Nitobond PVA, Nitotile SP are some of the products manufactured by Fosroc.

Waterproofing by Silicon Based Water Repellant Material.

Silicon Based Water Repellant Materials

Sometimes, in buildings brick works are not plastered. Bricks are exposed as they are. If good quality, well burnt bricks are not used in such constructions, the absorptive bricks permits the movement of moisture inside. Old heritage buildings built in stone masonry may suffer from minute cracks in mortar joints or plastered surface may develop craziness. In such situations one cannot use any other waterproofing treatment which will spoil the intended architectural beauty of the structures. One will have to go for transparent waterproofing treatment. For this purpose silicon based water repellant materials are used by spraying or brushing. This silicon based material forms a thin water repellant transparent film on the surface. The manufacturers slightly modify this material to make it little flexible to accommodate minor building movements due to thermal effect.

The application must be done in one liberal coat so that all the cracks and crevices are effectively sealed. Brick surface absorbs this material making the surface water repellant. Sometimes bricks or blocks are immersed in such materials before using for greater water repellant qualities.

This type of waterproofing materials are used in many monumental stone buildings and old palaces so that original look of the stone masonry is maintained, while making the masonry waterproof.

The treatment though effective, is not found to be long lasting on account of the movement of building components and the lack of required flexibility of the film. The treatment may have to be repeated at closer intervals, say once in 3–4 years. As it is not a costly material, one can afford to repeat the treatment.

This material is covered in IS 12027 of 1987. NISIWA SH is the brand name of one such material manufactured by MC-Bauchemie (Ind) Pvt. Ltd.

Injection Grout for Cracks

Injection grouting is one of the powerful methods commonly adopted for stopping leakages in dams, basements, swimming pools, construction joints and even in the leaking roofs. A few years back, cement was used for grouting purposes. Cement is not an ideal material for grouting, as it shrinks while setting and hardening. Non-shrink or expansive cementing material is the appropriate material. We have quite a few materials available in the market for filling up cracks and crevices in concrete structures to make them waterproof or for repair and rehabilitation of structures. The grouts are produced with selected water repellant, silicifying chemical compounds and inert fillers to achieve varied characteristics like water impermeability, non shrinkage, free flowability etc. They are suitable for gravity grouting as well as pressure grouting. Grouting of concrete structure is one of the powerful methods for strengthening and waterproofing of unhealthy structures. Centicrete is the trade name of one of the materials manufactured by MC-Bauchemie. Conbex 100 is the material marketed by Fosroc chemicals.

Concrete Repair System

It was once thought that concrete structures are durable and lasts almost forever. But now it is realised that concrete is not as durable as it was thought to be. It was also the earlier belief that concrete needs no protection. It was discussed earlier that concrete needs to be maintained and protected. Another wrong notion that prevailed was that concrete cannot be repaired. Now there are materials and methods for effective repair of damaged concrete structures which is discussed below.

Concrete is constantly under attack of environmental pollution, moisture ingress, penetration of chlorides and sulphates and other deleterious chemicals. The durability of concrete is then affected. Of all forces of degradation, carbonation is believed to be one of the potent causes of deterioration of concrete. This aspect is going to be discussed in detail under chapter 9 – durability of concrete.

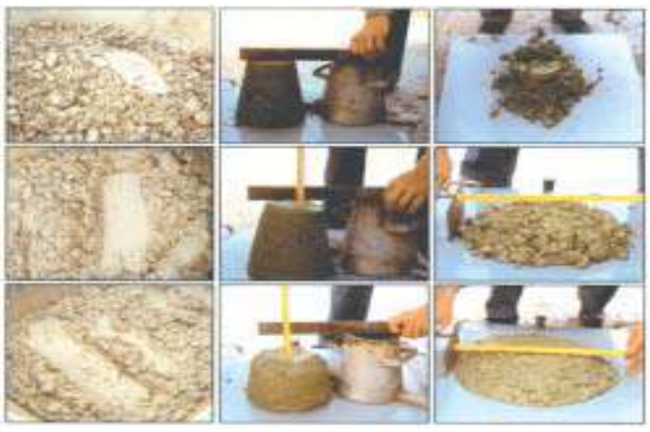
Concrete repair has become a major subject all over the world. In India, a few newly constructed major bridges have come for repair. In places like Mumbai, innumerable buildings require repair. Many government departments have constituted their own separate “Repair Boards” to deal only with repair. Water tanks are one type of structures often come to repair prematurely.

In the past, there was no effective method of repairing cracked, spalled and deteriorated concrete. They were left as such for eventual failure. In the recent past, guniting was practised for repair of concrete. Guniting has not proved to be an effective method of repair. But now very effective concrete repair system is available. The repair system can take care of the concrete cancer and increase the longevity of the structure. The repair material used are stronger than the parent material. The efficient bond coat, effective carbonation resistant fine mortar, corrosion inhibiting primer, protective coating make the system very effective. Where reinforcement is corroded more than 50%, extra bars may be provided before repair mortar is applied. The whole repair process becomes a bit costly but often repair is inevitable and the higher cost has to be endured

Mc-Bauchemie (India) Pvt. Ltd. have a series of repair materials and well designed repair system.

Fresh Concrete

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any 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. It is worthwhile looking back at what we have discussed in Chapters I and III regarding quantity of water before we discuss its role in fresh concrete in this chapter.



In Chapter I, we have discussed the role of water and the quantity of water required for chemical combination with cement and to occupy the gel pores. We have seen that the theoretical water/cement ratio required for these two purposes is about 0.38. Use of water/cement ratio more than this, will result in capillary cavities; and less than this, will result in incomplete hydration and also lack of space in the system for the development of gel.

In Chapter III, we have discussed that while making mortar for concrete, the quantity of water used will get altered at site either due to the presence of free surface moisture in the aggregates or due to the absorption characteristics of dry and porous aggregates. The water/cement ratio to be actually adopted at site is required to be adjusted keeping the above in mind.

In this chapter one more aspect for deciding the water/cement ratio will be introduced *i.e.,* the water/cement ratio required from the point of view of workability of concrete.

Workability

A theoretical water/cement ratio calculated from the considerations discussed above is not going to give an ideal situation for maximum strength. Hundred per cent compaction of concrete is an important parameter for contributing to the maximum strength. Lack of compaction will result in air voids whose demaging effect on strength and durability is equally or more predominant than the presence of capillary cavities.

Harsh concrete unworkable
Medium workability generally workable
Highly workable concrete

Degree of workability

To enable the concrete to be fully compacted with given efforts, normally a higher water/cement ratio than that calculated by theoretical considerations may be required. That is to say the function of water is also to lubricate the concrete so that the concrete can be compacted with specified effort forthcoming at the site of work. The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish it sufficiently easily, the presence of a certain quantity of water is of vital importance.

The quality of concrete satisfying the above requirements is termed as workable concrete. The word "workability" or workable concrete signifies much wider and deeper meaning than the other terminology "consistency" often used loosely for workability. Consistency is a general term to indicate the degree of fluidity or the degree of mobility. A concrete which has high consistency and which is more mobile, need not be of right workability for a particular job. Every job requires a particular workability. A concrete which is considered workable for mass concrete foundation is not workable for concrete to be used in roof construction, or even in roof construction, concrete considered workable when vibrator is used, is not workable when concrete is to be compacted by hand. Similarly a concrete considered workable when used in thick section is not workable when required to be used in thin sections. Therefore, the word workability assumes full significance of the type of work, thickness of section, extent of reinforcement and mode of compaction.

For a concrete technologist, a comprehensive knowledge of workability is required to design a mix. Workability is a parameter, a mix designer is required to specify in the mix design process, with full understanding of the type of work, distance of transport, loss of slump, method of placing, and many other parameters involved. Assumption of right workability with proper understanding backed by experience will make the concreting operation economical and durable.

Many research workers tried to define the word workability. But as it signifies much wider properties and qualities of concrete, and does not project any one particular meaning, it eludes all precise definitions. Road Research laboratory, U.K., who have extensively studied the field of compaction and workability, defined workability as "the property of concrete which determines the amount of useful internal work necessary to produce full compaction." Another definition which envelopes a wider meaning is that, it is defined as the "ease with which concrete can be compacted hundred per cent having regard to mode of compaction and place of deposition." Without dwelling much on the merits and demerits of various definitions of workability, having explained the importance and full meaning of the term workability, we shall see the factors affecting workability.

Factors Affecting Workability

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

(*a*) Water Content (*b*) Mix Proportions
(*c*) Size of Aggregates (*d*) Shape of Aggregates
(*e*) Surface Texture of Aggregate (*f*) Grading of Aggregate
(*g*) Use of Admixtures.

A 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 site. It should be noted that from the desirability point of view, increase of water content is the last recourse to be taken for improving the workability even in the case of uncontrolled concrete. For controlled concrete one cannot arbitrarily increase the water content. In case, all other steps to improve workability fail, only as last recourse the addition of more water can be considered. More water can be added, provided a correspondingly higher quantity of cement is also added to keep the water/cement ratio constant, so that the strength remains the same.

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

Shape of AggregatesThe shape of aggregates influences 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 of rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate. Not only that, being round in shape, the frictional resistance is also greatly reduced. This explains the reason why river sand and gravel provide greater workability to concrete than crushed sand and aggregate.

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

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

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

Use of AdmixturesOf all the factors mentioned above, the most import factor which affects the workability is the use of admixtures. In Chapter 5, it is amply described that the plasticizers and superplasticizers greatly improve the workability many folds. It is to be noted that initial slump of concrete mix or what is called the slump of reference mix should be about 2 to 3 cm to enhance the slump many fold at a minimum doze. One should manupulate other factors to obtain initial slump of 2 to 3 cm in the reference mix. Without initial slump of 2 – 3 cm, the workability can be increased to higher level but it requires higher dosage – hence uneconomical.

Use of air-entraining agent being surface-active, reduces the internal friction between the particles. They also act as artificial fine aggregates of very smooth surface. It can be viewed that air bubbles act as a sort of ball bearing between the particles to slide past each other and give easy mobility to the particles. Similarly, the fine glassy pozzolanic materials, inspite of increasing the surface area, offer better lubricating effects for giving better workability.

Measurement of Workability

It is discussed earlier that workability of concrete is a complex property. Just as it eludes all precise definition, it also eludes precise measurements. Numerous attempts have been made by many research workers to quantitatively measure this important and vital property of concrete. But none of these methods are satisfactory for precisely measuring or expressing this property to bring out its full meaning. Some of the tests, measure the parameters very close to workability and provide useful information. The following tests are commonly employed to measure workability.

(*a*) Slump Test (*b*) Compacting Factor Test
(*c*) Flow Test ((*d*) Kelly Ball Test
(*e*) Vee Bee Consistometer Test.

Slump Test

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete. However, it is used conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch. Repeated batches of the same mix, brought to the same slump, will have the same water content and water cement ratio, provided the weights of aggregate, cement and admixtures are uniform and aggregate grading is within acceptable limits. Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slumps. Quality of concrete can also be further assessed by giving a few tappings or blows by tamping rod to the base plate. The deformation shows the characteristics of concrete with respect to tendency for segregation.

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

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

The thickness of the metallic sheet for the mould should not be thinner than 1.6 mm. Sometimes the mould is provided with suitable guides for lifting vertically up. For tamping the concrete, a steel tamping rod 16 mm dia, 0.6 meter along with bullet end is used. Fig. 6.1, shows the details of the slump cone appartus. The internal surface of the mould is thoroughly cleaned and freed from superfluous moisture and adherence of any old set concrete before commencing the test. The mould is placed on a smooth, horizontal, rigid and non-absorbant surface The mould is then filled in four layers, each approximately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping rod taking care to distribute the strokes evenly over the cross section. After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subsidence is referred as SLUMP of concrete. The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm. is taken as Slump of Concrete. ASTM measure the centre of the slumped concrete as the difference in height. ASTM also specifies 3 layers.

The pattern of slump is shown in Fig It indicates the characteristic of concrete in addition to the slump value. If the concrete slumps evenly it is called true slamp. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mould and the average value of the subsidence. Shear slump also indicates that the concrete is non-cohesive and shows the characteristic of segregation.

It is seen that the slump test gives fairly good consistent results for a plastic-mix. This test is not sensitive for a stiff-mix. In case of dry-mix, no variation can be detected between mixes of different workability. In the case of rich mixes, the value is often satisfactory, their slump being sensitive to variations in workability. IS 456 of 2000 suggests that in the "very low" category of workability where strict control is necessary, for example, pavement quality concrete, (PQC) measurement of workability by determination of compacting factor will be more appropriate than slump and a value of 0.75 to 0.80 compacting factor is suggested.

The above IS also suggests that in the "very high" category of workability, measurement of workability by determination of "flow" by flow test will be more appropriate. However, in a lean-mix with a tendency of harshness a true slump can easily change to shear slump. In such case, the tests should be repeated.

Despite many limitations, the slump test is very useful on site to check day-to-day or hour-to-hour variation in the quality of mix. An increase in slump, may mean for instance that the moisture content of the aggregate has suddenly increased or there has been sudden change in the grading of aggregate. The slump test gives warning to correct the causes for change of slump value. The simplicity of this test is yet another reason, why this test is still popular in spite of the fact that many other workability tests are in vogue. Table 6.1 shows the nominal slump value for different degrees of workability.

The Bureau of Indian standards, in the past, generally adopted compacting factor test values for denoting workability. Even in the IS 10262 of 1982 dealing with Recommended Guide Line for Concrete Mix Design, adopted compacting factor for denoting workability. But now in the revision of IS 456 of 2000 the code has reverted back to slump value to denote the workability rather than compacting factor. It shows that slump test has more practical utility than the other tests for workability.

K-Slump Tester

Very recently a new appartus called "K-Slump Tester" has been devised. It can be used 6. 1 to measure the slump directly in one minute after the tester is inserted in the fresh concrete to the level of the floater disc. This tester can also be used to measure the relative workability.

The appartus comprises of the following four principal parts:-

1. A chrome plated steel tube with external and internal diameters of 1.9 and 1.6 cm respectively. The tube is 25 cm long and its lower part is used to make the test. The length of this part is 15.5 cm which includes the solid cone that facilitates inserting the tube into the concrete. Two types of openings are provided in this part: 4 rectangular slots 5.1 cm long and 0.8 cm wide and 22 round holes 0.64 cm in diameter; all these openings are distributed uniformly in the lower part as shown in Figure

K-Slump Tester

Compacting Factor Test

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test. The diagram of the apparatus is shown in Figure 6.4. The essential dimensions of the hoppers and mould and the distance between them are shown in Table 6.2.

The compacting factor test has been developed at the Road Research Laboratory U.K. and it is claimed that it is one of the most efficient tests for measuring the workability of concrete. This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. The degree of compaction, called the compacting factor is measured by the density ratio *i.e.,* the ratio of the density actually achieved in the test to density of same concrete fully compacted.

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.

Fig. 6.5 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

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

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

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 1881 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 Fig. 6.6. (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. 6.6 (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. 6.6. (a) is provided on each side of the table so that the lower front edge of the table can only be lifted 40 ± 1 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

This is a simple field test consisting of the measurement of the indentation made by 15 cm diameter metal hemisphere weighing 13.6 kg. when freely placed on fresh concrete. The test has been devised by Kelly and hence known as Kelly Ball Test. This has not been covered by Indian Standards Specification. The advantages of this test is that it can be performed on the concrete placed in site and it is claimed that this test can be performed faster with a greater precision than slump test. The disadvantages are that it requires a large sample of concrete and it cannot be used when the concrete is placed in thin section. The minimum depth of concrete must be at least 20 cm and the minimum distance from the centre of the ball to nearest edge of the concrete 23 cm.

The surface of the concrete is struck off level, avoiding excess working, the ball is lowered gradually on the surface of the concrete. The depth of penetration is read immediately on the stem to the nearest 6 mm. The test can be performed in about 15 seconds and it gives much more consistent results than Slump Test. Fig. 6.9. shows the Kelly Ball apparatus.

Vee Bee Consistometer Test

This is a good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod. The apparatus is shown in Figure. 6.10.

Slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer. The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot. The electrical vibrator is then switched on and simultaneously a stop watch started. The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape. This can be judged by observing the glass disc from the top for disappearance of transparency. Immediately when the concrete fully assumes a cylindrical shape, the stop watch is switched off. The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as Vee Bee Degree. This method is very suitable for very dry concrete whose slump value cannot be measured by Slump Test, but the vibration is too vigorous for concrete with a slump greater than about 50 mm.

Segregation

Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. 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 Vee-Bee Consistometer 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.

Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. It too wet a mix is excessively vibrated, it is likely that the concrete gets segregated. It should also be remembered that vibration is continued just for required time for optimim 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.

In the recent time we use concrete with very high slump 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.

While finishing concrete floors or pavement, with a view to achieve a smooth surface, masons are likely to 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. Segragation caused on this account, impairs the homogeneity and serviceability of concrete. The excess mortar at the top causes plastic shrinkage cracks.

From the foregoing discussion, it can be gathered that the tendency for segregation can be remedied by correctly proportioning the mix, by proper handling, transporting, placing, compacting and finishing. At any stage, 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. 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.

Bleeding

Bleeding is sometimes referred as water gain. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slab or road slabs and when concrete is placed in sunny weather show excessive bleeding.

Due to bleeding, water comes up and accumulates at the surface. Sometimes, along with this water, certain quantity of cement also comes to the surface. When the surface is worked up with the trowel and floats, the aggregate goes down and the cement and water come up to the top surface. This formation of cement paste at the surface is known as "Laitance".

In such a case, the top surface of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season. Owing to the fact that the top surface has a higher content of water and is also devoid of aggregate matter; it also develops higher shrinkage cracks. If laitance is formed on a particular lift, a plane of weakness would form and the bond with the next lift would be poor. This could be avoided by removing the laitance fully before the next lift is poured.

Water while traversing from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete structures.

While the mixing water is in the process of coming up, it may be intercepted by aggregates. The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond between the aggregates and the paste. The above aspect is more pronounced in the case of flaky aggregate. Similarly, the water that accumulates below the reinforcing bars, particularly below the cranked bars, reduces the bond between the reinforcement and the concrete. The poor bond between the aggregate and the paste or the reinforcement and the paste due to bleeding can be remedied by revibration of concrete. The formation of laitance and the consequent bad effect can be reduced by delayed finishing operations.

Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement.

Bleeding is an inherent phenomenon in concrete. All the same, it can be reduced by proper proportioning and uniform and complete mixing. Use of finely divided pozzolanic materials reduces bleeding by creating a longer path for the water to traverse. It has been already discussed that the use of air-entraining agent is very effective in reducing the bleeding. It is also reported that the bleeding can be reduced by the use of finer cement or cement with low alkali content. Rich mixes are less susceptible to bleeding than lean mixes.

The bleeding is not completely harmful if the rate of evaporation of water from the surface is equal to the rate of bleeding. Removal of water, after it had played its role in providing workability, from the body of concrete by way of bleeding will do good to the concrete. Early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in a fully plastic condition at that stage, will get subsided and compacted. It is the delayed bleeding, when the concrete has lost its plasticity, that causes undue harm to the concrete. Controlled revibration may be adopted to overcome the bad effect of bleeding.

Bleeding presents a very serious problem when Slip Form Paver is used for construction of concrete pavements. If two much of bleeding water accumulates on the surface of pavement slab, the bleeding water flows out over the unsupported sides which causes collapsing of sides. Bleeding becomes a major consideration in such situations.

In the pavement construction finishing is done by texturing or brooming. Bleeding water delays the texturing and application of curing compounds.

Method of Test for Bleeding of Concrete

This method covers determination of relative quantity of mixing water that will bleed from a sample of freshly mixed concrete.

A cylindrical container of approximately 0.01 m^3 capacity, having an inside diameter of 250 mm and inside height of 280 mm is used. A tamping bar similar to the one used for slump test is used. A pepette for drawing off free water from the surface, a graduated jar of 100 cm^3 capacity is required for test.

A sample of freshly mixed concrete is obtained. The concrete is filled in 50 mm layer for a depth of 250 ± 3 mm (5 layers) and each layer is tamped by giving strokes, and the top surface is made smooth by trowelling.

The test specimen is weighed and the weight of the concrete is noted. Knowing the total water content in 1 m^3 of concrete quantity of water in the cylindrical container is also calculated.

The cylindrical container is kept in a level surface free from vibration at a temperature of 27°C ± 2°C. it is covered with a lid. Water accumulated at the top is drawn by means of pipette at 10 minutes interval for the first 40 minutes and at 30 minutes interval subsequently till bleeding ceases. To facilitate collection of bleeding water the container may be slightly tilted. All the bleeding water collected in a jar.

$$\text{Bleeding water percentage} = \frac{\text{Total quantity of bleeding water}}{\text{Total quantity of water in the sample of concrete}} \times 100$$

Setting Time of Concrete

We have discussed about the setting time of cement in Chapter 2. Setting time of cement is found out by a standard vicat apparatus in laboratory conditions. Setting time, both initial and final indicate the quality of cement.

Setting time of concrete differs widely from setting time of cement. Setting time of concrete does not coincide with the setting time of cement with which the concrete is made. The setting time of concrete depends upon the w/c ratio, temperature conditions, type of cement, use of mineral admixture, use of plasticizers–in particular retarding plasticizer. The setting parameter of concrete is more of practical significance for site engineers than setting time of cement. When retarding plasticizers are used, the increase in setting time, the duration upto which concrete remains in plastic condition is of special interest.

The setting time of concrete is found by pentrometer test. This method of test is covered by IS 8142 of 1976 and ASTM C – 403. The procedure given below may also be applied to prepared mortar and grouts.

The apparatus consist of a container which should have minimum lateral dimension of 150 mm and minimum depth of 150 mm.

There are six penetration needles with bearing areas of 645, 323, 161, 65, 32 and 16 mm . Each needle stem is scribed circumferentially at a distance of 25 mm from the bearing 2 area.

A device is provided to measure the force required to cause penetration of the needle.

The test procedure involves the collection of representative sample of concrete in sufficient quantity and sieve it through 4.75 mm sieve and the resulting mortar is filled in the container. Compact the mortar by rodding, tapping, rocking or by vibrating. Level the surface and keep it covered to prevent the loss of moisture. Remove bleeding water, if any, by means of pipette. Insert a needle of appropriate size, depending upon the degree of setting of the mortar in the following manner.

Bring the bearing surface of needle in contact with the mortar surface. Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25 ± 1.5 mm, as indicated by the scribe mark. The time taken to penetrate 25 mm depth could be about 10 seconds. Record the force required to produce 25 mm penetration and the time of inserting from the time water is added to cement. Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance. For the subsequent penetration avoid the area where the mortar has been disturbed. The clear distance should be two times the diameter of the bearing area. Needle is inserted at least 25 mm away from the wall of container.

Plot a graph of penetration resistance as ordinate and elapsed time as abscissa. Not less than six penetration resistance determination is made. Continue the tests until one penetration resistance of at least 27.6 MPa is reached. Connect the various point by a smooth curve.

Needle with different bearing area

From penetration resistance equal to 3.5 MPa, draw a horizontal line. The point of intersection of this with the smooth curve, is read on the *x*- axis which gives the initial setting time. Similarly a horizontal line is drawn from the penetration resistance of 27.6 MPa and point it cuts the smooth curve is read on the *x*- axis which gives the final set.

A typical graph is shown in Fig. 6.11

Process of Manufacture of Concrete

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

(*a*) Batching (*b*) Mixing (*c*) Transporting
(*d*) Placing (*e*) Compacting (*f*) Curing
(*g*) Finishing.

(*a*) Batching

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

(*i*) Volume batching (*ii*) Weigh batching

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

Cement is always measured by weight. It is never measured in volume. Generally, for each batch mix, one bag of cement is used. The volume of one bag of cement is taken as thirty five (35) litres. Gauge boxes are used for measuring the fine and coarse aggregates. The typical sketch of a guage box is shown in Figure 6.12. The volume of the box is made equal to the volume of one bag of cement *i.e.*, 35 litres or multiple thereof. The gauge boxes are made comparatively deeper with narrow surface rather than shallow with wider surface to facilitate easy estimation of top level. Sometimes bottomless gauge-boxes are used. This should be avoided. Correction to the effect of bulking should be made to cater for bulking of fine aggregate, when the fine aggregate is moist and volume batching is adopted.

Gauge boxes are generall called farmas. They can be made of timber or steel plates. Often in India volume batching is adopted even for large concreting operations. In a major site it is recommended to have the following gauge boxes at site to cater for change in Mix Design or bulking of sand. The volume of each gauge box is clearly marked with paint on the external surface.

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

Cans for measuring water

In modern batching plants sophisticated automatic microprocessor controlled weigh batching arrangements, not only accurately measures the constituent materials, but also the moisture content of aggregates. Moisture content is automatically measured by sensor probes and corrective action is taken to deduct that much quantity of water contained in sand from the total quantity of water. A number of such sophisticated batching plants are working in our country. for the last 4 – 5 years.

Mixing

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

(*i*) Hand mixing (*ii*) Machine mixing

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

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

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

Laboratory tilting drum mixer

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

Very little is known about the relative mixing efficiencies of the various types of mixers, but some evidences are there to suggest that pan mixers with a revolving star of blades are more efficient. They are specially suitable for stiff and lean mixes, which present difficulties with most other types of mixers, mainly due to sticking of mortar in the drum. The shape of the drum, the angle and size of blades, the angle at which the drum is held, affect the efficiency of mixer. It is seen that tilting drum to some extent is more efficient than non-tilting drum. In non-tilting drum for discharging concrete, a chute is introduced into the drum by operating a lever. The concrete which is being mixed in the drum, falls into the inclined chute and gets discharged out. It is seen that a little more of segregation takes place, when a non-tilting mixer is used. It is observed in practice that, generally, in any type of mixer, even after thorough mixing in the drum, while it is discharged, more of coarse aggregate comes out first and at the end matrix gets discharged. It is necessary that a little bit of re-mixing is essential, after discharged from mixer, on the platform to off-set the effect of segregation caused while concrete is discharged from the mixer.

:

a. Tilting: 85 T, 100 T, 140 T, 200 T

b. Non-Tilting: 200 NT, 280 NT, 375 NT, 500 NT, 1000 NT

c. Reversing: 200 R, 280 R, 375 R, 500 R and 1000 R

The letters T, NT, R denote tilting, non-tilting and reversing respectively. Fig 6.13 illustrates diagrammatically the type of mixers.

Normally, a batch of concrete is made with ingredients corresponding to 50 kg cement. If one has a choice for indenting a mixer, one should ask for such a capacity mixer that should hold all the materials for one bag of cement. This of course, depends on the proportion of the mix. For example, for 1 : 2 : 4 mix, the ideal mixer is of 200 litres capacity, whereas if the ratio is 1 : 3 : 6, the requirement

Concrete mixer with Pan / paddle mixer

will be of 280 litres capacity to facilitate

hydraulic hopper 10/7

one bag mix. Mixer of 200 litres capacity is insufficient for 1 : 3 : 6 mix and also mixer of 280 litres is too big, hence uneconomical for 1 : 2 : 4 concrete.

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

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

Before the loaded skip is discharged to the drum, about 25 per cent of the total quantity of water required for mixing, is introduced into the mixer drum to wet the drum and to prevent any cement sticking to the blades or at the bottom of the drum. Immediately, on discharging the dry material into the drum, the remaining 75 per cent of water is added to the drum. If the mixer has got an arrangement for independent feeding of

water, it is desirable that the remaining 75 per cent of water is admitted simultaneously along with the other materials. The time is counted from the moment all the materials, particularly, the complete quantity of water is fed into the drum.

Reversible drum concrete mixer / mini batching plant When plasticizer or superplasticizer is used, the usual procedure could be adopted except that about one litre of water is held back.

Calculated quantity of plasticizer or superplasticizer is mixed with that one litre of water and the same is added to the mixer drum after about one minute of mixing. It is desirable that concrete is mixed little longer (say 1/2 minute more) so that the plasticizing effect is fully achieved by proper dispersion.When plasticizers are used, generally one has to do number of trials in the laboratory for arriving at proper dosage and required slump. Small scale laboratory mixers are inefficient and do not mix the ingredients properly. Plasticizer in small quantity do not get properly dispersed with cement particles. To improve the situations, Concrete high-speed mixer in a batching the following sequence may be adopted. plant.

Firstly, add all the water except about half a litre. Add cement and then add sand. Make an intimate mortar mix. Dilute calculated quantity of plasticizer with the remaining half a litre of water and pour it into the drum. Rotate the drum for another half a minute, so that plasticizer gets well mixed with cement mortar and then add both the fractions (20 mm and 10 mm) of coarse aggregate. This procedure is found to give better and consistent results.

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

It is seen from the experiments that the quality of concrete in terms of compressive strength will increase with the increase in the time of mixing, but for mixing time beyond two minutes, the improvement in compressive strength is not very significant. Fig. 6.14. shows the effect of mixing time on strength of concrete.

Concrete mixer is not a simple apparatus. Lot of considerations have gone as input in the design of the mixer drum. The shape of drum, the number of blades, inclination of blades with respect to drum surface, the length of blades, the depth of blades, the space between the drum and the blades, the space between metal strips of blades and speed of rotation etc., are important to give uniform mixing quality and optimum time of mixing.

Generally mixing time is related to the capacity of mixer. The mixing time varies between 1½ to 2½ minutes. Bigger the capacity of the drum more is the mixing time. However, modern high speed pan mixer used in RMC, mixes the concrete in about 15 to 30 secs. One cubic meter capacity high speed Pan Mixer takes only about 2 minutes for batching and mixing. The batching plant takes about 12 minutes to load a transit mixer of 6 m capacity. 3

Sometimes, at a site of work concrete may not be discharged from the drum and concrete may be kept rotating in the drum for long time, as for instance when some quarrel

or dispute takes place with the workers, or when unanticipated repair or modification is required to be done on the formwork and reinforcement. Long-time mixing of concrete will generally result in increase of compressive strength of concrete within limits. Due to mixing over long periods, the effective water/cement ratio gets reduced, owing to the absorption of water by aggregate and evaporation. It is also possible that the increase in strength may be due to the improvement in workability on account of excess of fines, resulting from the abrasion and attrition of coarse aggregate in the mix, and from the coarse aggregates themselves becoming rounded. The above may not be true in all conditions and in all cases. Sometimes, the evaporation of water and formation of excess fines may reduce the workability and hence bring about reduction in strength. The excess of fine may also cause greater shrinkage.

Modern ready mixed concrete plant.

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

Maintenance of Mixer

Concrete mixers are often used continuously without stopping for several hours for continuous mixing and placing. It is of utmost importance that a mixer should not stop in between concreting operation. For this reason, concrete mixer must be kept well maintained. Mixer is placed at the site on a firm and levelled platform. The drum and blades must be kept absolutely clean at the end of concreting operation. The drum must be kept in the tilting position or kept covered when not in use to prevent the collection of rain water. The skip is operated carefully and it must rest on proper cushion such as sand bags.

Transporting Concrete

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

(*a*) Mortar Pan (*b*) Wheel Barrow, Hand Cart
(*c*) Crane, Bucket and Rope way (*d*) Truck Mixer and Dumpers
(*e*) Belt Conveyors (*f*) Chute
(*g*) Skip and Hoist (*h*) Tansit Mixer
(*i*) Pump and Pipe Line
(*j*) Helicoptor.

Mortar Pan: Mortar Pan: Mortar Pan: Mortar Pan: Mortar Pan: Use of mortar pan for transporation of concrete is one of the common methods adopted in this country. It is labour intensive. In this case, concrete is carried in small quantities. While this method nullifies the segregation to some extent, particularly in thick members, it suffers from the disadvantage that this method exposes greater surface area of concrete for drying conditions. This results in

Tough Rider for transporting concrete.

greater loss of water, particularly, in hot weather concreting and under conditions of low humidity. It is to be noted that the mortar pans must be wetted to start with and it must be kept clean during the entire operation of concreting. Mortar pan method of conveyance of concrete can be adopted for concreting at the ground level, below or above the ground level without much difficulties. Truck mixer and dumper for transporting stiff concrete

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

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

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

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

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

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

Belt Conveyors have very limited applications in concrete construction. Belt Conveyors The principal objection is the tendency of the concrete to segregate on steep inclines, at transfer points or change of direction, and at the points where the belt passes over the rollers.

Another disadvantage is that the concrete is exposed over long stretches which causes drying and stiffening particularly, in hot, dry and windy weather. Segregation also takes place due to the vibration of rubber belt. It is necessary that the concrete should be remixed at the end of delivery before placing on the final position.

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

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

Transporting and placing concrete by chute. This is not a good method of transporting concrete. However, it is adopted, when movement of labour cannot be allowed due to lack of space or for fear of disturbance to reinforcement or other arrangements already incorporated. (Electrical conduits or switch boards etc.,).

Skip and Hoist This is one of the

widely adopted methods for transporting concrete vertically up for multistorey building construction. Employing mortar pan with the staging

Tower Hoist and Winch, for lifting concrete to higher and human ladder for transporting level. concrete is not normally possible for more than 3 or 4 storeyed building constructions. For laying concrete in taller structures, chain hoist or platform hoist or skip hoist is adopted.

At the ground level, mixer directly feeds the skip and the skip travels up over rails upto the level where concrete is required. At that point, the skip discharges the concrete automatically or on manual operation. The quality of concrete *i.e.* the freedom from segregation will depend upon the extent of travel and rolling over the rails. If the concrete has travelled a considerable height, it is necessary that concrete on discharge is required to be turned over before being placed finally.

Transit Mixer, a popular mathod of transporting

Transit Mixer

concrete over a long distance. Transit mixer is one of the most popular equipments for transporting concrete over a long distance particularly in Ready Mixed Concrete plant (RMC). In India, today (2000 AD) there are about 35 RMC plants and a number of central batching plants are working. It is a fair estimate that there are over 600 transit mixers in operation in India. They are truck mounted having a capacity of 4 to 7 m . There are two 3 variations. In one, mixed concrete is transported to the site by keeping it agitated all along at a speed varying between 2 to 6 revolutions per minute. In the other category, the concrete is batched at the central batching plant and mixing is done in the truck mixer either in transit or immediately prior to discharging the concrete at site. Transit-mixing permits longer haul and is less vulnerable in case of delay. The truck mixer the speed of rotating of drum is between 4–16 revolution per minute. A limit of 300 revolutions for both agitating and mixing is laid down by ASTM C 94 or alternatively, the concretes must be placed within 12 of mixing. In 1 case of transit mixing, water need not be added till such time the mixing is commenced. BS 5328 – 1991, restrict the time of 2 hours during which, cement and moist sand are allowed to remain in contact. But the above restrictions are to be on the safe side. Exceeding these limit is not going to be harmful if the mix remains sufficiently workable for full compaction.

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

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

Pumping arrangements

As per estimate made by CM Doordi, the cost of transportation of concrete by transit mixer varies between Rs 160 to 180 per cubic metre. 6. 2

Pumps and Pipeline

Pumping of concrete is universally accepted as one of the main methods of concrete transportation and placing. Adoption of pumping is increasing throughout the world as pumps become more reliable and also the concrete mixes that enable the concrete to be pumped are also better understood.

Development of Concrete PumpThe first patent for a concrete pump was taken in USA in the year 1913 . By about 1930 several countries developed and manufactured concrete 6 . 3 pump with sliding plate valves. By about 1950s and 1960s concrete pumping became widely used method in Germany. Forty per cent of their concrete was placed by pumping. The keen rivalry between the leading German manufacturers, namely, Schwing, Putzmeister and Elba, has boosted the development of concrete pump and in particular the valve design which is the most important part of the whole system.

Concrete Pumps The modern concrete pump is a sophisticated, reliable and robust machine. In the past a simple two-stroke mechanical pump consisted of a receiving hopper, an inlet and an outlet valve, a piston and a cylinder. The pump was powered by a diesel engine. The Pump and pipeline pumping action starts with the suction stroke drawing concrete into the cylinder as the piston moves backwards. During this operation the outlet value is closed. On the forward stroke, the inlet valve closes and the outlet valve opens to allow concrete to be pushed into the delivery pipe. Fig. illustrates the principle.

The modern concrete pump still operates on the same principles but with lot of improvements and refinements in the whole operations. During 1963, squeeze type pump was developed in U.S.A. In this concrete placed in a collecting hopper is fed by rotating blades into a flexible pipe connected to the pumping chamber, which is under a vacuum of about 600 mm of mercury. The vacuum ensures that, except when being squeezed by roller, the pipe shape remains cylindrical and thus permits a continuous flow of concrete. Two rotating rollers progressively squeeze the flexible pipes and thus move the concrete into the delivery pipe. Fig. 6.16. shows the action of squeeze pump.

The hydraulic piston pump is the most widely used modern pump. Specification differ but concept of working of modern pump is the same as it was for original mechanically driven pumps. A pump consists of three parts, a concrete receiving happer, a valve system and a power transmission system.

There are three main types of concrete pump. They are mobile, trailor or static and screed or mortar pump.

Types of valve The most important part of any concrete pump is the valve system. The main types of valve are peristaltic or squeeze type valves, sliding gate or rotating value, flapper valves, and hollow transfer tube valves.

Hollow transfer tube valves are most commonly used type of valve. Another type which is used extensively is the Rock Valve. The S valve used by Putzmeister is another example of a transfer tube value.

Pipelines and couplings It is not enough to have an efficient pump. It is equally important to have correct diameter of pipeline with adequate wall thickness for a given operating pressure and well designed coupling system for trouble free operation. A poor pipeline can easily cause blockages arising from leakage of grout. Pushing of abrasive material at high pressure, through pipeline inevitably creates a great deal of wear. Continuous handling, frequent securing and releasing of couplings creates wear at joints. All these must be maintained well for trouble free function and safety.

It is important to choose the correct diameter and wall thickness of the pipeline to match the pump and required placing rate. Generally almost all pumped concrete is conveyed through 125 mm pipeline. There are exceptions. For long, horizontal distance involving high pumping pressures, a large diameter pipe would be more suitable on account of less resistance to flow. For pumping concrete to heights, on account of the fact that gravity and the weight of concrete in the line, a smallest possible diameter of pipelines should be used.

As a guide, a pump with an output of 30 m /h and with not more than 200 m of 3 pipeline one may suggest 100 mm diameter, but for length in excess of 500 meter, a 150 mm diameter could be considered.

Diameter of pipeline has also bearing on the size of aggregate. General rule is that the pipe diameter should be between 3 to 4 times the largest size of aggregate. For example if maximum size of aggregate in concrete is 40 mm, the diameter of pipe could be between 120 mm to 160 mm. But use of 125 mm pipe can be considered suitable.

The individual pipe sections with lengths of 1m, 2m or 3 m are connected by means of various types of quick-locking couplings. For change in pipe line directions bends of different degrees (90 deg., 60 deg., 45 deg., 30 deg. and 15 deg.) are available. The bends have a radius of 1 m. But bends with radius of r = 250 mm are used in placing booms.

Laying the Pipeline A carefully laid pipeline is the prerequisite for trouble free pumping operation. Time, money and trouble are saved at sites if the installation of concrete pump and the laying of pipelines are thoroughly planned and carried out with care. Leaky pipes and coupling points often results in plugs and impede the pushing of concrete on account of escape of air or water. Pipelines must be well anchored when bends are introduced.

Particular care must be taken when laying vertical line. It is difficult to dismantle individual pipe. Therefore, install only such pipes which are in good condition. Pumps should not be kept very close to the vertical pipe. There must be some starting distance. This could be about 10 to 15% of the vertical distance.

Capabilities of Concrete Pump Concrete has been pumped to a height over 400 m and a horizontal distance of over 2000 m. This requires selected high pressure pump and special attention to concrete mix design. It is reported that in February, 1985, a record for vertical concrete pumping of 432 m was achieved at the Estangento sallente power station in the Spanish Pyrenees. A Putzmeister stationary high pressure pump with an S-transfer tube valve was used. This pump had a theoretical output of 120 m /h, 180 mm delivery cylinder and 3 an effective concrete pressure of over 200 bar, 630 meter of 125 mm diameter high pressure pipeline was used.

Well pumpable concrete Badly pumpable concrete

For the above work, concrete mix consisted of 506 kg 12 – 25 mm granite aggregate, 362 kg 5 – 12 mm granite aggregate, 655 kg 0 – 5 mm granite sand, 0 – 3 mm river sand, 211 kg cement, 90 kg fly ash and 183 litre water.

Placing Concrete

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

(*a*) Placing concrete within Paving concrete by slip-forming to get sinusoidal profile for linking with the adjacent slab. earth mould.
(example: Foundation Courtesy : Wirtgen concrete for a wall or column).

(*b*) Placing concrete within large earth mould or timber plank formwork.
(example: Road slab and Airfield slab).

(*c*) Placing concrete in layers within timber or steel shutters.
(example: Mass concrete in dam construction or construction of concrete abutment or pier).

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

(*e*) Placing concrete under water.

Concrete is invariably laid as foundation bed below the walls or columns. Before placing the concrete in the foundation, all the loose earth must be removed from the bed. Any root of trees passing through the foundation must be cut, charred or tarred effectively to prevent its further growth and piercing the concrete at a later date. The surface of the earth, if dry, must be just made damp so that the earth does not absorb water from concrete. On the other hand if the foundation bed is too wet and rain-soaked, the water and slush must be removed completely to expose firm bed before placing concrete. If there is any seepage of water taking place into the foundation trench, effective method for diverting the flow of water must be adopted before concrete is placed in the trench or pit.

Mould with floating suspension for simultaneous castig of parapetwall.

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

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

Before placing the concrete, the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush. In case of dam, even sand blasting is also adopted. The old surface is sometimes hacked and made rough by removing all the laitance and loose material. The surface is wetted. Sometimes, a neat cement slurry or a very thin layer of rich mortar with fine sand is dashed against the old surface, and then the fresh concrete is placed. The whole operation must be progressed and arranged in such a way that, cold joints are avoided as far as possible. When concrete is laid in layers, it is better to leave the top of the layer rough, so that the succeeding layer can have a good bond with the previous layer. Where the concrete is subjected to horizontal thrust, bond bars, bond rails or bond stones are provided to obtain a good bond between the successive layers. Of course, such arrangements are required for placing mass concrete in layers, but not for reinforced concrete.

Certain good rules should be observed while placing concrete within the formwork, as in the case of beams and columns. Firstly, it must be checked that the reinforcement is correctly tied, placed and is having appropriate cover. The joints between planks, plywoods or sheets must be properly and effectively plugged so that matrix will not escape when the concrete is vibrated. The inside of the formwork should be applied with mould releasing agents for easy stripping. Such purpose made mould releasing agents are separately available for steel or timber shuttering. The reinforcement should be clean and free from oil. Where reinforcement is placed in a congested manner, the concrete must be placed very carefully, in small quantity at a time so that it does not block the entry of subsequent concrete. The above situation often takes place in heavily reinforced concrete columns with close lateral ties, at the junction of column and beam and in deep beams. Generally, difficulties are experienced for placing concrete in the column. Often concrete is required to be poured from a greater height. When the concrete is poured from a height, against reinforcement and lateral ties, it is likely to segregate or block the space to prevent further entry of concrete. To avoid this, concrete is directed by tremie, drop chute or by any other means to direct the concrete within the reinforcement and ties. Sometimes, when the formwork is too narrow, or reinforcement is too congested to allow the use of tremie or drop chute, a small opening in one of the sides is made and the concrete is introduced from this opening instead of pouring from the top. It is advisable that care must be taken at the stage of detailing of reinforcement for the difficulty in pouring concrete. In long span bridges the depth of prestressed concrete girders may be of the order of even 4 – 5 meters involving congested reinforcement. In such situations planning for placing concrete in one operation requires serious considerations on the part of designer.

Placing concrete by pump and placing boom.

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

Time Stripping Formwork should not be removed until the concrete has developed a strength of at least twice the stress to which concrete may be subjected at the time of removal of formwork. In special circumstances the strength development of concrete can be assessed by placing companion cubes near the structure and curing the same in the manner simulating curing conditions of structures. In normal circumstances, where ambient temperature does not fall below 15°C and where ordinary Portland cement is used and adequate curing is done, following striking period can be considered sufficient as per IS 456 of 2000.

Underwater Concreting

Concrete is often required to be placed underwater or in a trench filled with the bentonite slurry. In such cases, use of bottom dump bucket or tremie pipe is made use of. In the bottom dump bucket concrete is taken through the water in a water-tight box or bucket and on reaching the final place of deposition the bottom is made to open by some mechanism and the whole concrete is dumped slowly. This method will not give a satisfactory result as certain amount of washing away of cement is bound to occur.

In some situations, dry or semi-dry mixture of cement, fine and coarse aggregate are filled in cement bags and such bagged concrete is deposited on the bed below the water. This method also does not give satisfactory concrete, as the concrete mass will be full of voids interspersed with the putricible gunny bags. The satisfactory method of placing concrete under water is by the use of tremie pipe.

The word "tremie" is derived from the french word hopper.

A tremie pipe is a pipe having a diameter of about 20 cm capable of easy coupling for increase or decrease of length. A funnel is fitted to the top end to facilitate pouring of concrete. The bottom end is closed with a plug or thick polyethylene sheet or such other material and taken below the water and made to rest at the point where the concrete is going to be placed. Since the end is blocked, no water will have entered the pipe. The concrete having a very high slump of about 15 to 20 cm is poured into the funnel. When the whole length of pipe is filled up with the concrete, the tremie pipe is lifted up and a slight jerk is given by a winch and pully arrangement. When the pipe is raised and given a jerk, due to the weight of concrete, the bottom plug falls and the concrete gets discharged. Particular care must be taken at this stage to see that the end of the tremie pipe remains inside the concrete, so that no water enters into the pipe from the bottom. In other words, the tremie pipe remains plugged at the lower end by concrete. Again concrete is poured over the funnel and when the whole length of the tremie pipe is filled with concrete, the pipe is again slightly lifted and given slight jerk. Care is taken all the time to keep the lower end of the tremie pipe well embedded in the wet concrete. The concrete in the tremie pipe gets discharged. In this way, concrete work is progressed without stopping till the concrete level comes above the water level.

Fig. 6.22 shows the underwater concreting by tremie.

This method if executed properly, has the advantage that the concrete does not get affected by water except the top layer. The top layer is scrubbed or cut off to remove the affected concrete at the end of the whole operation.

During the course of concreting, no pumping of water should be permitted. If simultaneous pumping is done, it may suck the cement particles. Under water concreting need not be compacted, as concrete gets automatically compacted by the hydrostatic pressure of water. Secondly, the concrete is of such consistency that it does not normally require compaction. One of the disadvantages of under water concreting in this method is that a high water/cement ratio is required for high consistency which reduces the strength of concrete. But at present, with the use of superplasticizer, it is not a constraint. A concrete with as low a w/c ratio as 0.3 or even less can be placed by tremie method.

Another method, not so commonly employed to place concrete below water is the grouting process of prepacked aggregate. Coarse aggregate is dumped to assume full dimension of the concrete mass. Cement mortar grout is injected through pipes, which extend up to the bottom of the aggregate bed. The pipes are slowly withdrawn, as the grouting progresses. The grout forces the water out from the interstices and occupies the space. For plugging the well foundation this method is often adopted.

Concrete also can be placed under water by the use of pipes and concrete pumps. The pipeline is plugged at one end and lowered until it rests at the bottom. Pumping is then started. When the pipe is completely filled, the plug is forced out, the concrete surrounding the lower end of the pipe seals the pipe. The pumping is done against the pressure of the plug at the lower end. When the pumping effort required is too great to overcome the pressure, the pipe is withdrawn and the operation is repeated. This process is repeated until concrete reaches the level above water.

General Points on Using Vibrators

Vibrators may be powered by any of the following units:

(*a*) Electric motors either driving the vibrator through flexible shaft or situated in the head of the vibrator.

(*b*) Internal combustion engine driving the vibrator needle through flexible shaft, and

(*c*) Compressed-air motor situated near the head of the vibrator.

Where reliable supplies of electricity is available the electric motor is generally the most satisfactory and economical power unit. The speed is relatively constant, and the cables supplying current are light and easily handled.

Small portable petrol engines are sometimes used for vibrating concrete. They are more easily put out of action by site conditions. They are not so reliable as the electric or compressed-air motors. They should be located conveniently near the work to be vibrated and should be properly secured to their base.

Compressed-air motors are generally quite suitable but pneumatic vibrators are sometimes difficult to manipulate where the compressor cannot be placed adjacent to the work such as on high scaffoldings or at depths below ground level due to the heavy weight of air hoses.

Compressed-air vibrators give trouble especially in cold weather, by freezing at exhaust unless alcohol is trickled into the air line or dry air is used. Glycol type antifreeze agents tend to cause gumming of the vibrator valves. There is also a tendency for moisture to collect in the motor, hence care should be taken to remove the possible damage.

The speed of both the petrol and compressed-air motors tend to vary giving rise to variation in the compacting effect of the vibrator.

Height of Concrete Layer

Concrete is placed in thin layers consistent with the method being used to place and vibrate the concrete. Usually concrete shall be placed in a thickness not more than 60 cm and on initial placing in thickness not more than 15 cm. The suprimposed load increasing with the height of the layer will favour the action of the vibrator, but as it is also the path of air forced upwards, it may trap air rising up by vibration. Very deep layers (say more than 60 cm) should, therefore, be avoided although the height of layer can also be one metre provided the vibrator used is sufficiently powerful, as in dams.

Depth of Immersion of Vibrator

To be fully effective, the active part of the vibrator shall be completely immersed in the concrete. Its compacting action can be usually assisted by maintaining a head of concrete above the active part of the vibrator, the primary object of which is to press down upon and confine the concrete in the zone of influence of the vibrator. The vibrator head shall be dipped through the filling which is to be consolidated to a further depth of 10 to 20 cm in the lower layer which has already been consolidated so that there is a good combination of various layers and the grout in the lower layer is distributed in the new filling.

Vibrating near the Formwork

For obtaining a smooth close textured external surface, the concrete should have a sufficient content of matrix. The vibrator head shall not be brought very near the formwork as this may cause formation of water whirls (stagnations), especially if the concrete containing too little of fine aggregate. On the other hand, a close textured surface may not be obtained, if the positions of insertion are too far away from the formwork. The most suitable distance of the vibrator from the formwork is 10 to 20 cm. With the vibration done at the correct depth and with sufficient grout rising up at the formwork, the outside surface will generally have a close textured appearance. In the positions of formwork difficult to reach and in concrete walls less than 30 cm thick it is preferable to use vibrators of small size which can be brought to the required place and which will not excessively strain the formwork.

Vibrating High Walls and Columns

While designing the formwork, reinforcement, as well as the division of layers for high walls and columns, it should be kept in mind that with the usual driving shaft lengths it is not possible to penetrate the vibrating head more than three metres in the formwork. In the case of higher walls and columns it is recommended to introduce the shaft driven vibrating needle through a side opening into the formwork. For use with high walls and columns, the flexible driving shaft can be brought to a length of six to eight metres or even more by using adopter pieces. The motor-in-head type vibrators are more useful for the purpose in cases where a very long current cable can be used for sinking the vibrator to a greater depth.

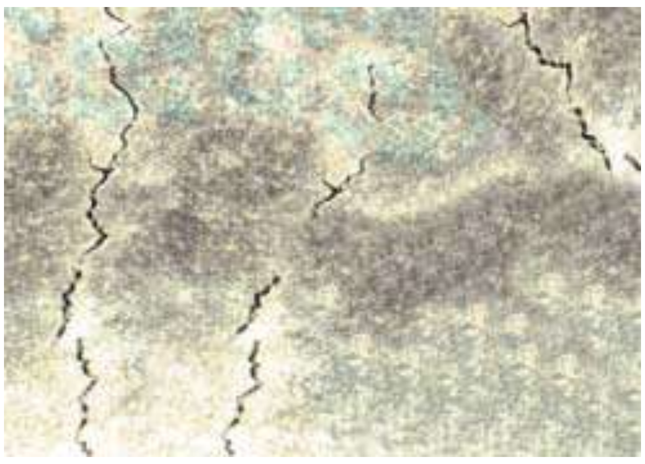
Vibration of Lightweight Concrete

In general, principles and recommended practices for consolidation of concrete of normal weight hold good for concrete made with light weight aggregate, provided certain precautions are observed.

There is always a tendency for light weight pieces of aggregate to rise to the surface of fresh concrete, particularly under the action of over-vibration; and a fairly stiff mix, with the minimum amount of vibration necessary to consolidate the concrete in the forms without honey-comb is the best insurance against undesirable segregation. The rise of lightweight coarse aggregate particles to the surface, caused by over-vibration resulting from too wet a mix makes finishing difficult if not impossible.

Curing of Concrete

We have discussed in Chapter I the hydration aspect of cement. Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a process continuing for long time. Of cource, the rate of hydration is fast to start with, but countinues over a very long time at a decreasing rate. The quantity of the product of hydration and consequently the amount of gel formed depends upon the extent of hydration. It has been mentioned earlier that cement requires a water/cement ratio about 0.23 for hydration and a water/cement ratio of 0.15 for filling the voids in the gel pores. In other words, a water/cement ratio of about 0.38 would be required to hydrate all the particles of cement and also to occupy the space in the gel pores. Theoretically, for a concrete made and contained in a sealed container a water satisfy the requirement of



water for hydration and at the same time no capillary vavities would be left. However, it is seen that practically a water/cement ratio of 0.5 will be required for complete hydration in a sealed container for keeping up the desirable relative humidity level.

In the field and in actual work, it is a different story. Even though a higher water/cement ratio is used, since the concrete is open to atmosphere, the water used in the concrete evaporates and the water available in the concrete will not be sufficient for effective hydration to take place particularly in the top layer. Fig. 5.33 on page 173, Chapter 5, shows the drying behaviour of concrete. If the hydration is to continue unbated, extra water must be added to replenish the loss of water on account of absorption and evaporation. Alternatively, some measures must be taken by way of provision of impervious covering or application of curing compounds to prevent the loss of water from the surface of the concrete. Therefore, the curing can be considered as creation of a favourable environment during the early period for uninterrupted hydration. The desirable conditions are, a suitable temperature and ample moisture.

Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately, it can be described as the process

of maintaining a satisfactory moisture content and a favourable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service.

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

A concrete laid in the afternoon of a hot summer day in a dry climatic region, is apt to dry out quickly. The surface layer of concrete exposed to acute drying condition, with the combined effect of hot sun and drying wind is likely to be made up of poorly hydrated cement with inferior gel structure which does not give the desirable bond and strength characteristics. In addition, the top surface, particularly that of road or floor pavement is also subjected to a large magnitude of plastic shrinkage stresses. The dried concrete naturally being weak, cannot withstand these stresses with the result that innumerable cracks develop at the surface Fig. 6.24, shows plastic shrinkage cracks on concrete surface due to quick drying and inadequate early curing. The top surface of such hardened concrete on account of poor gel structure, suffers from lack of wearing quality and abrasion resistance. Therefore, such surfaces create mud in the rainy season and dust in summer.

The quick surface drying of concrete results in the movement of moisture from the interior to the surface. This steep moisture gradient cause high internal stresses which are also responsible for internal micro cracks in the semi-plastic concrete.

Concrete, while hydrating, releases high heat of hydration. This heat is harmful from the point of view of volume stability. If the heat generated is removed by some means, the adverse effect due to the generation of heat can be reduced. This can be done by a thorough water curing. Fig. shows the influence of curing by ponding and wet covering.

Curing Methods

Curing methods may be divided broadly into four categories:

(*a*) Water curing (*b*) Membrane curing (*c*) Application of heat (*d*) Miscellaneous

Water Curing

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

(*a*) Immersion (*b*) Ponding

(*c*) Spraying or Fogging (*d*) Wet covering

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

Membrane Curing

Sometimes, concrete works are carried out in places where there is acute shortage of water. The lavish application of water for water curing is not possible for reasons of economy. It has been pointed out earlier that curing does not mean only application of water, it means also creation of conditions for promotion of uninterrupted and progressive hydration. It is also pointed out that the quantity of water, normally mixed for making concrete is more than sufficient to hydrate the cement, provided this water is not allowed to go out from the body of concrete. For this reason, concrete could be covered with membrane

Membrane curing by spraying.

which will effectively seal off the evaporation of water from concrete. It is found that the application of membrane or a sealing compound, after a short spell of water curing for one or two days is sometimes beneficial.

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

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

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

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

Enough has been written in Chapter 5 on the modern curing compounds that are available today. Increase in volume of construction, shortage of water and need for conservation of water, increase in cost of labour and availability of effective curing compounds have encouraged the use of curing compounds in concrete construction. Curing compound is an obvious choice for curing canal lining, sloping roofs and textured surface of concrete pavements.

Curing vertical surface by wet covering.

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

For further details refer Chapter 5 where more information about curing compounds. Method for determining the efficiency of curing compounds etc., are given.

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

Application of heat

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

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

(*a*) Concrete is vulnerable to damage only for short time.
(*b*) Concrete member can be handled very quickly.
(*c*) Less space will be sufficient in the casting yerd.
(*d*) A smaller curing tank will be sufficient.
(*e*) A higher outturn is possible for a given capital outlay.
(*f*) The work can be put on to service at a much early time,
(*g*) A fewer number of formwork will be sufficient or alternatively with the given number of formwork more outturn will be achieved.
(*h*) Prestressing bed can be released early for further casting.

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

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

(*a*) Steam curing at ordinary pressure.
(*b*) Steam curing at high pressure.
(*c*) Curing by Infra-red radiation.
(*d*) Electrical curing.

Steam curing at ordinary pressure

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

Beam under steam curing.

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

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

It is interesting to note that concrete subjected to higher temperature at the early period of hydration is found to lose some of the strength gained at a later age. Such concrete is said to undergo "Retrogression of Strength". Figure shows the effect of temperature on strength of concrete. It can be seen from Figure that the concrete subjected to higher temperature at early age, no doubt attains higher strength at a shorter duration, but suffers considerable retrogression of strength. Fig. On the contrary, concrete cured at a comparatively lower temperature takes longer time to develop strength but the strength attained will not be lost at later ages. The phenomenon of retrogression of strength explains that faster hydration will result in the formation of poor quality gels with porous open structure, whereas the gel formed slowly but steadily at lower temperature are of good quality which are compact and dense in nature. This aspect can be compared to the growth of wood higher proportion of C_2S is not benefited to the same extent, as it produces lower amount of $Ca(OH)_2$

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

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

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

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

Due to the absence of free calcium hydroxide no efflorescence is seen in case of high pressure steam cured concrete.

Due to the formation of coarser gel, the bond strength of concrete to the reinforcement is reduced by about 30 per cent to 50 per cent when compared with ordinary moist-cured concrete. High pressure steam cured concrete is rather brittle and whitish in colour. On the whole, high pressure steam curing produces good quality dense and durable concrete:

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

Curing by Infra-red Radiation

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

Electrical Curing

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

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

Miscellaneous Methods of Curing

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

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

Finishing

Finishing operation is the last operation in making concrete. Finishing in real sence does not apply to all concrete operations. For a beam concreting, finishing may not be applicable, whereas for the concrete road pavement, airfield pavement or for the flooring of a domestic building, careful finishing is of great importance. Concrete is often dubbed as a drab material, incapable of offering pleasant architectural appearance and finish. This shortcoming of concrete is being rectified and concretes these days are made to exhibit pleasant surface finishes. Particularly, many types of prefabricated concrete panels used as floor slab or wall unit are made in such a way as to give very attractive architectural affect. Even concrete claddings are made to give attractive look.

In recent years there has been a growing tendency to develop and use various surface treatments which permit concrete structures to proudly proclaim its nature instead of covering itself with an expensive veneer. The property of concrete to reproduce form markings such as board mark finishes, use of linings or special types of formworks, special techniques for the application of applied finishes have been encouraged. Surface finishes may be grouped as under:

(*a*) Formwork Finishes (*b*) Surface Treatment (*c*) Applied Finishes.

Formwork Finishes

Concrete obeys the shape of formwork *i.e.,* centering work. By judiciously assembling the formwork either in plane surface or in undulated fashion or having the joints in a particular "V" shaped manner to get regular fins or groves, a pleasing surface finish can be given to concrete. The architect' s imaginations can be fully exploited to give many varieties of look to the concrete surface. The use of small battens can give a good look to the concrete surface.

A pre-fabricated wall unit cast between steel formwork having very smooth surface using right proportioning of materials can give such a nice surface which can never be obtained by the best masons. Similarly, the prefabricated floor units can have such a fine finish at the ceiling which cannot be obtained by the best masons with the best efforts. These days with the cost of labour going up, attention is naturally directed to the self-finishing of the concrete surface, particularly, for floor slabs, by the use of good formwork material such as steel sheets or shuttering type plywood.

Mechanical trowel for finishing factory floor.

Sometimes surface hardener is sprinkled and finished.

Strength of Concrete And Effect Of Creep

Water/Cement Ratio

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

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

where x =water/cement ratio by volume and for 28 days results the constants A and B are 14,000 lbs/sq. in. and 7 respectively. 7 .1

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

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

$$S = K\left(\frac{c}{c+e+a}\right)^{2}$$

where S = Strength of concrete

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

K = a constant.

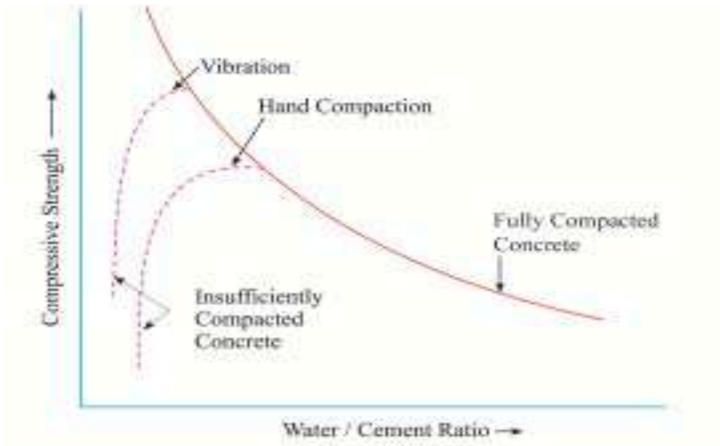


Fig. 7.1. The relation between strength and water/cement ratio of concrete.

This expression the volume of air is also included because it is not only the water/ cement ratio but also the degree of compaction, which indirectly means the volume of air filled voids in the concrete is taken into account in estimating the strength of concrete. The relation between the water/cement ratio and strength of concrete is shown in Fig. 7.1. It can be seen that lower water/cement ratio could be used when the concrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio is required when concrete is hand-compacted. In both cases when the water/cement ratio is below the practical limit the strength of the concrete falls rapidly due to introduction of air voids.

The graph showing the relationship between the strength and water/cement ratio is approximately hyperbolic in shape. Sometimes it is difficult to interpolate the intermediate value. From geometry it can be deduced that if the graphs is drawn between the strength and the cement/water ratio an approximately linear relationship will be obtained. This linear relationship is more convenient to use than water/cement ratio curve for interpolation. Fig. 7.2 shows the relationship between compressive strength and cement/water ratio.

Effect of Maximum size of Aggregate on Strength

At one time it was thought that the use of larger size aggregate leads to higher strength. This was due to the fact that the larger the aggregate the lower is the total surface area and, therefore, the lower is the requirement of water for the given workability. For this reason, a lower water/cement ratio can be used which will result in higher strength.

However, later it was found that the use of larger size aggregate did not contribute to higher strength as expected from the theoretical considerations due to the following reasons.

The larger maximum size aggregate gives lower surface area for developments of gel bonds which is responsible for the lower strength of the concrete. Secondly bigger aggregate size causes a more heterogeneity in the concrete which will prevent the uniform distribution of load when stressed.

When large size aggregate is used, due to internal bleeding, the transition zone will become much weaker due to the development of microcracks which result in lower compressive strength.

Generally, high strength concrete or rich concrete is adversely affected by the use of large size aggregate. But in lean mixes or weaker concrete the influence of size of the aggregate gets reduced. It is interesting to note that in lean mixes larger aggregate gives highest strength while in rich mixes it is the smaller aggregate which yields higher strength.
the influence of maximum size of aggregate on compressive strength of concrete.
depicts the influence of size of aggregate on compressive strength of concrete for different w/c ratio.

Relation Between Compressive and Tensile Strength

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

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

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

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

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

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

High Strength Concrete

Concrete is generally classified as Normal Strength Concrete (NSC), High Strength Concrete (HSC) and Ultra High Strength Concrete (UHSC). There are no clear cut boundary for the above classification. Indian Standard Recommended Methods of Mix Design denotes the boundary at 35 MPa between NSC and HSC. They did not talk about UHSC. But elsewhere in the international forum, about thirty years ago, the high strength lable was applied to concrete having strength above 40 MPa. More recently, the threshold rose to 50 to 60 MPa. In the world scenario, however, in the last 15 years, concrete of very high strength entered the field of construction, in particular construction of high-rise buildings and long span bridges. Concrete strengths of 90 to 120 MPa are occasionally used. Table 7.8 shows the kind of high strength produced in RMC plant.

The advent of Prestressed Concrete Technology Techniques has given impetus for making concrete of higher strength. In India, there are cases of using high strength concrete for prestressed concrete bridges. The first prestressed concrete bridge was built in 1949 for the Assam Rail Link at Siliguri. In fifty' s a number of pretressed concrete structures were built using concrete of strength from 35 MPa to 45 MPa. But strength of concrete more than 35 MPa was not commonly used in general construction practices. Probably concrete of strength more than 35 MPa was used in large scale in Konkan Railway project during early 90's and concretisation of Mumbai Muncipal Corporation Roads. It is only during 90' s use of high strength concrete has taken its due place in Indian construction scenario. Of late concrete of strength varying from 45 MPa to 60 MPa has been used in high rise buildings at Mumbai, Delhi and other Metropolitan cities. Similarly high strength concrete was employed in bridges and flyovers. Presently (year 2000) in India, concrete of strength 75 MPa is being used for the first time in one of the flyovers at Mumbai. Other notable example of using high strength concrete in India is in the construction of containment Dome at Kaiga Power Project. They have used High performance concrete of strength 60 MPa with silica fume as one of the constituents.

Vidya Sagar Setu at Kolkata where longest cable stayed bridge (in India) was built using high strength concrete.

Ready Mixed Concrete has taken its roots in India now. The manufacture of high strength concrete will grow to find its due place in concrete construction for all the obvious benefits. In the modern batching plants high strength concrete is produced in a mechanical manner. Of course, one has to take care about mix proportioning, shape of aggregates, use of supplementary cementitious materials, silica fume and superplasticizers. With the modern equipments, understanding of the role of the constituent materials, production of high strength concrete has become a routine matter.

There are special methods of making high strength concrete. They are given below.

(*a*) Seeding (*b*) Revibration (*c*) High speed slurry mixing;
(*d*) Use of admixtures (*e*) Inhibition of cracks (*f*) Sulphur impregnation(*g*) Use of cementitious aggregates.

Seeding: This involves adding a small percentage of finely ground, fully hydrated Portland cement to the fresh concrete mix. The mechanism by which this is supposed to aid strength development is difficult to explain. This method may not hold much promise.

Revibration: Concrete undergoes plastic shrinkage. Mixing water creates continuous capillary channels, bleeding, and water accumulates at some selected places. All these reduce the strength of concrete. Controlled revibration removes all these defects and increases the strength of concrete.

High Speed slurry mixing: This process involves the advance preparation of cement-water mixture which is then blended with aggregate to produce concrete. Higher compressive strength obtained is attributed to more efficient hydration of cement particles and water achieved in the vigorous blending of cement paste.

Use of Admixtures: Use of water reducing agents are known to produce increased compressive strengths.

Inhibition of cracks: Concrete fails by the formation and propagation of cracks. If the propagation of cracks is inhibited, the strength will be higher. Replacement of 2– 3% of fine aggregate by polythene or polystyrene "lenticules" 0.025 mm thick and 3 to 4 mm in diameter results in higher strength. They appear to act as crack arresters without necessitating extra water for workability. Concrete cubes made in this way have yielded strength upto 105 MPa.

Sulphur Impregnation: Satisfactory high strength concrete have been produced by impregnating low strength porous concrete by sulphur. The process consists of moist curing the fresh concrete specimens for 24 hours, drying them at 120°C for 24 hours, immersing the specimen in molten sulphur under vacuum for 2 hours and then releasing the vacuum and soaking them for an additional ½ hour for further infiltration of sulphur. The sulphur-infiltrated concrete has given strength upto 58 MPa.

Use of Cementitious aggregates: It has been found that use of cementitious aggregates has yielded high strength. Cement fondu is kind of clinker. This glassy clinker when finely ground results in a kind of cement. When coarsely crushed, it makes a kind of aggregate known as ALAG. Using Alag as aggregate, strength upto 125 MPa has been obtained with water/cement ratio 0.32.

Creep

Creep can be defined as "the time-dependent" part of the strain resulting from stress. We have discussed earlier that the stress-strain relationship of concrete is not a straight line relationship but a curved one. The degree of curvature of the stress-strain relationship depends upon many factors amongst which the intensity of stress and time for which the load is acting are of significant interest. Therefore, it clearly shows that the relation between stress and strain for concrete is a function of time. The gradual increase in strain, without increase in stress, with the time is due to creep. From this explanation creep can also be defined as the increase in strain under sustained stress.

All materials undergo creep under some conditions of loading to a greater or smaller extent. But concrete creeps significantly at all stresses and for a long time. Furthermore, creep of concrete is approximately linear function of stress upto 30 to 40 per cent of its strength. The order of magnitude of creep of concrete is much greater than that of other crystalline material except for metals in the final stage of yielding prior to failure. Therefore, creep in concrete is considered to be an isolated rheological phenomenon and this is associated with the gel structure of cement paste. Cement paste plays a dominant role in the deformation of concrete. The aggregates, depending upon the type and proportions modify the deformation characteristics to a greater or lesser extent. Therefore, it is logical initially to examine the structure of cement paste and how it influences creep behaviour and then to consider how the presence of aggregate modifies the creep behaviour.

Cement paste essentially consists of unhydrated cement grains surrounded by the product of hydration mostly in the form of gel. These gels are interpenetrated by gel pores and interspersed by capillary cavities. The process of hydration generates more and more of gel and subsequently there will be reduction of unhydrated cement and capillary cavities. In young concrete, gel pores are filled with gel water and capillary cavities may or may not be

filled with water. The movement of water held in gel and paste structure takes place under
the influence of internal and external water vapour pressure. The movement of water may also
take place due to the sustained load on concrete.

The formation of gel and the state of existence of water are the significant factors on the
deformative characteristics of concrete. The gel provides the rigidity both by the formation of
chemical bonds and by the surface force of attraction while the water can be existing in three
categories namely combined water, gel water and capillary water.

It is interesting to find how such a conglomeration of very fine colloidal particles with
enclosed water-filled viods behave under the action of external forces. One of the explanations
given to the mechanics of creeps is based on the theory that the colloidal particles slide against
each other to re-adjust their position displacing the water held in gel pores and capillary
cavities. This flow of gel and the consequent

Factors Affecting Creep

Influence of Influence of Influence of Aggregate: Aggregate undergoes very little creep.

It is really the paste which Influence of Influence of Aggr egate:
is responsible for the creep. However, the aggregate influences the creep of concrete through
a restraining effect on the magnitude of creep. The paste which is creeping under load is
restrained by aggregate which do not creep. The stronger the aggregate the more is the
restraining effect and hence the less is the magnitude of creep. Figure 8.14 shows the effect
of the quality of aggregate on the magnitude of creep.

The grading, the shape, the maximum size of aggregate have been suggested as factors
affecting creep. But it is later shown that the effect of aggregate and their properties
mentioned above do not effect the creep , but indirectly they affect the creep from the
point of view of total aggregate content in the concrete. The modulus of elasticity of
aggregate is one of the important factors influencing creep. It can be easily imagined that the
higher the modulus of elasticity the less is the creep. Light weight aggregate shows
substantially higher creep than normal weight aggregate. Persuambly this is because of lower
modulus of elasticity.

The amount of paste content and its quality is one of the
most important factors influencing creep. A poorer paste structure undergoes higher creep.
Therefore, it can be said that creep increases with increase in water/cement ratio. In other
words, it can also be said that creep is inversely proportional to the strength of concrete.
Broadly speaking, all other factors which are affecting the water/cement ratio is also affecting
the creep. The following table shows the creep of concretes of different strength.
of water is responsible for complex
deformation behaviour and creep of concrete.

Creep takes place only under stress. Under sustained stress, with time, the gel, the adsorbed water layer, the water held in the gel pores and capillary pores yields, flows and
readjust themselves, which behaviour is termed as creep in concrete.

Sulphate Attack

Most soils contain some sulphate in the form of calcium, sodium, potassium and magnesium. They occur in soil or ground water. Because of solubility of calcium sulphate is low, ground waters contain more of other sulphates and less of calcium sulphate. Ammonium sulphate is frequently present in agricultural soil and water from the use of fertilizers or from sewage and industrial effluents. Decay of organic matters in marshy land, shallow lakes often leads to the formation of H_2S, which can be transformed into sulphuric acid by bacterial action.

Water used in concrete cooling towers can also be a potential source of sulphate attack on concrete. Therefore sulphate attack is a common occurrence in natural or industrial situations.

Solid sulphates do not attack the concrete severely but when the chemicals are in solution, they find entry into porous concrete and react with the hydrated cement products. Of all the sulphates, magnesium sulphate causes maximum damage to concrete. A characteristic whitish appearance is the indication of sulphate attack.

The term sulphate attack denote an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates. In the hardened concrete, calcium aluminate hydrate (C-A-H) can react with sulphate salt from outside. The product of reaction is calcium sulphoaluminate, forming within the framework of hydrated cement paste. Because of the increase in volume of the solid phase which can go up to 227 per cent, a gradual disintegration of concrete takes place.

The reactions of the various sulphates with hardened cement paste is shown below

Let us take the example of Sodium Sulphate attacking $Ca(OH)_2$

Ca(OH) + Na SO . 10H O CaSO . 2H O + 2NaOH + 8H O.

2 2 4 2 4 2 2

The reaction with calcium aluminate hydrate is as follows

$$2(3CaO \cdot Al_2O_3 \cdot 12H_2O) + 3(Na_2SO_4 \cdot 10H_2O)$$
$$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O + 2Al(OH)_3 + 6NaOH + 17\,H_2O$$

Calcium sulphate attacks only calcium aluminate hydrate producing calcium sulpho aluminate ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$) known as ettringite. Molecules of water may be 32 or 31.

On the other hand magnesium sulphate has a more far reaching action than other sulphates because it reacts not only with calcium hydroxide and hydrated calcium aluminates like other sulphates but also decomposes the hydrated calcium silicates completely and makes it a friable mass.

The rate of sulphate attack increases with the increase in the strength of solution. A saturated solution of magnesium sulphate can cause serious damage to concrete with higher water cement ratio in a short time. However, if the concrete is made with low water cement ratio, the concrete can withstand the action of magnesium sulphate for 2 or 3 years.
parts. 1000 PPM is considered moderately severe and 2000 PPM is considered very severe, especially if $MgSO_4$ is the predominant constituent.

Another factor influencing the rate of attack is the speed in which the sulphate gone into the reaction is replenished. For this it can be seen that when the concrete is subjected to the pressure of sulphate bearing water on one side the rate of attack is highest. Similarly, alternate wetting and drying due to tidal variation or spraying leads to rapid attack.

Methods of Controlling Sulphate Attack

Having studied the mechanism of sulphate attack on concrete it will be easy for us to deal with the methods for controlling the sulphate attack.

(*a*) **Use of Sulphate Resisting Cement**

The most efficient method of resisting the sulphate attack is to use cement with the low C_3A content. This has been discussed in detail earlier in chapter I. In general, it has been found that a C_3A content of 7% gives a rough division between cements of good and poor performance in sulphate waters.

(*b*) **Quality Concrete**

A well designed, placed and compacted concrete which is dense and impermeable exhibits a higher resistance to sulphate attack. Similarly, a concrete with low water/cement ratio also demonstrates a higher resistance to sulphate attack.

(*c*) **Use of air-entrainment**

Use of air-entrainment to the extent of about 6% (six per cent) has beneficial effect on the sulphate resisting qualities of concrete. The beneficial effect is possibly due to reduction of segregation, improvement in workability, reduction in bleeding and in general better impermeability of concrete.

(*d*) **Use of pozzolana**

Incorporation of or replacing a part of cement by a pozzolanic material reduces the sulphate attack. Admixing of pozzolana converts the leachable calcium hydroxide into insoluble non-leachable cementitious product. This pozzolanic action is responsible for impermeability of concrete. Secondly, the removal of calcium hydroxide reduces the susceptibility of concrete to attack by magnesium sulphate.

(*e*) **High Pressure Steam Curing**

High pressure steam curing improve the resistance of concrete to sulphate attack. This improvement is due to the change of C AH into a less reactive phase and also to the removal or reduction of calcium hydroxide by the reaction of silica which is invariably mixed when high pressure steam curing method is adopted.

(*f*) **Use of High Alumina Cement**

The cause of great resistance shown by high alumina cement to the action of sulphate is still not fully understood. However, it is attributed in part to the absence of any free calcium

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e set cement, in contrast to Portland cement. High alumina cement contains approximately 40% alumina, a compound very susceptible to sulphate attack, when in normal portland cement. But this percentage of alumina present in high alumina cement behaves in a different way. The primary cause of resistance is attributed to formation of protective films which inhibit the penetration or diffusion of sulphate ions into the interior.

Corrosion Control

From the literature survey and case studies it has been reported that 40% of failure of structures is on account of corrosion of embedded steel reinforcement in concrete. Therefore corrosion control of steel reinforcement is a subject of paramount importance.

First and foremost for corrosion control is the good quality of concrete through good construction practices. It is a very vast subject touches the fundamentals of choosing constituent material and good rules to be followed during various stages of production of concrete. In particular the use of lowest possible water/cement ratio having regard to workability. In view of the general availability of superplasticizers, it should be used to cut down the W/C ratio to make dense concrete.

Proper mix design, use of right quality and quantity of cement for different exposure conditions is to beadopted. Recently it hasbeen realised that lowerW/C ratio which has been always associated with lower permeability is notenough to makeimpermeable concretecontributing to highdurability. Use of supplementary Electro Micrograph showing cementitious materials corrosion in good concrete such as fly ash, ground granulated blastfurnace slag (ggbs), silica fume etc. are required to be used as admixtures or in the form of blended cement in addition to lowest possible W/C ratio to make concrete dense. These materials improve more than one properties of concrete which will eventually reduce corrosion of reinforcement. Tests on mortar containing have shown that water permeability is reduced by a factor up to 100. It is also reported that 60 per cent ggbs reduced the diffusion of chloride ions into the concrete by as much as 10 times. Silica fume contributes to the all-round improvements in the quality of concrete which are responsible for reducing

Crack formed due to bursting pressure on account of rusting of reinforcements

Example of delamination of concrete cover corrosion of steel reinforcement. The improvement in the microstructure of hydrated cement paste is ultimately responsible for protecting the steel reinforcement from corrosion.

In short it can be said that if we make good concrete with low permeability and improved microstructure, it will be durable by itself and also it can take care of the reinforcement contained in it to a great extent. It is always not possible to make such ideal concrete, particularly, in view of the complex environmental and exposure conditions. Further, the inherent long term drying shrinkage and microcracks in concrete, the problems become more serious. This demands certain other measures to control the corrosion of steel reinforcement.

They are listed and briefly explained.

- Metallurgical methods
- Corrosion inhibitors
- Coatings to reinforcement
- Cathodic protection
- Coatings to concrete
- Design and detailing.

Testing of Hardened Concrete

Compression Test

Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic
properties of concrete are qualitatively related to its compressive strength.

Cube beam and cylinder moulding

The compression test is carried out on specimens cubical or cylindrical in shape. Prism
is also sometimes used, but it is not common in our country. Sometimes, the compression
strength of concrete is determined using parts of a beam tested in flexure. The end parts of

beam are left intact after failure in flexure and, because the beam is usually of square cross
section, this part of the beam could be used to find out the compressive strength.

The cube specimen is of the size 15 x 15 x 15 cm. If the largest nominal size of the aggregate does not exceed 20 mm, 10 cm size cubes may also be used as an alternative.

Cylindrical test specimens have a length equal to twice the diameter. They are 15 cm in
diameter and 30 cm long. Smaller test specimens may be used but a ratio of the diameter of
the specimen to maximum size of aggregate, not less than 3 to 1 is maintained.

Moulds

Metal moulds, preferably steel or cast iron, thick enough to prevent distortion are required. They are made in such a manner as to facilitate the removal of the moulded specimen without damage and are so machined that, when it is assembled ready for use, the dimensions and internal faces are required to be

The height of the mould and the distance between the opposite faces are of the specified size ± 0.2 mm. The angle between adjacent internal faces and between internal faces and top and bottom planes of the mould is required to be 90° ± 0.5°. The interior faces of the mould, are plane surfaces with a permissible variation of 0.03 mm. Each mould is provided with a metal base plate

Vibrating table for cubes

having a plane surface. The base plate is of such dimensions as to support the mould during
the filling without leakage and it is preferably attached to the mould by springs or screws. The

parts of the mould, when assembled, are positively and rigidly held together, and suitable
methods of ensuring this, both during the filling and on subsequent handling of the filled
mould, are required to be provided.

The cylindrical mould is required to be of metal which shall be not less than 3 mm thick.
Each mould is capable of being opened longitudinally to facilitate removal of the specimen
and is provided with means of keeping it closed while in use. Care should be taken so that
the ends are not departed from a plane surface, perpendicular to the axis of the mould, by
more than 0.05 mm. When assembled ready for use the mean internal diameter of the mould
should be 15.0 cm ± 0.2 mm. and in no direction the internal diameter be less than 14.95
cm. or more than 15.05 cm. The height maintained is 30.0 cm ± 0.1 mm. Each mould is
provided with a metal base plate, and with a capping plate of glass or orther suitable material.
The base plate and the capping plate are required to be at least 6.5 mm thick and such that
they do not depart from a plane surface by more than 0.02 mm. The base plate supports the
mould during filling without leakage and is rigidly attached to the mould. The mould and
base plate are coated with a thin film of mould oil before use, in order to prevent adhesion
of concrete.

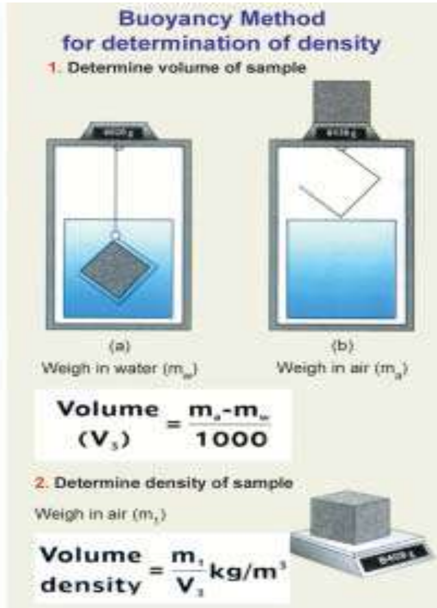
A steel bar 16 mm in diameter, 0.6 m long and bullet pointed at the lower end serves as a tamping bar.

Compacting

The test cube specimens are made as soon as practicable after mixing and in such a way
as to produce full compaction of the concrete with neither segregation nor excessive laitance.
The concrete is filled into the mould in layers approximately 5 cm deep. In placing each

Buoyancy Balance

scoopful of concrete, the scoop is required to
be moved around the top edge of the
mould as the concrete slides from it, in order



to ensure a symmetrical distribution of the
concrete within the mould. Each layer is
compacted either by hand or by vibration.
After the top layer has been compacted the
surface of the concrete is brought to the
finished level with the top of the mould, using
a trowel. The top is covered with a glass or metal plate to prevent evaporation.

Compacting by Hand

When compacting by hand, the standard tamping bar is used and the strokes of the bar
are distributed in a uniform manner over the cross-section of the mould. The number of strokes
per layer required to produce the specified conditions vary according to the type of concrete.
For cubical specimens, in no case should the concrete be subject to less than 35 strokes per
layer for 15 cm or 25 strokes per layer for 10 cm cubes. For cylindrical specimens, the number
of strokes are not less than thirty per layer. The strokes penetrate into the underlying layer and
the bottom layer is rodded throughout its depth. Where voids are left by the tamping bar, the
sides of the mould are tapped to close the voids.

Compacting by Vibration

When compacting by vibration, each layer is vibrated by means of an electric or pneumatic hammer or vibrator or by means of a suitable vibrating table until the specified condition is attained. The mode and quantum of vibration of the laboratory specimen shall be as nearly the same as those adopted in actual concreting operations. Care must be taken while compacting high slump concrete which are generally placed by pumping. If care its not taken severe segregation takes place in the mould, which results in low strength when cubes are crushed. The cube crushing strength does not represent the strength of the concrete.

Curing

The test specimens are stored in place free from vibration, in moist air of at least 90% relative humidity and at a temperature of 27° ± 2°C for 24 hours ± / hour from the time of 1

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addition of water to the dry ingredients. After this period, the specimens are marked and removed from the moulds and unless required for test within 24 hours, immediately submerged in clean fresh water or saturated lime solution and kept there until taken out just prior to test. The water or solution in which the specimens are submerged, are renewed every seven days and are maintained at a temperature of 27° ± 2°C. The specimens are not to be allowed to become dry at any time until they have been tested.

Making and Curing Compression Test Specimen in the Field

The test specimens are stored on the site at a place free from vibration, under damp matting, sacks or other similar material for 24 hours ± / hour from the time of addition of 1

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water to the other ingredients. The temperature of the place of storage should be within the
range of 22° to 32°C. After the period of 24 hours, they should be marked for later identification removed from the moulds and unless required for testing within 24 hours, stored
in clean water at a temperature of 24° to 30°C until they are transported to the testing laboratory. They should be sent to the testing laboratory well packed in damp sand, damp
sacks, or other suitable material so as to arrive there in a damp condition not less than 24
hours before the time of test. On arrival at the testing laboratory, the specimens are stored in
water at a temperature of 27° ± 2°C until the time of test. Records of the daily maximum and
minimum temperature should be kept both during the period the specimens remain on the
site and in the laboratory particularly in cold weather regions.

Comparison between Cube and Cylinder Strength

It is difficult to say whether cube test gives more realistic strength properties of concrete
or cylinder gives a better picture about the strength of concrete. However, it can be said that
the cylinder is less affected by the end restrains caused by platens and hence it seems

to give more uniform results than cube. Therefore, the use of cylinder is becoming more popular, particularly in the research laboratories.

Cylinders are cast and tested in the same position, whereas cubes are cast in one direction and tested from the other direction. In actual structures in the field, the casting and loading is similar to that of the cylinder and not like the cube. As such, cylinder simulates the condition of the actual structural member in the field in respect of direction of load.

The points in favour of the cube specimen are that the shape of the cube resembles the shape of the structural members often met with on the ground. The cube does not require capping, whereas cylinder requires capping. The capping material used in case cylinder may influence to some extent the strength of the cylinder.

The Flexural Strength of Concrete

Concrete as we know is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforcing bars are provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other reasons. Therefore, the knowledge of tensile strength of concrete is of importance.

A concrete road slab is called upon to resist tensile stresses from two principal sources– wheel loads and volume change in the concrete. Wheel loads may cause high tensile stresses due to bending, when there is an inadequate subgrade support. Volume changes, resulting from changes in temperature and moisture, may produce tensile stresses, due to warping and due to the movement of the slab along the subgrade.

Stresses due to volume changes alone may be high. The longitudinal tensile stress in the bottom of the pavement, caused by restraint and temperature warping, frequently amounts to as much as 2.5 MPa at certain periods of the year and the corresponding stress in the transverse direction is approximately 0.9 MPa. These stresses are additive to those produced by wheel loads on unsupported portions of the slab.

Determination of Tensile Strength

Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the "pull" applied

to the concrete. While a number of investigations involving the direct measurement of tensile strength have been made, beam tests are found to be dependable to measure flexural strength property of concrete.

The value of the modulus of rupture (extreme fibre stress in bending) depends on the dimension of the beam and manner of loading. The systems of loading used in finding out the flexural tension are central point loading and third point loading. In the central point loading, maximum fibre stress will come below the point of loading where the bending moment is maximum. In case of symmetrical two point loading, the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum. It can be expected that the two point loading will yield a lower value of the modulus of rupture than the centre point loading. Figure 10.4 shows the modulus of rupture of beams of different sizes subjected to centre point and third

Flexural testing of concrete beam mould

point loading. I.S. 516-1959, specifies two point loading. The details of the specimen and
procedure are described in the succeeding paragraphs.

Principles of flexural testing

The standard size of the specimens are 15 x 15 x 70 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 20 mm, specimens 10 x 10 x 50 cm may be
used.

The mould should be of metal, preferably steel or cast iron and the metal should be of
sufficient thickness to prevent spreading or warping. The mould should be constructed with
the longer dimension horizontal and in such a manner as to facilitate the removal of the moulded specimens without damage.

The tamping bar should be a steel bar weighing 2 kg, 40 cm long and should have a ramming face 25 mm square.

The testing machine may be of any reliable type of sufficient capacity for the tests and
capable of applying the load at the rate specified. The permissible errors should not be greater
that ± 0.5 per cent of the applied load where a high degree of accuracy is required and not
greater than ± 1.5 per cent of the applied load for commercial type of use. The bed of the
testing machine should be provided with two steel rollers, 38 mm in diameter, on which the
specimen is to be supported, and these rollers should be so mounted that the distance from
centre to centre is 60 mm for 15 cm specimen or 40 cm for 10.0 cm specimens. The load is
applied through two similar rollers mounted at the third points of the supporting span, that
is, spaced at 20 or 13.3 cm centre to centre. The load is divided equally between the two
loading rollers, and all rollers are mounted in such a manner that the load is applied axially
and without subjecting specimen to any torsional stresses or restrains.

Non-Destructive Testing Methods

Non-destructive methods have been in use for about four decades. In this period, the development has taken place to such an extent that it is now considered as a powerful method for evaluating existing concrete structures with regard to their strength and durability
apart form assessment and control of quality of hardened concrete. In certain cases, the investigation of crack depth, microcracks, and progressive deterioration are also studied by this
method.

Though non-destructive testing methods are relatively simple to perform, the analysis and
interpretation of test results are not so easy. Therefore, special knowledge is required to
analyses the hardenedproperties of concrete.

. Some such properties of concrete are hardness, resistance to
penetration of projectiles, rebound number, resonant frequency and ability to allow ultrasonic
pulse velocity to propagate through it. The electrical properties of concrete, its ability to absorb,
scatter and transmit X-rays and Gamma-rays, its response to nuclear activation and its acoustic
emission allow us to estimate its moisture content, density, thickness and its cement content.
Based upon the above, various non-destructive methods of testing concrete have been developed:

1. Surface hardness tests: These are of indentation type, include the Williams testing pistol and impact hammers, and are used only for estimation of concrete strength.
2. Rebound test: The rebound hammer test measures the elastic rebound of concrete and is primarily used for estimation of concrete strength and for comparative investigations.
3. Penetration and Pull out techniques: These include the use of the Simbi hammer, Spit pins, the Windsor probe, and the pullout test. These measure the penetration and pullout resistance of concrete and are used for strength estimations, but they can also be used for comparative studies.
4. Dynamic or vibration tests: These include resonant frequency and mechanical sonic

and ultrasonic pulse velocity methods. These are used to evaluate durability and uniformity of concrete and to estimate its strength and elastic properties.

5. Combined methods: The combined methods involving ultrasonic pulse velocity and rebound hammer have been used to estimate strength of concrete.

6. Radioactive and nuclear methods: These include the X-ray and Gamma-ray penetration tests for measurement of density and thickness of concrete. Also, the neutron scattering and neutron activation methods are used for moisture and cement content determination.

7. Magnetic and electrical methods: The magnetic methods are primarily concerned with determining cover of reinforcement in concrete, whereas the electrical methods, including microwave absorption techniques, have been used to measure moisture content and thickness of concrete.

8. Acoustic emission techniques: These have been used to study the initiation and growth of cracks in concrete.

9. Surfaces Hardness Methods: The fact that concrete hardens with increase in age, the measure of hardness of surface may indicate the strength of concrete. Various methods and equipments are devised to measure hardness of concrete surface. William testing pistol, Frank spring hammer, and Einbeck pendulum hammer are some of the devices for measuring surface hardness.

Rebound Number and Strength of Concrete

Investigations have shown that there is a general correlation between compressive strength of concrete and rebound number; however, there is a wide degree of disagreement

Pullout test

A pullout test measures the force required to pull out from the concrete a specially shaped rod whose enlarged end has been cast into that concrete. The stronger the concrete, the more is the force required to pullout. The ideal way to use pullout test in the field would be to incorporate assemblies in the structure. These standard specimens could then be pulled out at any point of time. The force required denotes the strength of concrete. Another way to use pullout test in the field would be to cast one or two large blocks of concrete incorporating pullout assemblies. Pullout test could then be performed to assess the strength of concrete.

Concrete Mix Design

Concept of Mix Design

It will be worthwhile to recall at this stage the relationships between aggregate and paste
which are the two essential ingredients of concrete. Workability of the mass is provided by the
lubricating effect of the paste and is influenced by the amount and dilution of paste. The
strength of concrete is limited by the strength of paste, since mineral aggregates with rare
exceptions, are far stronger than the paste compound. Essentially the permeability of concrete
is governed by the quality and continuity of the paste, since little water flows through

aggregate either under pressure or by capillarity. Further, the predominant contribution to drying shrinkage of concretes is that of paste.

Since the properties of concrete are governed to a considerable extent by the quality of paste, it is helpful to consider more closely the structure of the paste. The fresh paste is a suspension, not a solution of cement in water.

The more dilute the paste, the greater the spacing between cement particles, and thus the weaker will be the ultimate paste structure. The other conditions being equal, for workable mixes, the strength of concrete varies as an inverse function of the water/cement ratio. Since the quantity of water required also depends upon the amount of paste, it is important that as little paste as possible should be used and hence the importance of grading.

Variables in Proportioning

With the given materials, the four variable factors to be considered in connection with specifying a concrete mix are:

(*a*) Water-Cement ratio
(*b*) Cement content or cement-aggregate ratio
(*c*) Gradation of the aggregates
(*d*) Consistency.

In general all four of these inter-related variables cannot be chosen or manipulated arbitrarily. Usually two or three factors are specified, and the others are adjusted to give minimum workability and economy. Water/cement ratio expresses the dilution of the paste-cement content varies directly with the amount of paste. Gradation of aggregate is controlled by varying the amount of given fine and coarse aggregate. Consistency is established by practical requirements of placing. In brief, the effort in proportioning is to use a minimum amount of paste (and therefore cement) that will lubricate the mass while fresh and after hardening will bind the aggregate particles together and fill the space between them. Any excess of paste involves greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering action. This is achieved by minimising the voids by good gradation.

Various Methods of Proportioning

(*a*) Arbitrary proportion
(*b*) Fineness modulus method
(*c*) Maximum density method
(*d*) Surface area method
(*e*) Indian Road Congress, IRC 44 method
(*f*) High strength concrete mix design
(*g*) Mix design based on flexural strength
(*h*) Road note No. 4 (Grading Curve method)
(*i*) ACI Committee 211 method
(*j*) DOE method
(*k*) Mix design for pumpable concrete
(*l*) Indian standard Recommended method IS 10262-82

Out of the above methods, some of them are not very widely used these days because of some defficulties or drawbacks in the procedures for arriving at the satisfactory proportions.
The ACI Committee 211 method, the DOE method and Indian standard recommended methods are commonly used. Since concrete is very commonly placed by pumping these days method of mix design of pumpable concrete has become important. Therefore, only the more popular and currently used methods are described.

Before we deal with some of the important methods of concrete mix design, it is necessary to get acquainted with statistical quality control methods, which are common to all the methods of mix design.

Statistical Quality Control of Concrete

Concrete like most other construction processes, have certain amount of variability both in materials as well as in constructional methods. This results in variation of strength from batch to batch and also within the batch. It becomes very difficult to assess the strength of the final product. It is not possible to have a large number of destructive tests for evaluating the strength of the end products and as such we have to resort to sample tests. It will be very

costly to have very rigid criteria to reject the structure on the basis of a single or a few standard samples. The basis of acceptance of a sample is that a reasonable control of concrete work can be provided, by ensuring that the probability of test result falling below the design strength is not more than a specified tolerance level.

The aim of quality control is to limit the variability as much as practicable. Statistical quality control method provides a scientific approach to the concrete designer to understand the realistic variability of the materials so as to lay down design specifications with proper tolerance to cater for unavoidable variations. The acceptance criteria are based on statistical evaluation of the test result of samples taken at random during execution. By devising a proper sampling plan it is possible to ensure a certain quality at a specified risk. Thus the method provides a scientific basis of acceptance which is not only realistic but also restrictive as required by the design requirements for the concrete construction.

The quality of concrete will be of immense value for large contracts where the specifications insist on certain minimum requirements. The efforts put in will be more than repaid by the resulting savings in the overall concreting operations.

The compressive strength test cubes from random sampling of a mix, exhibit variations, which are inherent in the various operations involved in the making and testing of concrete. If a number of cube test results are plotted on histogram, the results are found so follow a bell shaped curve known as "Normal Distribution Curve". The results are said to follow a normal distribution curve if they are equally spaced about the mean value and if the largest number of the cubes have a strength closer to the mean value, and very few number of results with much greater or less value than the mean value. However, some divergence from the smooth curve can be expected, particularly if the number of results available is relatively

small. Fig 11.1
and Fig 11.2 show the histogram and the normal distribution curve respectively.

The arithmetic mean or the average value of the number of test result gives no indication
of the extent of variation of strength. However, this can be ascertained by relating the individual strength to the mean strength and determining the variation from the mean with
the help of the properties of the normal distribution curve.

(*a*) Target mean strength of concrete
(*b*) Selection of water-cement ratio
(*c*) Selection of water and sand content
(*d*) Determination of cement content
(*e*) Determination of coarse and fine aggregate contents
(*f*) Actual quantities required for the mix per bag of cement

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CONCLUSION

- Concrete is the most rapidly used engineering material in the world of construction business. To achieve a high standard, high durability and an attractive building structure, the key is to obtain a quality concrete during a construction project.
- Too much water occupies space in concrete and on evaporation, voids are created in concrete, which reduces the concrete's strength and durability.
- The volume change in concrete results in crack formation and the factor which contributes the volume change is the permeability.
- Permeability is the contributing factor for volume change and water-cement ratio is the fundamental cause of higher permeability. Thus, the use of higher water-cement ratio – *permeability – volume change – cracks – disintegration – failure of concrete* is a cyclic process in concrete. Hence, for a durable and a high strength concrete, use of lowest possible water-cement ratio is the fundamental requirement to produce dense and impermeable concrete.

Quality control can be expressed as the application of the operational techniques and activities, which sustain the quality of a product or service to satisfy given needs

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