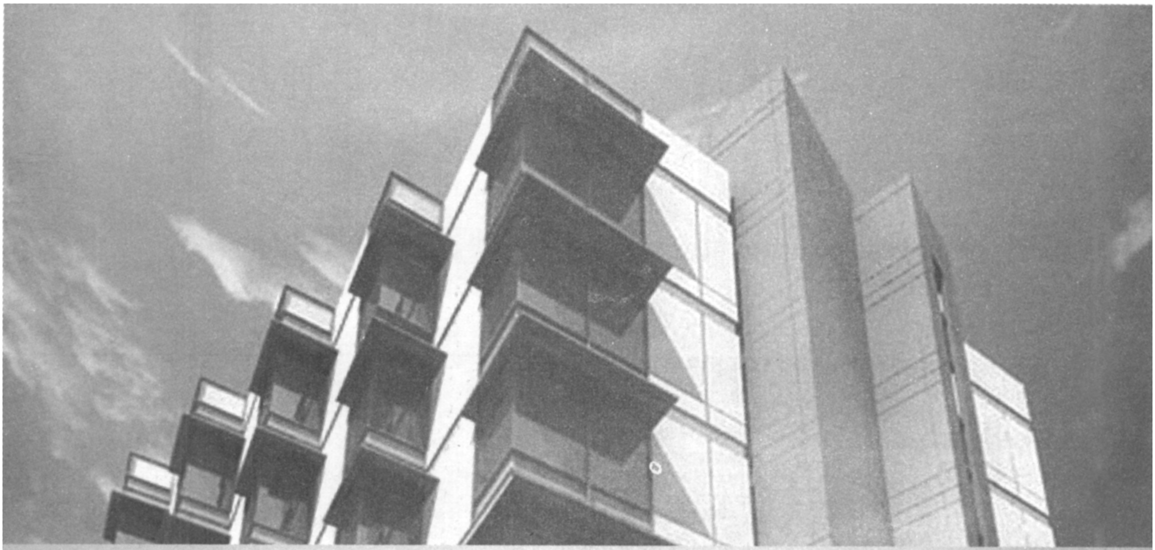

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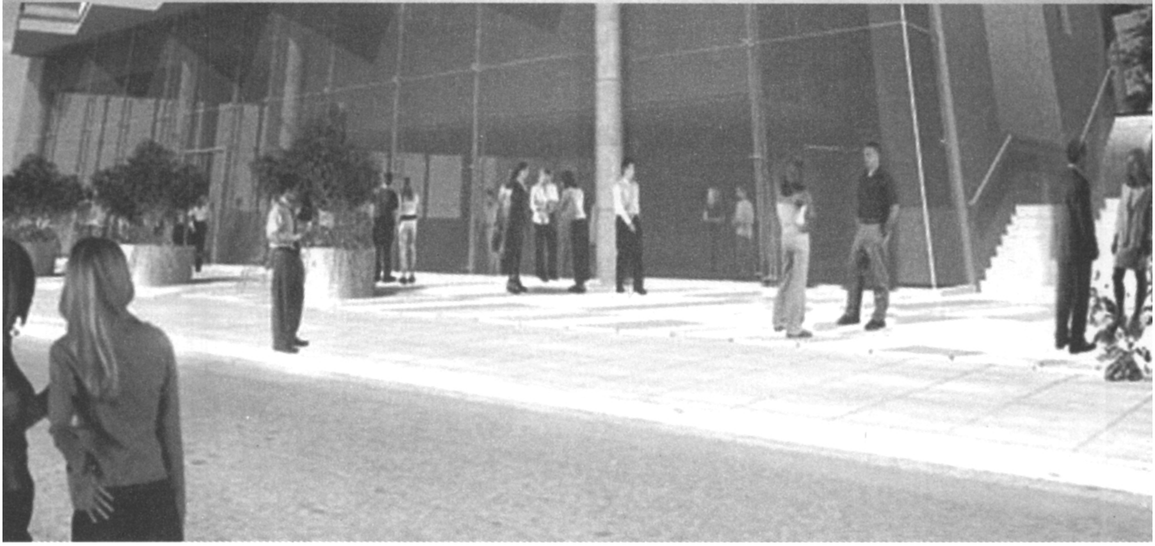
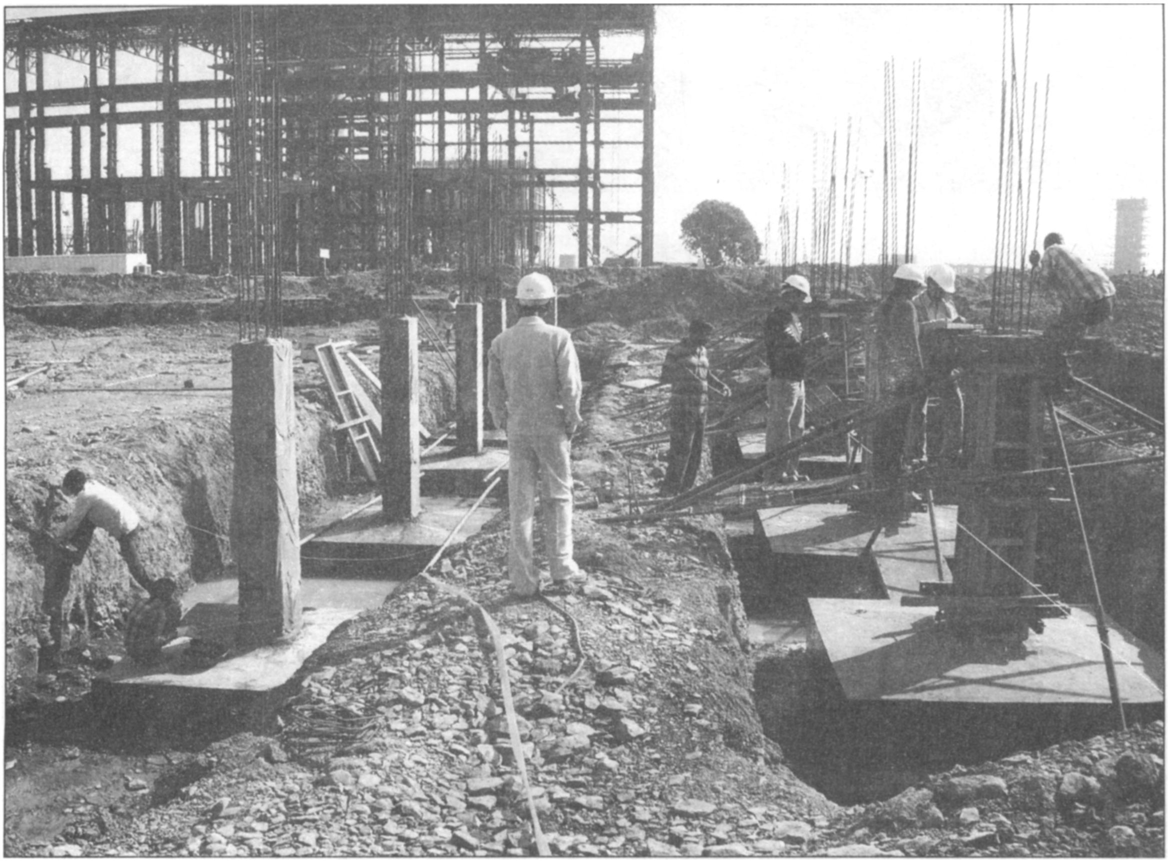




CHAPTER 1

# *Introduction to Cement Concrete and Quality Management*

## LEARNING OBJECTIVES

**The learner understands the importance of** cement concrete **and** quality management **in construction industry and will be able to:**

- Define **cement concrete;**
- Describe **historical development** of modern cement concrete;
- Describe **importance** of cement concrete in construction industry;
- Explain **failures** of concrete;
- Explain quality with reference to the concept of **concrete chain;**
- Explain the **importance of quality** management in construction;
- Explain the importance of studying the text in a particular **sequence.**

## 1.1 DEFINITION

Concrete may be defined as a **mixture of cement** (binding material), **aggregates** (inert materials-both coarse and fine), and **water,** which when mixed and placed in suitable forms and allowed to **cure** under appropriate conditions, **hardens like stone.** The chemical **reaction between cement and water** (hydration) results into **binding** of aggregates to form **"concrete"**- a superior construction material of great potential. **Cement, water** and **sand** forms **mortar** and fills the voids in coarse aggregate particles. The concrete gains strength and other related properties with curing and age. The process of hardening by curing results in gain of strength of concrete.

## 1.2 HISTORY

It may be noticed from the findings of ancient civilizations of Mohenjodaro, and Greek, that concrete and mortars were used in one or the other form in the construction. Later on Romans developed mortar and concrete leading to the present mortars and concrete. These construction materials came to a sound footing after the **advent of portland cement** by an English brick layer named **Joseph Aspdin in 1824.** With the research and scientific development, the cement concrete became one of the most important and **versatile construction material** being used all over the world. The present day cement concrete is a highly developed construction material and is used in almost all type of structures. With the advancement in technology, it is now possible to obtain cement concrete of wide range of properties (such as **strength, durability** and **resistance** to certain specific forces).

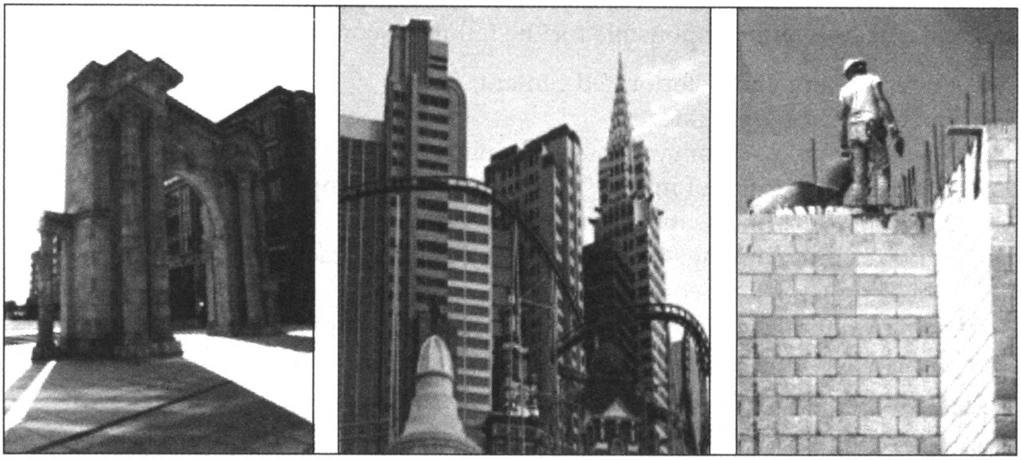
A few years ago when concrete technology was not understood well by engineers, technicians and contractors, cement concrete was being used as a simple construction material without exercising scientific principles for its quality control. Different ingredients were mixed in an adhoc manner without knowing and predicting the accurate behaviour of concrete so obtained. **It was Duff Abram who, by his finding of water-cement ratio law in 1919** changed the concept of concrete as a simple adhoc construction material to concrete as a **scientific construction material** with possibility of control on its **quality.** Since Duff Abram's statement of water-cement ratio law, lot of research has been carried out on the behaviour of concrete, its quality and ingredients in different situations.

As a result of these developments, the cement concrete construction was better understood and carried out based on sound scientific principles. Availability of scientific knowledge and data made it possible to **use cement concrete** extensively in variety of structures under **different environmental conditions** and for various uses. Cement concrete is used with proper **mix design,** provides a number of advantages over other construction materials in most of modern structures.

## 1.3 IMPORTANCE

Initially in India, the construction industry and the engineers have not taken advantages of research and scientific developments in concrete construction to its fullest extent due to lack of education and training facilities in concrete technology. Due to lack of knowledge and skill of supervisors and construction contractors have **wrong notion that greater the quantity of cement in concrete better will be the quality and strength of concrete.** For desired quality, strength and economy in concrete construction, it is necessary to study various aspects of concrete on scientific basis.

India is a developing country and it has launched five-year plans for multipurpose development projects in Agriculture, Industry, Mining, Transport, Power, etc. All these five year plans involve large construction of roads, bridges, dams, industries, dock and harbours, power houses, nuclear power plants, aerodromes, irrigation schemes, public health engineering schemes, educational buildings, residential building schemes and other public structures. All these constructions/schemes demand optimum and efficient use of construction resources. Most of modern heavy constructions require huge quantity of cement concrete. Thus for efficient and optimum use of construction resources, it is most important to study properties and behaviour of cement concrete. Proper knowledge and skill of cement concrete shall lead to lot of economy and quality in construction.



The good quality cement concrete construction has many advantages over other construction materials. Cement concrete can be produced for very high strength (as high as 40 N/mm$^2$) with ordinary portland cement of 33 grade and 80 N/mm$^2$ with other high strength cements of 43 and 53 grades and use of admixtures. Cement concrete provides possibilities of creating aesthetically beautiful structures (shells, folded plates). Concrete can be used for construction in very wide range of environments (extreme cold/hot weather, under water, chemically surcharged, and atomic reactors) with the use of **special admixtures** and special cements. Cement concrete can also be used in combination with other materials (**RCC** and **prestressed** cement concrete) for structures subjected to different type of forces. Cement concrete can also be advantageously used for **precast construction** to replace many conventional scarce and costly materials such as timber. Cement concrete constructions are used for **covering very large spans.** Due to its **impermeability** cement concrete construction is used for **water retaining structures.** Cement concrete constructions are **economical** in comparison to many other construction materials.

The civil engineers and technicians having complete knowledge, competency and skill in concrete construction stand good job opportunities in construction industries in public and private sectors. They also have good scope of starting and successfully running their own industry in precast concrete constructions and allied industries.

## 1.4 FAILURE OF CONCRETE

Many times structures fail due to failure of concrete. Such failures occur in following ways:

a) **Overstressing** of weak and/or porous concrete leading to structural cracks;
b) Improper location and formation of **construction and expansion** joints in concrete structures leading to cracks;
c) Failure of **reinforcement due to corrosion** caused by **insufficient cover** and **porous concrete**; and
d) Improper **form work fixing** and removal.

The main causes of failure of concrete are attributed to its poor **quality of ingredients** and/or **poor concrete practices.** Both these reasons are caused due to **ignorance and negligence** on the parts of supervisors and engineers. To avoid concrete failures, care has to be taken right from the **selection of ingredients** till hardened concrete is put to service. The following is the list of factors/causes mainly responsible for the failure of concrete constructions:

i. Use of poor quality and deteriorated cement;
ii. Use of poor quality aggregate;
iii. Use of poor quality and contaminated mixing water;
iv. Using too much quantity of mixing water for ease of compaction;
v. Lack of proper rigid and water proof formwork;
vi. Inefficient batching, mixing, transporting and placing practices;
vii. Improper and insufficient compaction;
viii. Improper formation and location of construction and expansion joints;
ix. Poor surface finishing and bleeding on the surface;
x. Lack of proper curing; and
xi. Fixing and improper removal of form work.

The failure of concrete can be understood easily through a concept of "**Concrete Chain**" shown in Fig. 1.1. Quality of a chain is attributed to the quality of its poorest or **weakest link.** Thus considering concrete as a chain, its **quality shall be determined by its weakest link** in the concrete chain. For achieving good quality of concrete, every link and stage shall be equally important and must be understood well.

To avoid failures of concrete, the engineers and supervisors/technicians should understand the behaviour of cement concrete and develop appropriate competencies in testing its quality. Properly constructed and supervised concrete structures serve functionally well for the designed life span of 50 to 100 years. It is, therefore, essential for engineers and technicians to undergo education and training in concrete construction for:

i. **Understanding the principles** of concrete technology and apply them during construction, supervision and testing;
ii. **Supervising and managing** concrete manufacture and construction;
iii. **Developing skills in selecting and testing** concrete ingredients and concrete for certain specific requirements;
iv. **Interpreting the test result** and accordingly modifying the concrete proportions or ingredients to suit the required quality and specifications; and
v. **Planning for quality and economy** in concrete construction.

**Fig. 1.1.** Concrete Quality Chain

## 1.5 QUALITY MANAGEMENT

Quality Management of concrete construction involves understanding of the principles of quality control as well as management. Management, in its simplest meaning is an act or manner of dealing **planning, controlling, directing** and **guiding people** or team involved in concrete construction to **achieve the desired properties.** Quality of concrete may be defined as the extent to which its **properties are met to satisfy the user's expected needs** and construction functions in a given situation. Thus, quality management in concrete construction is considered as **customer and environment focused,** concrete **property centred** and **good construction practice** based. Quality management in concrete construction is a continuous process of monitoring the properties to match the requirements of good construction practices and desired specifications at various stages to satisfy customer (user) and environmental needs.

Quality management involves following basic functions:

- **Design of concrete Mix** to suit user and environmental needs;
- **Testing and controlling** concrete materials and operations;
- **Directing, guiding and coordinating** construction **team** for correct practices.

Concrete mix design will require assessment of expected properties and specifications of concrete elements under expected environmental conditions and usage. Concrete mix design will also require testing and assessment of characteristic data of basic ingredients and admixtures for certain desired properties of concrete in a given situation. Concrete **mix design alone may not be enough** to achieve the desired quality of concrete construction but it also **requires guidance and coordination** of construction team.

As a first step to quality management in concrete construction, the team involved must be provided with continuing education and training to update their knowledge and skills of testing **concrete properties, factors influencing** the quality, and **correct procedures and characteristic data** on quality of cement concrete construction by adequate testing at various levels.

Another aspect in quality management is concerned with **identification and assessment of characteristics** of basic materials and admixtures of cement concrete. This requires testing of various ingredients and concrete (both plastic and hardened) for desired characteristics. Depending on the requirements these tests may be conducted in laboratory or field conditions at various stages. Design of concrete mix proportions must be done based on actual conditions and characteristics of materials. Trials must be carried out with the designed concrete mix to ensure the desired quality. Various steps to ensure quality of concrete constructions are dealt in subsequent chapters.

To ensure understanding and achievement of the desired quality of concrete construction, the text material on "Quality Management Of Cement Concrete Construction" is presented in a simple sequence as follows:

| | |
|---|---|
| 1 Introduction to Cement Concrete and Quality Management | Unit-I |
| 2 Basic Properties of Cement Concrete | |
| 3 Influence of Basic Ingredients on Quality | |
| 4 Influence of Special Admixtures on Quality | Unit-II |
| 5 Influence of Concreting Operations on Quality | |

| | | |
|---|---|---|
| 6 | Basic Principles of Cement Concrete Mix Design | Unit-III |
| 7 | Management and Statistical Quality Control Procedures | |
| 8 | Cement Concrete Mix Design Procedures | Unit-IV |
| 9 | Concrete Mix Quality Trials | |
| 10 | Quality Assurance Under Special Conditions of Placement | |
| 11 | Repair, Maintenance and Protection of Concrete Elements | |
| 12 | Tests for Quality Assurance of Cement Concrete | |

For optimum learning, the reader must study the text in the same **sequence** as developed on the **basis of scientific principles of learning.** The learner must also carryout practice tasks listed at the end of each chapter. Working professionals/engineers must also conduct practical tests for quality assurance as explained briefly in chapter 12. These tests can be conducted in the laboratory or at work-site as necessary.

Quality management of cement concrete construction will go a long way in reducing the wastages and failures and also enhancing the service life of concrete structures. Concrete construction forms a major component of every national development project and hence quality assurance in concrete construction will facilitate and accelerate development through savings and enhancement of service life of structures.

## 1.6 SUMMARY

Considering modern era of globalization and highly competitive world market, quality plays key role in every field. **Quality plays** even more **critical role in construction** industry where **wrong doings cannot be reversed at later stage.** Modern construction industry all over the world hinges around "cement concrete construction" and hence quality management of cement concrete construction plays key role in every country's development.

Cement concrete construction got established since the **advent of portland cement in 1824** and **Duff Abram's law of W/C ratio in 1919.** With further development of many **new materials and scientific principles** of technology and statistical quality, the **quality management of cement concrete construction** has acquired **central stage** in construction industry.

**Quality of concrete is determined by its weakest link.** Concrete fails due to: **over stressing** and **structural cracks, improper construction and expansion joints,** reinforcement **corrosion, poor workmanship** and **inadequate cover, improper formwork, poor quality materials, inadequate compaction** and **curing.**

Quality management involves **design of concrete mix** for a **specific situation and purpose, testing materials** and **controlling concrete operations,** guiding and coordinating construction team for correct practices. Quality assurance of cement concrete requires thorough understanding of **principles of concrete technology and management.** Continuous education and training of construction engineers and engineering students is essential for quality management of cement concrete construction.

## PRACTICE QUESTIONS

1.1 Define cement concrete in not more than 50 words.

1.2 Describe the basis of present development of cement concrete construction in about 100 words.

1.3 Describe the importance of cement concrete construction in development projects in about 100 words.

1.4 List factors leading to failure of concrete.

1.5 Explain the concept of concrete chain in relation to quality.

1.6 Explain the importance of quality management in construction.

## CHAPTER 2

# *Basic Properties of Cement Concrete*

### LEARNING OBJECTIVES

The learner **understands** the basic **properties of cement concrete** and will be able to:

- **List main properties** of cement concrete both in **plastic and hardened states**;
- **Explain importance** of **workability** in quality management of cement concrete construction;
- **Define** the terms of **workability, segregation,** and **bleeding** in concrete;
- **Explain** the steps of **controlling bleeding** in cement concrete;
- **List five methods** of **measuring workability** with limitation of each;
- **Explain slump test** for measuring workability;
- **Explain compacting factor** test for cement concrete;
- **Write short notes on Vee-Bee** degrees and flow in cement concrete;
- **List type of strengths** in cement concrete;
- **Explain inter-relationship** of compressive strength with flexural and bond strengths of cement concrete;
- **Explain durability** of cement concrete;
- **Explain resistance** of cement concrete **to chemical attack;**
- **Explain importance of impermeability** of cement concrete on its service life and quality;
- **Explain importance of dimensional changes** in cement concrete;
- **Explain** the concept of **elastic modulus** in cement concrete;
- **Differentiate** between **shrinkage and creep** in cement concrete;
- **Describe unit weight** of cement concrete;
- **Explain the importance of expansion** in cement concrete.

## 2.1 INTRODUCTION

Every construction project manager has endeavour to achieve the **best quality** construction at the **most economical cost.** Cement concrete construction forms a major part in most of the construction projects. In their endeavour to achieve quality and economy, all engineers, supervisors, contractors and technicians must understand the properties of cement concrete. Understanding of properties and behaviours exhibited by cement concrete at various stages will facilitate suitable control on quality of construction. Cement concrete has two distinct stages of construction viz. **fresh** (plastic) and **hardened** (solid). For achievement and control of quality of cement concrete construction, it is, therefore, essential to clearly understand the properties and behaviours in both stages and their inter-relationship.

## 2.2 PROPERTIES IN FRESH STATE

The properties during **fresh or plastic state** are very **important** as it is this stage that the control on the concrete can be exercised to obtain the desired behaviour even in the hardened concrete. The **properties cannot be modified** after hardening of concrete and necessary adjustments shall have to be done in fresh concrete only. Properties of fresh concrete during **plastic state** are thus very **important for the control of its ultimate quality** in hardened state. These properties in fresh state are:

- Good **Workability;**
- Freedom from **Segregation**; and
- Freedom from **Bleeding** and **Harshness.**

### 2.2.1 Good Workability

The **strength** of concrete of given mix proportions in its hardened state is seriously affected by the degree of its **compaction during plastic state.** It is, therefore, important for fresh concrete to have suitable consistency for **full compaction.** Due to proper consistency of fresh concrete, it is possible to transport, place, compact and finish concrete easily without causing segregation. This fresh concrete mix which can be transported, placed and **compacted easily without segregation** is said to be **workable concrete mix.** As found by research, the strength of hardened concrete directly depends on its density. To obtain **optimum density,** it is essential to **compact concrete fully** to drive away all entrapped air from fresh concrete. For this full compaction to take place easily, the concrete mix should be of such consistency that all particles can easily move closer with the available external effort to the remotest corner of formwork. Thus in simple terms, **workability is defined as the ease with which fresh concrete can be placed and compacted fully without segregation.**

The **workability** as merely ease of placement and resistance to segregation is too simple and will result in different workabilities for the same concrete mix depending on the type of structure, placing conditions and method of compaction. Thus, the workability should be considered as an important **physical property of fresh concrete** alone without reference to method of compaction and particular type of construction. For achieving compaction either by hand ramming or by vibration, the process essentially consists of the **elimination of entrapped air** from the concrete mix until it has reached as close a configuration as is possible in the given mix. In this process, the work is done to overcome the friction between the individual particles in the concrete mix (called **internal friction**) and also between the concrete and the surface of the mould or reinforcement (called **external surface friction**). Some work is also done (wasted) in vibrating the mould or already consolidated portion of concrete. Since only the **internal friction is an intrinsic characteristic** of the mix, workability can be scientifically defined as the **amount of useful internal work necessary to produce full compaction.**

It is not only important to study workability in achieving full compaction of fresh concrete but also very vital as far as finished hardened concrete is concerned. The concrete must have a workability such that **compaction to maximum density** is possible with reasonable amount of work under given conditions. From relationships between the degree of compaction (as measured by density ratio) and the resulting strength (as measured by strength ratio), the importance of compaction for finished concrete is quite evident. The degree of compaction is expressed as **density ratio,** i.e. a ratio of the **actual density** of given concrete to the **density of** the same mix if **fully compacted.** Similarly, the strength ratio is considered as the ratio of the strength of the concrete as actually (partially) compacted to the strength of the same mix when fully compacted. From the relationship, it is evident that even a small reduction in density due to presence of voids results into very large reduction in the strength. **Five percent of voids (density ratio 0.95)** can result into **lowering of strength by as much as 30%** (strength ratio about 0.70) and even **2 percent voids** can result in drop of strength of more than **10 percent.** Voids in concrete are either bubbles of entrapped air or empty spaces left after evaporation of excess water. The volume of these voids depend on water-cement ratio of the concrete mix. The air bubbles are governed by the grading of the fine particles in the mix and are more easily expelled from a wetter mix than from a dry one. It follows, therefore, that for any given method of compaction there may be a **optimum water content** of the mix at which the sum of the volumes of air bubbles and water space will be a minimum. At this optimum water content the highest density ratio of the concrete would be obtained. Optimum water may vary for different methods of compaction.

### 2.2.2 Freedom from Segregation

In general terms it is implied that workable concrete should **not segregate** i.e. it should be **cohesive.** However, strictly speaking the absence of a tendency to segregate is not included in the definition of a workable concrete mix. For full compaction, it is essential that there is no appreciable segregation. **Segregation** can be defined as **separation of the constituents** (specially coarse aggregate) of a heterogeneous mixture so as to make their distribution non-uniform. In cement concrete, the difference in the size of the particles and specific gravity of the ingredients are the primary causes of segregation. The aggregate used in concrete has coarser and finer particles in various proportions. When the proportion of **coarse particles** is comparatively **large than fine particles,** the coarse particles tend to segregate from the rest of the mortar. Apart from improper proportioning, the incorrect handling of mixed concrete during discharge, transportation, and placement as well as **overcompaction** may also cause the segregation. Segregation can be checked by suitable grading and by careful handling.

The segregation occurs in two ways. In the first, the coarser particles tend to separate out by travelling farther along the slope or by setting more than the finer particles. The second form of segregation occurs, particularly in wet mixes, by separation of grout (cement plus water) from the mix. For very wet and lean mixes, second type of segregation may occur. By proper grading of aggregates, the segregation can be controlled to a great extent. Another way of controlling segregation in concrete is by proper handling and placing concrete. The concrete should be placed as near its final position as possible to minimize the danger of segregation during motion of concrete ingredients through considerable height of chutes. For laying concrete through considerable heights or chutes, specially with changing direction, cohesive concrete mixes should be used for avoiding segregation. Adoption of proper procedures in handling of concrete shall help in reduction of segregation in concrete mix.

The separation of mortar from the coarse aggregate keeps the void unfilled and results into honey combing which causes decrease in density and ultimately reduction in strength of concrete. **Segregation can be prevented** by:

(i) Ensuring a certain **minimum proportion of finer** material in concrete mix;
(ii) **Properly grading** the aggregate;
(iii) **Controlling water** content in concrete mix; and
(iv) Adopting **correct handling** procedures.

Air entraining in concrete reduces the danger of segregation. Segregation is difficult to measure quantitatively, but is easily detected by visual inspection at site. A good information of cohesion of the mix is obtained by the flow test. Tendency of segregation in the mix can be observed by visual observation of coarse aggregate distribution in the concrete mix.

### 2.2.3 Freedom from Bleeding and Harshness

Bleeding is a form of segregation in which some of the water in the mix tends to rise to the surface of the freshly placed concrete. This is caused by the inability of the solid particles of the mix to **hold all of the mixing water** during their downward settlement in the process of compaction. This happens when the quantity of water in the mix is more than is necessary for the cement paste to lubricate the aggregate particles. **Over compaction** also causes the coarser materials to settle down forcing the water to rise up and appear at the surface along with some cement. **Bleeding** could also take place due to the coarsely ground cement or due to less fines in fine aggregate. The separation of water from cement and sand or separation of cement paste from the mortar allowing the water or cement paste to appear at the surface is called **bleeding.**

As a result of bleeding the top surface of concrete layer becomes very wet. If subsequent concrete layer is laid on this excessive wet layer of concrete, the surface water of bleeding is trapped in the concrete which results into **weak, porous** and **non-durable** concrete.

Finishing of top surface alongwith mixing of bleeding water causes a very **weak wearing surface.** This can be avoided by delaying finishing operation till evaporation of bleeding water. If evaporation from the surface is faster than the bleeding rate, it may cause plastic **shrinkage cracks.**

Sometimes, the rising water gets trapped on the underside of coarse aggregate particles or reinforcement, thus creating zones of poor bond. The water so entrapped leaves behind capillaries, resulting into **increased permeability.** Appreciable bleeding also causes increased danger of frost damage specially in thin slabs.

Bleeding need not necessarily be harmful if it is undisturbed and the surface water evaporates reducing the effective water/cement ratio of the mix. On the other hand, if the rising water carries with it a considerable amount of the finer cement particles, **laitance** will be formed at the surface. Such a **laitance** at the top surface of a slab will result into **porous and dusty surface.** If such a layer of laitance is formed between the consecutive layers of concrete, it will result in inadequate bond between the layers of earlier and freshly laid concrete. For this reason **laitance** should always be **removed** by brushing and washing the old surface.

The tendency of bleeding depends mainly on the properties of cement. Fineness of cement reduces the bleeding. Cements having high alkali content, and a high proportion of $C_3A$ or calcium chloride shall have lesser tendency of bleeding. **Rich mixes are less prone to bleeding** compared to lean mixes. Pozzolana and flyash addition to concrete reduces its bleeding tendency. Air entrainment also reduces bleeding so that finishing takes place faster.

It may be summarised that bleeding can be prevented by:

i. **Controlling the water** content;
ii. Using **finer grading of fine** aggregate;
iii. Using **finely ground cement**;
iv. Using **cements with higher alkali** and $C_3A$ content;
v. **Controlling compaction**;
vi. **Delaying finishing** operation; and
vii. Using **rich cohesive mixes.**

**Harshness can be defined as the resistance to surface finishing** of fresh concrete. Harshness is caused when the mix proportions contain too less fines along with too less mixing water. The quantity of fines is not enough to keep the mix cohesive and the quantity of water is not enough to lubricate or wet the surface of the aggregate particles to provide the desired workability. The workability of the concrete is very poor and there is no mortar or cement slurry available at the surface for finishing operation. Thus for the concrete mix to have good surface finishing qualities, it should be **cohesive, workable** and contain **just sufficient quantity of mixing water.** The fresh concrete mix should provide enough creamy mortar or paste at the surface during floating and finishing operation without causing bleeding or segregation. Harshness is generally observed in lean and dry mixes.

## 2.3 MEASUREMENT OF WORKABILITY

There is no unique test which can directly measure the workability. However, there are numerous methods of determining certain physical quantities which try to correlate workability to some extent. None of these methods is fully satisfactory although these provide useful guidance regarding variation in workability within certain limits. Since the **workability of fresh concrete plays important role in controlling quality of hardened concrete,** its measurement and control is of great significance.

The phenomenon of workability is associated with four concepts:

i. **Ease of flow;**
ii. **Cohesiveness** - Movement without tendency to segregate;
iii. **Prevention of bleeding**; and
iv. **Prevention of harshness.**

The concrete mix is said to be workable if it flows easily without segregation, or causing any bleeding and harshness. Various methods of measurement of workability takes into account some of these concepts. Following are the methods of measuring workability:

i. **Slump Test**

ii. **Compacting Factor Test**
iii. **Vee-Bee Test**
iv. **Flow Test**
v. **Remoulding Test**
vi. **Ball Penetration Test** (Kelly Ball Test)

In India the first four methods are used, out of which first two are the most common.

### 2.3.1 Slump Test

This test is used extensively at work sites all over the world. Although the slump test for workability of concrete is easy to carry out, but it does not measure the workability of concrete

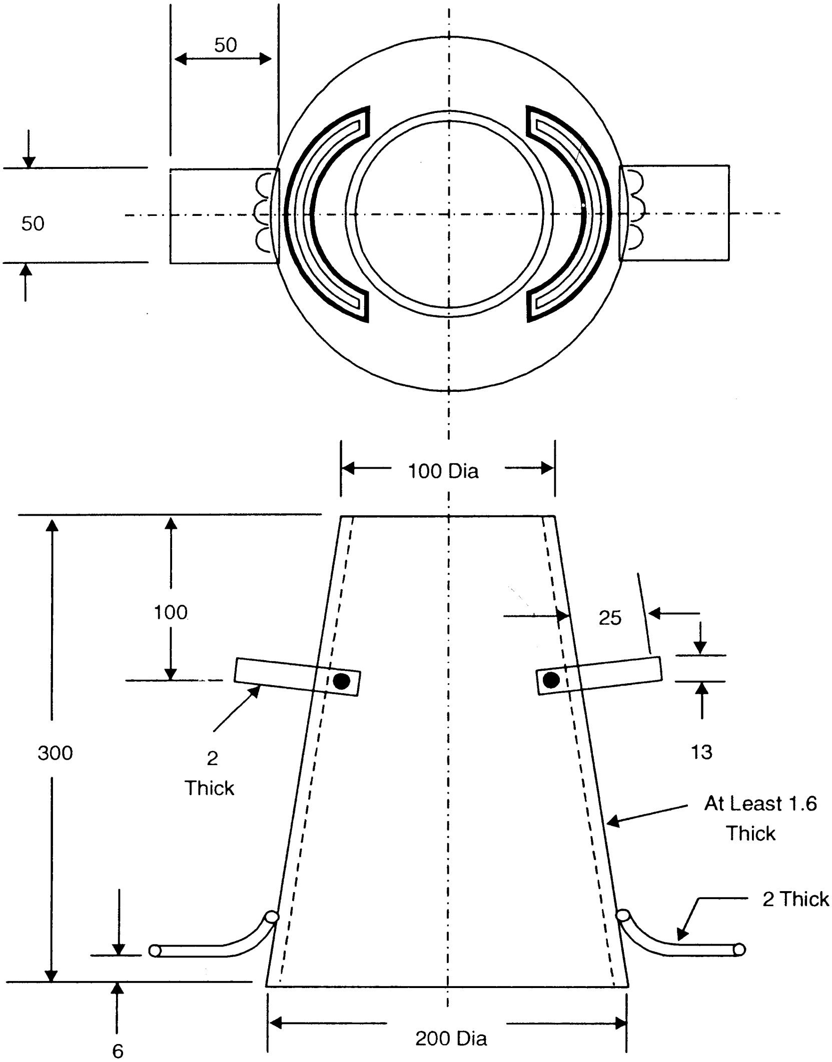


Fig. 2.1. Typical Mould for Slump Test (All Dimensions are in mm)

directly. This method is quite useful in detecting variations in water content and uniformity of a mix of given proportions.

The slump test is specified in IS:1199-1959 (Fig. 2.1). The slump test apparatus consists of a truncated cone having 100 mm top diameter, 200 mm bottom diameter, and 300 mm height. The cone is filled in four layers, each approximately one-quarter of the height of the mould. Each layer shall be tamped uniformly with 25 strokes of bullet pointed 16 mm diameter and 600 mm long tamping rod. Top surface of moulded concrete cone is struck off with trowel and finished quickly. The mould is then lifted gently and vertically. The laterally unsupported concrete settles under its own weight and hence the top surface subsides vertically. The vertical subsistence from the original top surface is called **slump** and can be measured with the help of scale in millimetre. In other words, **the decrease in the height of the highest top surface of the slumped concrete, is called slump.** For reducing the influence of the mould friction, the inside surface of the mould must be moistened or oiled before the beginning of every observation.

The concrete may slump as **true slump**, **shear slump**, or **collapse slump** (Fig. 2.2). Any slump specimen which collapses or shears of laterally gives incorrect result and if this occurs, the test shall be repeated with another sample from the same mix to confirm the tendency of the mix. If the observation repeats, the fact is recorded in the test results.

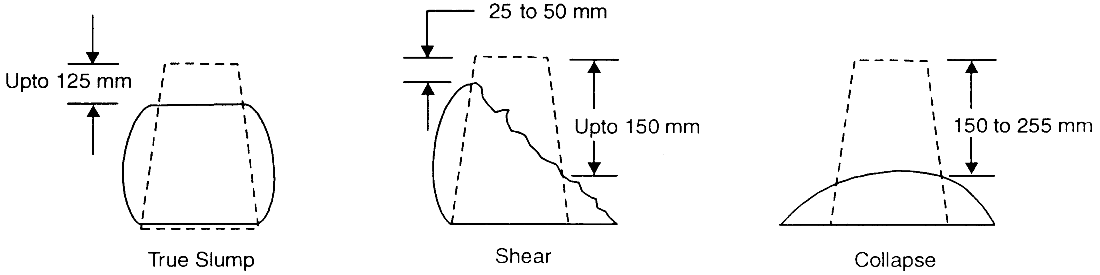


**Fig. 2.2.** Slump: True, Shear and Collapse

The test of cohesiveness and workability of the mix can also be obtained after completion of slump measurement. The steel plate base, of the moulded slump concrete cone after the slump test, is tapped gently with the tamping rod. The tendency of concrete cone to slump further can be observed. The concrete having appreciable slump may gradually slump further if it is cohesive and well-proportioned and may fall apart if it is poorly proportioned.

Concrete mixes of dry and stiff consistency have generally zero slump, and hence in such mixes the variation of workability cannot be detected in mixes of variable workability by using slump test. While in rich mixes of medium consistency, the slump test is quite sensitive to variation in workability and can be used for control of workability of the mix. In case of lean mixes with tendency of harshness, the slump may be true, collapse or shear pattern and indicate a vast variation even in the mix of the same workability. In some cases, the concrete mixes of different workabilities may show similar slumps. This makes the slump test unreliable in such cases. Thus there is **no unique relationship of slump and workability.**

Despite of these limitations, the slump test is the **most commonly adopted** test on the construction site to check variation in the quality and quantity of materials fed into the mixer. An increase in slump may indicate the increase in moisture content of aggregate or change in grading of aggregate (such as reduction in sand content or coarse grading). Thus sudden rise or fall in slump values, provide immediate warning to mixer operator to remedy the situation.

The procedure of conducting these tests may be studied in chapter 12 of this textbook.

### 2.3.2 Compacting Factor Test

Since the slump test has no direct relation with the internal energy required to achieve full compaction of concrete, other methods are developed to relate the external work applied to the internal work required for full compaction. The most reliable test developed so far uses the inverse approach i.e. the degree of compaction achieved by a standard amount of work is determined. The **compacting factor** is based on the principle that the work applied includes the **work against the internal friction** and surface friction. The work done against the surface friction can be reduced to a minimum by proper lubrication of the internal surface of the mould although, this surface friction also depends on the workability of the mix. The compacting factor test is a very useful measurement of workability (Fig. 2.3) to detect the variation specially in dry mixes.

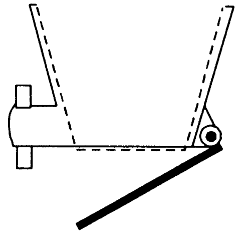
The **degree of compaction**, called the **compacting factor**, is measured by the **density ratio** i.e. **the ratio of the density actually achieved in the partially compacted concrete for standard amount of work to the density of the same concrete fully compacted.** In the test, the concrete is allowed to fall through a **standard height (203 mm)**, thus ensuring the standard amount of work. The compacting factor apparatus consists of the two conical hoppers (**A** and **B**) mounted above a cylindrical mould (**C**) **of 152 mm** internal diameter and 305 mm internal height (IS: 1199-1959). The distance between the bottom of lower hopper B and top of cylinder C is 203 mm. The compaction of concrete in cylindrical mould is produced by the destruction of kinetic energy of the falling concrete of standard weight from the lower hopper B to Cylinder C. The excess concrete is cut by sliding two steel floats or trowels across the top of the cylindrical mould and the external surface is also cleaned. The weight of partially compacted concrete in the cylindrical mould of standard volume is determined. The mould is emptied and then **refilled in four layers** of about 75 mm with the same concrete to achieve full compaction by heavy ramming or suitable vibration. Weight of this fully compacted concrete in the same standard cylindrical mould is determined.

The **ratio of weight of partially compacted concrete** by standard work and **weight of fully compacted concrete** of the same standard volume in the cylindrical mould represents the **density ratio** or **degree of compaction** and hence called **compacting factor.**

The compacting factor test is sufficiently sensitive to enable to determine the small differences in workability arising on account of the initial process in hydration of cement. Each test, therefore, should be carried out at a constant time interval after the completion of mixing to obtain comparable results. Generally the concrete from top hopper should be released after 2 minutes after completion of mixing of concrete.

The dry mixes will have a low degree of compaction and hence low value of compacting factor. **Low value of compacting factor indicates low degree of workability** and low slump too. The wet mixes have a high value of compacting factor and consequently represent high degree of workability and high slump.

The assumption that all mixes with the same compacting factor require the same amount of useful work is not always true. Similarly, the assumption that the wasted work represents a constant proportion of the total work done regardless of the characteristics of the mix is also not correct. Even with all these assumptions, the compacting factor test provides a good measure of workability.



View of Trap Door Partly Open

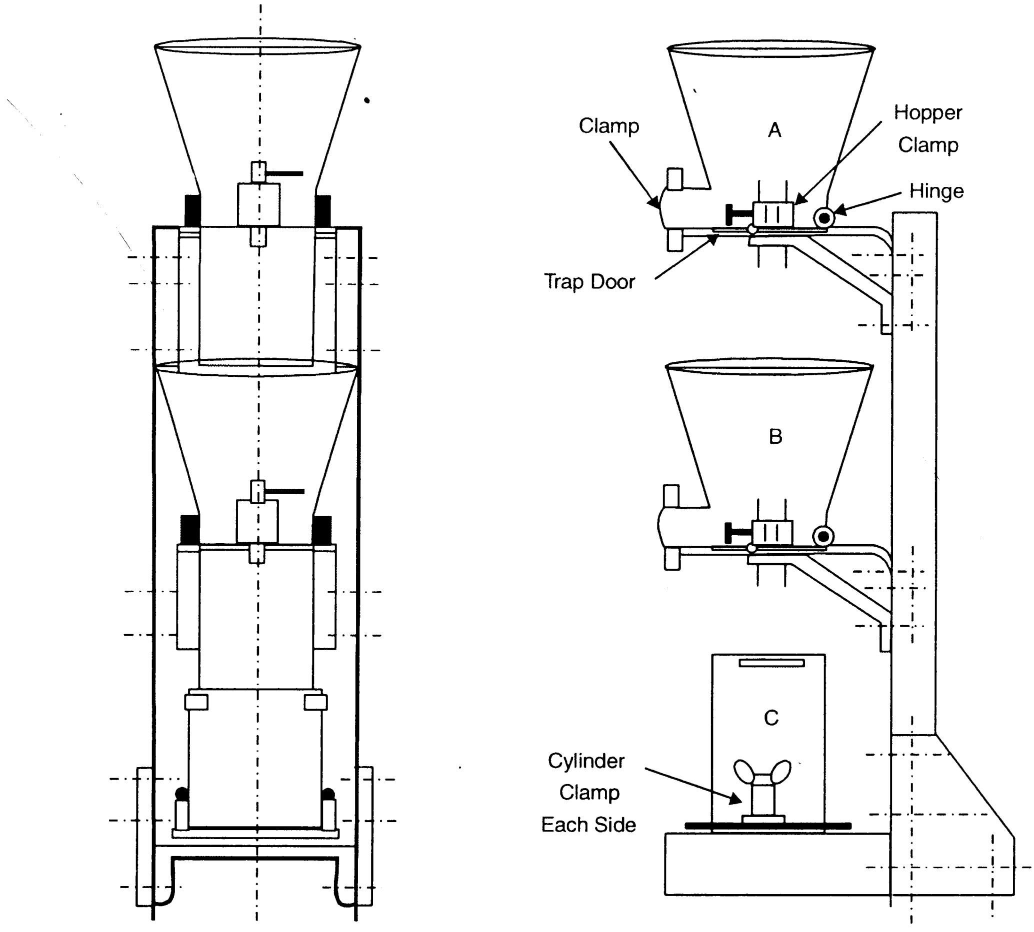


**Fig. 2.3.** Compacting Factor Apparatus

An automatic compacting factor test apparatus has been developed in which the cylinder is supported by a spring balance and can be calibrated for a given mix to read workability directly. The apparatus can also be calibrated to indicate the excess or deficiency of water in litres per batch or per cubic metre of concrete.

### 2.3.3 Vee-Bee Test

This test is developed using the principle of remoulding test with certain modifications in the apparatus and compaction by vibration instead of jolting. The apparatus was first developed by **V. Bahamer (Vee-Bee)** of Sweden.

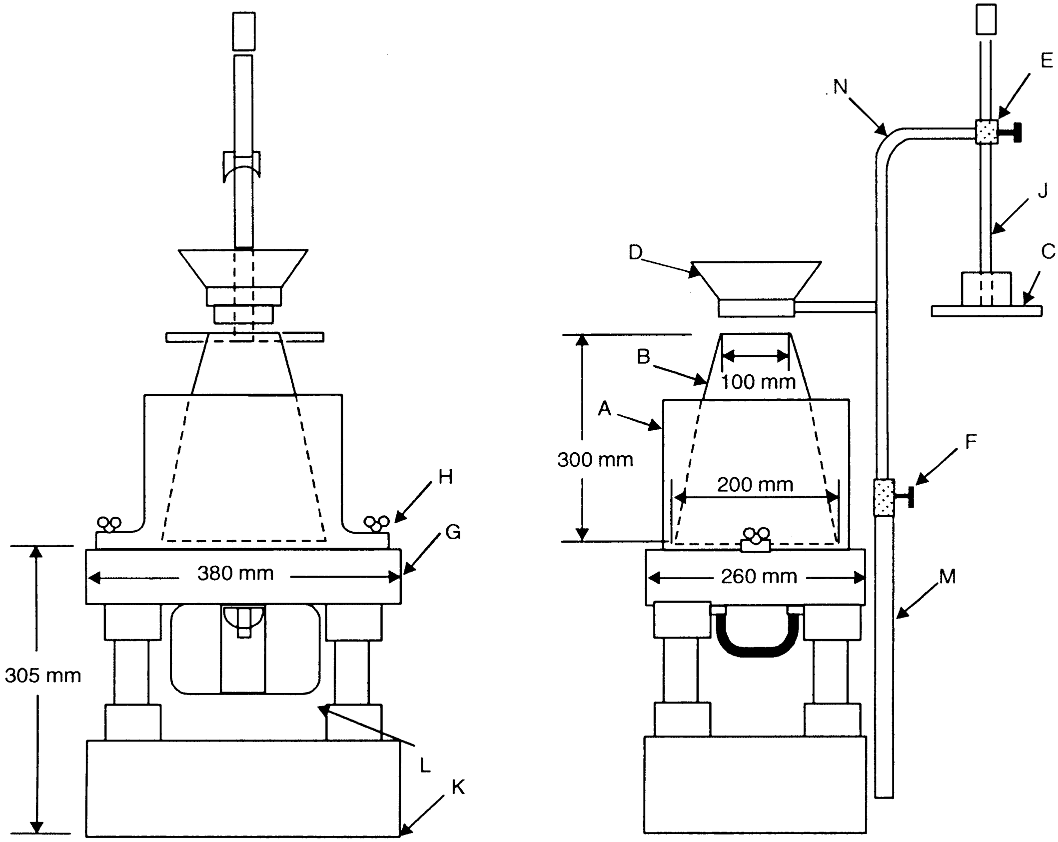


**Fig. 2.4.** VEE-BEE Consistometer

In Vee-Bee apparatus, **(Fig. 2.4)** time is measured in seconds for transforming a concrete specimen in the shape of conical frustum into a cylinder by vibration. The major components of the apparatus are (IS:1199-59):

a) Vibrating table resting on elastic spring supports (G)
b) Cylindrical metal container (A)
c) Sheet metal cone, open at both ends (B), Swivel arm holder (M) and Swivel arm (N) with funnel (D), glass disc (C) and guide-sleeve (E), and
d) Prime mover (electric motor)

Vibrating table (G) is 380 mm long and 260 mm wide and is supported on the rubber shock absorbers at a height of about 305 mm above floor level. The table is mounted on the base and is vibrated with a electrically operated vibrometer working on 220 volts three phase, 50 cycles alternating current. Sheet metal cone (B) is placed inside the metal cylindrical container (A) which is fixed on to the vibrating table with two holding nuts. The sheet metal cone (B) is 300 mm high and its diameter is 200 mm at the bottom and 100 mm at the top. The glass disc rider (C) is screwed at the bottom of the graduated rod (J). The rod scale (J) is used to measure the slump of the concrete cone and the volume of concrete after vibration into the cylindrical container. A standard rod of 20 mm diameter and 500 mm length is used to fill the slump cone by tamping in 4 layers.

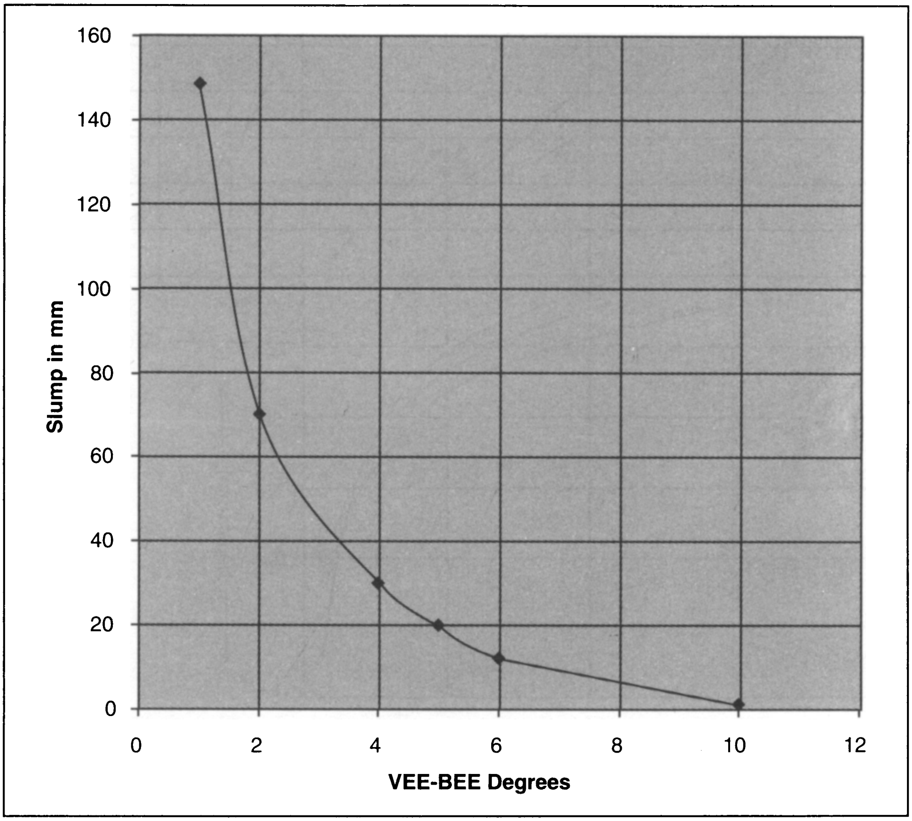


**Fig. 2.5(a).** Relationship between Slump in mm and Vee-Bee Degree

The glass disc rider is placed on the top of the slump cone in the cylindrical pot and the position of the disc rider adjusted and noted before filling the cone. The slump cone placed in the cylindrical container, is filled in four layers tamping with the standard iron rod (25 times each layer). The cone shall be lifted vertically and the slump noted on the graduated rod by bringing the glass disc rider in contact with the top of the concrete cone. The electric vibrator shall be switched on alongwith starting of the stop watch. The vibration shall be continued until the whole concrete surface makes full contact with the glass disc rider (representing completion of transformation and compaction of cylindrical mould from conical concrete mould).

The time taken for this operation is noted and recorded in seconds. This time in seconds is expressed as Vee-Bee degrees. The curve in Fig. 2.5 shows the relationship in slump and Vee-Bee degrees in seconds (SP23-1982). The consistency scale and Vee-Bee degree are also given in the Table 2.1.

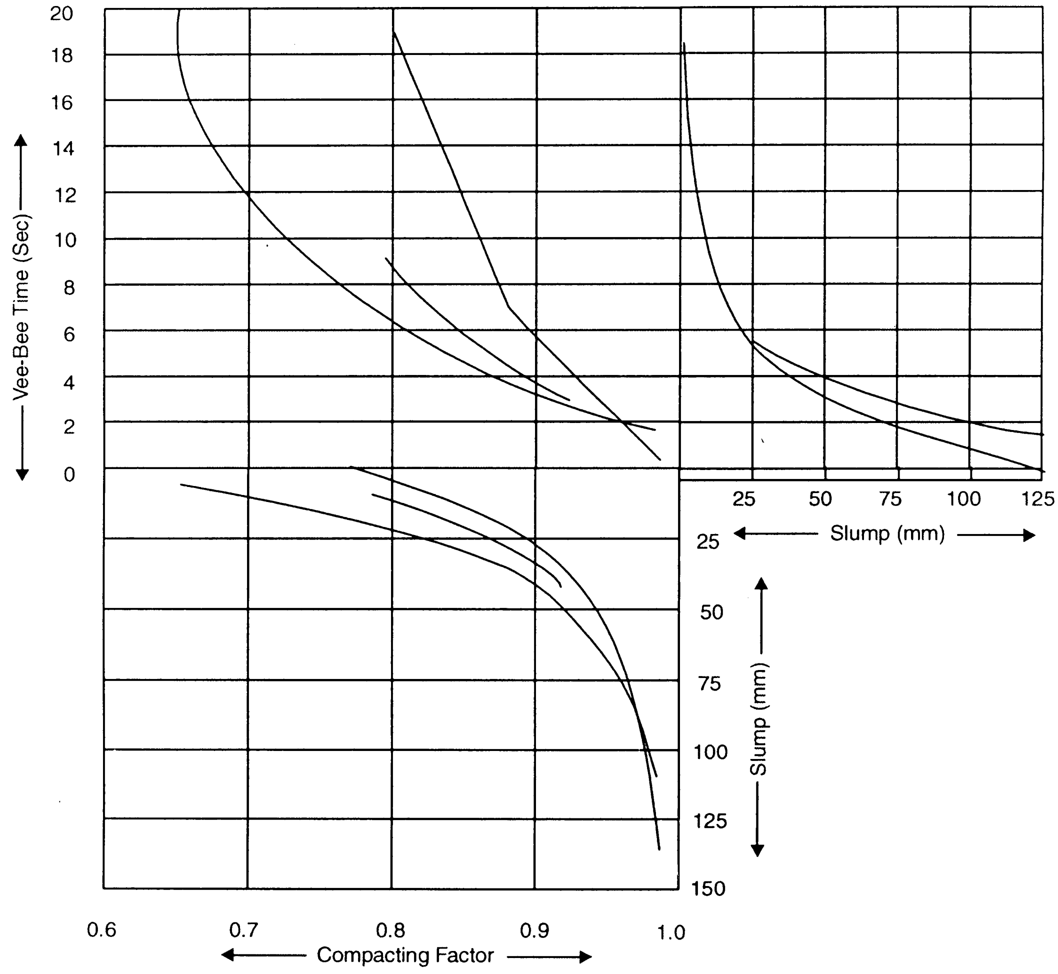


**Fig. 2.5(b).** Relationship between Slump, Compacting Factor and Vee-Bee Time for Concrete of Different Aggregate-Cement Ratios

The visual observation of glass rider for fixing the end point of compaction is some times the source of error. This may be over-come by fixing automatic device for recording time and the movement of the plate.

Compaction is achieved by using a vibrating table with an eccentric weight rotating at 3000 revolutions per minute and a maximum acceleration of 3 g to 4 g. It is assumed that the input of energy required for compaction is a measure of workability of the mix, and this is expressed in terms of time in seconds, i.e. the time required to remould the concrete cone specimen to cylinder. Some times a correction, for the change in volume of concrete from $V_0$ before to $V_1$ after vibration may be applied, by multiplying the time by $V_0$ / $V_1$.

Vee-Bee test is a good laboratory test, specially for very dry mixes. This is better than compacting factor test in which there is possibility of error due to tendency of some dry mixes to stick in the hoppers. The Vee-Bee test represents more closer treatment of concrete in relation to the method of placing actual concrete at work site.

**Table 2.1** Consistency and Vee-Bee Degrees (Ref. IS: 1199-1959)

| *Consistency* | *Vee-Bee Degrees (Seconds)* | *Characteristics* |
|---|---|---|
| Moist-Earth | 40 to 20 | Particles of C.A. in concrete are adhesive, but concrete does not clot. Risk of segregation. |
| Very Dry | 20 to 10 | Concrete has the consistency of very stiff porridge, forms a stiff mound when dumped and barely tends to shake or roll itself to form an almost horizontal surface when conveyed for a long time. |
| Dry | 10 to 5 | Concrete has the consistency of stiff porridge, forms a mound when dumped, and shakes or rolls itself to form a horizontal surface when conveyed for a long time. |
| Plastic | 5 to 3 | Concrete can be shaped into a ball between the palms of the hands, and adheres to the skin. |
| Semi Fluid | 3 to 1 | Concrete cannot be rolled into a ball between the palms of hands, but spreads out slowly and without affecting the cohesion of the constituents so that no segregation occurs. |
| Fluid | 1 to below 1 | Concrete spreads out rapidly and segregation takes place. |

### 2.3.4 Flow Test

This laboratory test gives indication of the consistency of concrete and its tendency to segregation by measuring the spread of concrete mould subjected to jolting. The flow test is of great value for segregation and it also provides good assessment of consistency of stiff, rich, and cohesive mixes. The test is useful to determine the fluidity of concrete, where the nominal size of aggregate does not exceed 38 mm. The test is covered in IS: 1199-1959. The apparatus consists essentially of a smooth brass top table of 762 mm diameter and shall be mounted on and bolted to a concrete base having a height of 400 to 500 mm and mass not less than 140 Kg. The table shall be so mounted that it can be jolted by a drop of 12.5 mm. The mould shall be made of a smooth metal casting in the form of the frustum of a cone with 250 mm bottom diameter, 170 mm top diameter, and 120 mm height. Top and bottom shall be open and at right angles to the axis of cone (Fig. 2.6).

The mould is placed at the centre of the table top and filled with concrete in two layers and each layer rodded by a standard tamping rod (16 mm diameter and 600 mm length with bullet pointed end) giving 25 strokes each. After compacting the top layer by rodding, the top surface of the concrete is struck off with trowel and all excess material removed and outside surface of the table cleaned. The mould is removed by lifting gently and vertically. The table is given 15 jolts in about 15 seconds by a wheel operating an actuating eccentric cam of 12.5 mm drop. The diameter of the spread of concrete shall be measured at 6 to 8 points and average diameter of spread noted.

The flow of concrete is defined as the percentage increase in the average diameter of the spread concrete (D mm) over the original diameter of the base (250 mm), i.e.

$$\text{Flow} = (\text{Spread diameter D in mm} - 250\text{ mm}) \times 100/250\text{ mm}.$$

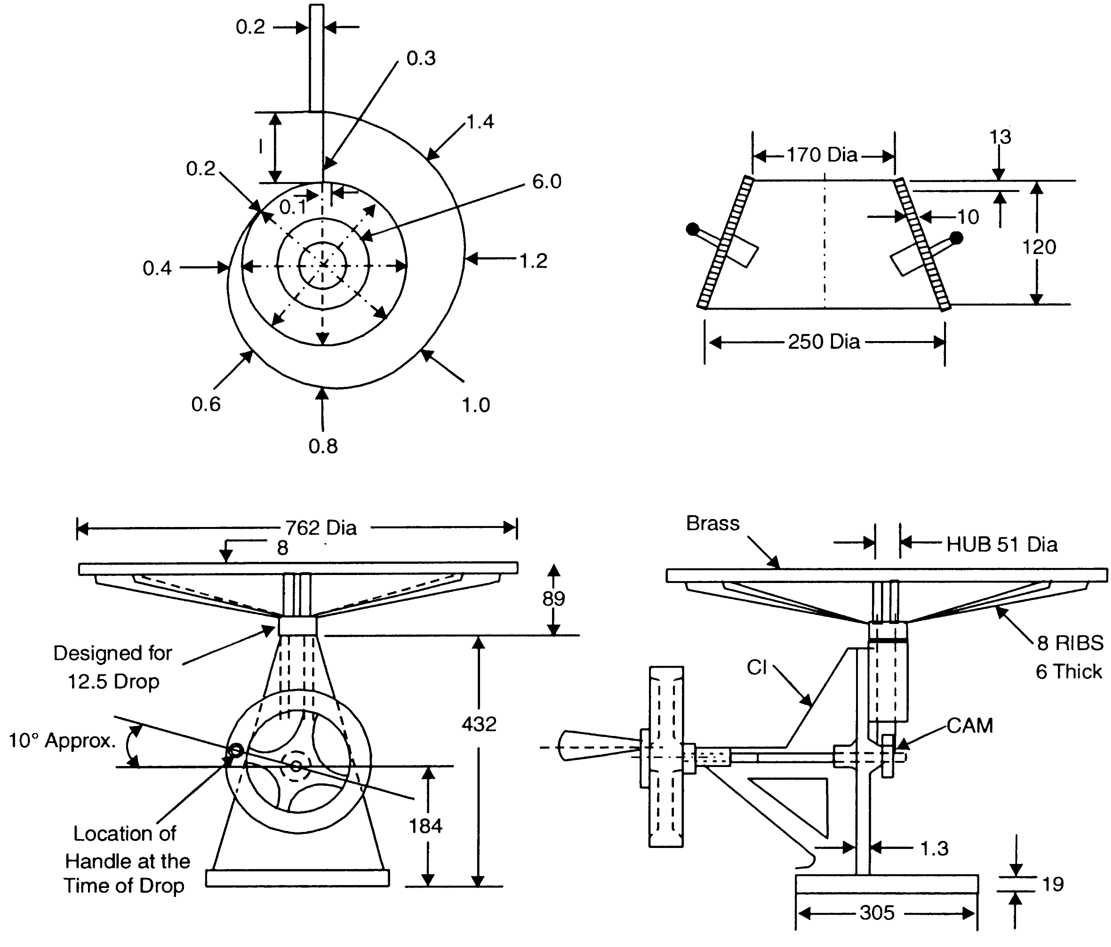


**Fig. 2.6.** Flow Table Apparatus (All Dimensions are in mm)

Values from 0 to 150 percent can be obtained. The jolting applied during the test induces the tendency of segregation, and if the mix is not cohesive the larger particles of aggregate will separate out and move toward the edge of the table. Another form of segregation may occur in sloppy mix where in cement paste tends to run away from the centre of table leaving the coarse material behind.

It may be noted that the flow-test does not measure the workability, as concrete having the same flow may differ considerably in their workability and also concrete with the same workability may differ in flow pattern. Flow test is specially useful in assessing the **tendency of segregation.**

## 2.4 PROPERTIES IN HARDENED STATE

Concrete in hardened state has following important properties:

- Strength
- Durability
- Impermeability
- Dimensional Changes
- Unit Weight

### 2.4.1 Strength of Concrete

The strength of concrete is defined as resistance to its failure against a system of loading. The strength of concrete is measured in various ways depending on loading pattern such as:

i. Compressive Strength
ii. Flexure Strength
iii. Bond Strength
iv. Resistance to Abrasion

All these strengths are influenced by certain specific factors and are also interdependent to some extent. The **cube crushing strength** is considered most important strength for identification of the concrete mix grade and quality.

*i. Compressive Strength*

It is the resistance of the concrete to **crushing.** Cement concrete has substantial compressive strength and forms a very important property for structural concrete. As per Indian Standards the crushing strength is measured as axial **load per unit area** at failure **on cubes of 150 mm** size at the **age of 28 days** and is specified in **N/mm$^2$.** This strength is used to specify the grade of concrete (such as M10, M15, M20, etc).

Using portland cements, concrete can be manufactured with compressive strength ranging from **10 N/mm$^2$** to **40 N/mm$^2$.** By using specially selected cement, admixtures, and other materials, concrete of compressive strength **60 N/mm$^2$** or even more can be obtained. Sometimes very lean concrete needed for mass concreting and base of foundations may have compressive strengths as low as 4 N/mm$^2$. In building construction concrete having compressive strength of **15 N/mm$^2$** (M15 grade) or **20N/mm$^2$** (M20 grade) is normally specified. For roads and bridges, structural concrete of compressive strengths ranging from 20 to 40 N/mm$^2$ (M20 to M40 grades) is generally specified. Higher grades of concrete (M30 to M60) are specially suitable for pre-stressed structures while concrete grades of M20 to M25 are commonly used for RCC structures.

**Compressive strength** of concrete is important because other strengths such as flexure, bond and abrasion resistance improve with increase in its compressive strength and it is also comparatively easier to measure compressive strength of concrete. From the quality control point of view the compressive strength of concrete is accepted as the main criterion for the acceptance of the quality of structural concrete. The ultimate failure under the action of a uniaxial compression is either a tensile failure of cement crystals or of bond in a direction perpendicular to the applied load, or a collapse caused by the development of inclined shear planes.

The compressive strength of cement concrete mainly depends on:

- the **type, quality** and **quantity** of cement;
- the **type, size, shape, strength** and **grading** of aggregates;
- the **water-cement** ratio;
- the degree of **workability** and **compaction**;
- the **type, quality** and **age** of **curing**;
  - the **shape** and **size** of specimen; and
  - **rate of loading** and condition of the specimen at the time of loading.

### *ii. Flexural Strength*

The resistance of concrete offered to tension under flexural loading (bending) is called its flexural strength. Cement concrete is comparatively **weak in tension.** Generally the flexural tensile strength of cement concrete is about **one-eighth** to **one-tenth** of its compressive strength. It is difficult to measure direct tensile strength and hence flexural tensile strength is commonly measured. The flexural tensile strength is slightly higher than the direct tensile strength because in the latter case there is no surrounding adjacent under-stressed material layer to stop the fracture. In fact the strength of the concrete, is to be considered as the strength of its weakest element. Hence the flexural strength is considered as the resistance to cracking under flexural loading. This flexural stress in concrete at the time of cracking is also called **modulus of rupture.** It is observed that there exists a relationship between tensile stress at cracking in flexure and compressive stress at cracking in direct compression specimen. This ratio is generally equal to Poisson's ratio of concrete and may vary from 0.11 to 0.21.

For optimum utilization of cement concrete in RCC structures, the **concrete is designed to resist most of compressive forces,** while **steel is designed to resist most of tensile force** under flexural loading. For simplicity, **the tensile resistance of cement concrete is neglected,** being small. Tensile strength of concrete becomes important in the design of concrete roads, airfield pavements, and concrete pipes.

Flexural tensile strength of concrete is affected greatly by the shape and texture of the aggregates. Other factors which generally influence the compressive strength of concrete also affect the flexural strength. The concrete with angular crushed aggregate offer more flexural strength in comparison to rounded smooth gravel due to better mechanical bonds in the former. The **ratio of tensile strength to its compressive strength decreases with age** of concrete and also with increase in its grade. According to IS: 456-2000, the flexural strength ($f_{cr}$) in **N/mm$^2$** can be approximately determined from the relation to its characteristic compressive strength ($f_{ck}$) in **N/mm$^2$** given as

$$\mathbf{f_{cr} = 0.7\sqrt{f_{ck}}\ N/mm^2} \qquad \text{(Ref: § 6.2.2 of IS 456-2000)}$$

### *iii. Bond Strength*

The structural concrete is used, along with steel in reinforced cement concrete elements. The strength of bond between the two materials plays an important role for the strength of RCC elements. Bond arises primarily from friction and adhesion between concrete and steel, and may also be affected by the shrinkage of concrete relative to steel. The property of **adhesion (grip) between steel and concrete is called Bond.** Bond also involves the mechanical properties of the concrete.

In general terms, bond is related to the quality of the concrete, and the compressive strength of concrete. The bond strength is approximately proportional to compressive strength upto certain grade of concrete. For higher grades of concrete, the proportionate increase in bond strength becomes progressively smaller in comparison to increase in compressive strength. It may be stated that **better the compressive strength of concrete, better will be the bond** strength. The property of bond strength of concrete is very useful in the design of reinforced cement concrete and other structures.

### *iv. Resistance to Abrasion*

The resistance of concrete to abrasion can be determined in several ways by simulating a mode of abrasion which occurs in practice. The simulation of the real condition of wear is not easy and it is also difficult to establish the relation of test results and the actual resistance of concrete to the type of wear. In all tests the **loss of weight of the specimen due to wear is** considered as a **measure of abrasion.**

In one of the method of the steel ball abrasion test, a load is applied to rotating head separated from the specimen by steel balls. The eroded material is removed by flowing water. Another method of dressing wheel test uses a drill press modifies to apply a load to rotating dressing wheels in contact with the specimen. Silicon carbide is used as an abrasive material. The dressing wheel and the steel ball tests estimate to relate the resistance of concrete to wheeled and heavy foot traffic in actual situation.

The **resistance to abrasion** of concrete is generally found to be **proportional to its compressive strength** and it is normally assumed that the concrete with high compressive strength has better resistance to abrasion. The resistance to abrasion is also influenced by the **type and shape of aggregate** in addition to the factors which are responsible for affecting the compressive strength of concrete. Softer aggregate results in greater wear in concrete in case of steel ball, and dressing wheel tests. While harder aggregate tends to splinter in the shot-blast type of test and causes a greater loss of weight representing higher wear.

Actual concrete which bleeds very little has a stronger surface layer and therefore, offers more resistance to abrasion. For concrete to develop high resistance to abrasion, proper moist curing is essential. The resistance to abrasion also improves with the use of medium, coarse and hard aggregate in concrete.

### 2.4.2 Durability

Durability of the concrete is defined as the **resistance to deterioration and disintegration against weathering** agencies in the environment and the conditions for which it has been designed to withstand over a period of time. The absence of durability may be as a result of either the external environment of concrete or by internal causes within the concrete itself. The external causes can be **physical, chemical,** or **mechanical** and may be created by **weathering,** occurrence of extreme temperatures, abrasion, electrolytic action and attack by natural or industrial liquids and gases. The internal causes are the **alkali-aggregate reaction, volumetric changes** and **permeability** of the concrete. Deterioration of concrete takes place, generally, due to more than one causes and it is difficult to isolate and assign one single specific cause. Permeability of concrete makes it prone to attack by various agencies:

Durability comprises of:

- Resistance to weathering;

- Resistance to chemical attack;
- Resistance to corrosion of steel; and
- Resistance to high temperature;

### *i. Resistance to weathering*

This mainly refers to the effect of hot and cold weather on concrete. As the temperature of saturated hardened concrete falls below freezing point, the water held in the capillary pores freezes to **ice crystals and expands in volume.** This creates expulsion of some pore water through creation of **pore water passages and cracks.** With increase in temperature above freezing point, these pore water crystals melt. Refreezing of pore water takes place with temperature falling below freezing point again. These alternate cycles of freezing and thawing exerts radial pressures on capillary pores and results in disruption and disintegration of concrete. If the pressure exerted by freezing of pore water exceeds the tensile strength of concrete, then it causes severe damage by **cracking and disintegration** of concrete. These damages are more severe in case of exposed surfaces and where salts are used for de-icing the concrete surface such as concrete roads in cold climates. These pores exist in concrete due to **presence of excessive mixing water** which has not reacted fully with cement particles to form hardened concrete.

Although the resistance of concrete to frost attack depends on its major properties (such as strength, extensibility, and creep), the factors responsible are **degree of saturation** and type of **pore structure** of cement paste. Concrete with high **water-cement ratios** are generally **more porous** and therefore, offers less resistance to frost attack. Concrete with **low water-cement ratios** are generally **more dense and strong** if compacted properly. Such concrete will have lesser pores, and therefore, offers better resistance to frost attack. The **resistance** to frost attack **increases with the age** of concrete due to increase in strength and reduction in capillary pores due to hydration of cement.

The conditions of exposure of concrete are also important. The greater the exposure of concrete with the moisture, greater will be the attack of frost. Road slabs, kerbs, retaining wall, bridge decking, railing, piers and external concrete walls are completely exposed to weather and frost attack, and therefore, these must be constructed to have better resistance to weather and higher strengths. For exposure conditions of severe frost attack, the concrete with air entraining agents should be used. **Air entraining agent develop very large number of minute air bubbles** (approximately 0.5 mm size) which act as barrier and absorber for pore water pressures and thereby reducing disintegration and disruption of concrete structure. Air entraining is done by use of animal and vegetable fats, natural wood resins, alkali salts of organic compounds (such as Darex).

The effect of hot weather on hardened concrete is not generally severe as compared to cold weather. Effect of hot weather is quite undesirable on fresh concrete. During very hot weather the pore water near concrete surface may partially be converted into vapour and evaporate leaving behind porous surface. This porous surface may allow ingress of external air and moisture, and thus cause damage to steel reinforcement near the surface.

The important ways to **improve the weathering resistance** of concrete are summarized as:

- **Low water-cement ratio** for obtaining high strength and dense concrete;
- **Proper compaction** for obtaining dense concrete;
- **Appropriate grading** of aggregate for maximum density;

- Continuous **moist curing** over a longer period; and
- Suitable **air entraining** in concrete for high workability and better resistance to frost attack.

### *ii. Resistance to Chemical Attack*

Concrete made with ordinary cement has low resistance to chemical attack. The common sources of chemical attack are: leaching out of cement, and the action of sulphates, seawater, and natural acidic waters. The resistance of concrete to chemical attack varies with the type of cement used. The resistance of concrete increases in the following order with use of different cements:

- Rapid hardening and ordinary portland cement;
- Portland Blast Furnace Slag Cement, and Low Heat Portland Cement;
- Supersulphated Cement; and
- High Alumna Cement

Solid salts generally do not attack concrete, but sulphate salts of magnesium, sodium and calcium, when present in solution react with hardened cement paste of concrete. Some clayey soils contain magnesium and calcium sulphates, and hence the ground water in such a place is a sulphate solution. The sulphate reacts with calcium hydroxide **$Ca(OH)_2$**, and calcium aluminate hydrate ($C_3A$) present in the cement concrete. The products of the reactions, gypsum and calcium sulphoaluminate, have a much greater volume than the compounds which are replaced. These reactions with sulphates lead to expansion and volumetric instability and hence disruption of concrete.

Some of these reactions such as sodium sulphate, magnesium sulphate are given below:

$$Na_2SO_4.10\,H_2O + Ca(OH)_2 = \underset{\text{(gypsum)}}{CaSO_4.2H_2O} + 2NaOH + 8H_2O$$

$$\begin{aligned}3(Na_2SO_4.10\,H_2O) + 2(3CaO.Al_2O_3.12\,H_2O) = {} & 6NaOH + 2Al(OH)_3 + 17H_2O \\ & + 3CaO.\,Al_2O_3.\,3CaSO_4.\,31H_2O \\ & \text{(Calcium sulpho aluminate)}\end{aligned}$$

Calcium sulphate attacks only calcium aluminate hydrate and forms calcium sulphoaluminate hydrate. Magnesium sulphate attacks calcium silicate hydrate as well as calcium hydroxide and calcium aluminate hydrate. These reactions are given as under:

$$3(MgSO_4.\,7H_2O) + 3CaO.\,SiO_2 = 3(CaSO_4.\,2\,H_2O) + 3Mg(OH)_2 + SiO_2 + 12H_2O$$

$$\begin{aligned}3(CaSO_4.\,2H_2O) + (3CaO.\,Al_2O_3.\,12\,H_2O) + 18H_2O = {} & (3CaO.\,Al_2O_3.\,3CaSO_4.\,36H_2O) \\ & \text{(Calcium sulpho aluminate)}\end{aligned}$$

$$\begin{aligned}3(MgSO_4.\,7H_2O) + 2(3CaO.\,Al_2O_3.\,12\,H_2O) = {} & 3CaO.\,Al_2O_3.\,3CaSO_4.\,31H_2O + 3Mg(OH)_2 \\ & + 2Al(OH)_3 + 8H_2O\end{aligned}$$

The reaction of magnesium sulphate is more severe than other sulphates. The rate of sulphate attack depends on the concentration of the solution. The concentration of the sulphates is expressed as the number of parts by weight of **$SO_3$** per million (PPM). 1000 PPM of sulphates is considered moderately severe and 2000 PPM is very severe, especially if magnesium sulphate is the main constituent.

Concrete exposed to the pressure of sulphate bearing water on one side, the attack will be maximum. Similarly alternate drying and saturation with sulphate bearing water also leads to faster deterioration of cement concrete. When the concrete is buried in the ground and there is no flow of sulphate bearing water, the condition shall be less severe.

Concrete attacked by sulphate has a characteristic whitish appearance on the surface. The damage starts at edges and corners and progresses by cracking and spalling which reduces concrete to a friable or even soft state.

The resistance of cement concrete to chemical attack can be improved by using cements having a low proportion of tri-calcium aluminate (**$C_3A$**). Cements containing less than 7 percent of **$C_3A$** can be considered to have fairly good resistance to sulphate attack. Proportion of **$C_3A$** can be reduced by suitably adjusting the raw material oxides during the manufacturing process to obtain sulphate resisting cement. Improved resistance to sulphate attack can also be obtained by the addition of, or partial replacement of cement by pozzolanas (such as flyash, slag and surkhi). Sulphate resisting cements are blast furnace slag cement, low heat portland cement, Portland pozzolanic cement, sulphate resisting portland cement, and supersulphated cement.

The resistance of concrete to sulphate attack also depends on its impermeability quality. Concrete must be dense and rich. High cement content and low water-cement provides better resistance to sulphate attack and hence higher durability.

### *iii. Resistance to Corrosion of Steel*

Good quality concrete provides good protective coating around steel reinforcement. The **alkalinity** of cement concrete leads to the formation of a thin invisible **protective oxide film** on steel reinforcement. The calcium hydroxide liberated during the hydration of cement reacts with **$CO_2$** from the atmosphere to form calcium carbonate. This process of carbonation increases the shrinkage on drying and tends to promote the development of cracks. The **carbonation also reduces the alkalinity** which reduces the effectiveness of the protective film. Soluble chlorides such as NaCl or $CaCl_2$ reduce the effectiveness of the alkaline protective film on steel.

To achieve good protection against corrosion of steel, sufficient thickness of cover of good quality (dense and impermeable) concrete should be provided. The **concrete cover** should not allow **ingress of moisture and air** which are necessary for corrosion of steel to occur. In porous concrete, the reinforcement is likely to corrode quickly. On **corrosion the volume of steel increases** and this causes concrete cover to crack and further increase the process of corrosion by providing easy ingress of moisture and air.

Sands containing salts if used in concrete, absorb moisture from air and cause efflorescence and weaken the concrete cover leading to ingress of moisture to steel reinforcement. Use of sea water or water containing **sulphates and chlorides** beyond certain permissible limits in cement concrete **causes volumetric instability** and unsound porous concrete cover to steel. This results into corrosion of steel. **Chlorides accelerate corrosion** of steel to some extent.

The inadequacy of reinforcement may also cause cracks in concrete cover, thus allowing the moisture to reach steel for initiating corrosion. The **permeability** of concrete is the most important factor which affects the process of **corrosion of steel** reinforcement due to ingress of water. All factors which reduces the permeability of concrete are also responsible to improve the resistance of concrete to corrosion of steel. Thus the concrete should be prepared with **low water-cement ratio** and **well compacted** to achieve high density and high strength to provide better resistance to corrosion of steel.

### *iv. Resistance to High Temperature and Fire*

Fire introduces high temperature gradient in concrete, and as a result the hot surface layers tend to expand and separate from the cooler interior layers. This encourages the formation of cracks near joints in poorly compacted parts of concrete, or in the planes of reinforcing bars. Once the reinforcement is exposed, it further accelerates the action of heat by conduction.

The effect on the strength of hardened concrete is small and irregular upto temperatures of 250°C. The concrete strength decreases with higher temperatures beyond 300°C. In some cases the concrete strength around 800°C remains only 20 to 25 % of its original strength. Leaner mixes suffer relatively lower loss of strength compared to rich mixes. Flexural strength is more severely affected than compressive strength of concrete. Concrete containing aggregate with no silica, suffer lower loss of strength. Low conductivity of concrete improves its fire resistance and hence **light weight concrete** with low thermal conductivity, offers **better fire resistance** as compared to ordinary dense concrete.

The concrete changes in colour at various temperatures and hence from the colour of concrete, maximum temperatures during fire and the residual strength can be estimated to assess the damage done by fire. Cement concrete becomes **pink or red during temperature range from 300 to 600°C** while it turns **grey or buff beyond 600°C.** The concrete whose colour has changed to pink or red due to fire is doubtful, while concrete that has changed beyond the grey stage shall be friable and porous. Such behaviour of concrete is important in atomic reactors, chimneys, and furnaces.

### 2.4.3 Impermeability

The **resistance** of the concrete to **passage of moisture** or flow of water through its body (pore spaces) is called **impermeability.** For good compaction, good workability is necessary and hence certain quantity of water more than that essential for complete chemical combination with cement is used. This excess mixing water occupies space and evaporates later and on drying leaves behind pores in concrete. In addition to these, there are air voids also. All such pores allow water flow through them and makes concrete permeable. The movement of water through the body of concrete can be caused not only by a pressure head of water but also by **humidity differential** on the two sides of concrete or by **osmotic effects.** Both the cement paste and the aggregate contain pores. In addition, the concrete as a whole contains voids due to incomplete compaction or bleeding. Since the paste envelops the aggregate particles, it is the permeability of the cement paste which has maximum effect on the permeability of concrete.

The pores in cement paste comprises of **gel pores** (about 28%) and **capillary pores** (0 to 40%) depending on W/C ratio and degree of hydration. The permeability of cement concrete is not a simple function of its porosity, but it depends also on the size, distribution, and continuity of the pores. Water can flow easily through the capillary pores than through the much smaller gel pores. Therefore, the **permeability** of cement paste is controlled mainly by the **capillary pores** of the paste. The permeability of cement paste reduces with the progress of hydration due to increase in volume of hydrated gel (about 2.1 times) compared to the volume of the unhydrated cement and thus filling the original water spaces. In mature paste the permeability depends on the size, shape and concentration of gel particles and on whether or not the capillaries have become discontinuous. **Permeability is lower** with higher cement content i.e. **lower Water-Cement ratio.** It is generally observed that there is steep reduction in permeability below a Water-Cement ratio of 0.60. This is due to creation of discontinuity in capillary pores.

The properties of cement, especially its fineness, also effects the permeability initially at an early age due to degree of hydration, but ultimate permeability may not differ. In general, it may be stated that higher the strength of concrete, lesser will be the permeability except when the shrinkage of cement causes rupture in the gel between the capillary pores and thus open new passage for water.

**Impermeability forms** a very important factor for the **durability** of any concrete. The impermeability or the resistance to the penetration of water increases the resistance to weathering (frost attack), and resistance to chemical attack. The resistance to ingress of water and air through concrete cover to steel, protects steel from corrosion. Thus for durability of exposed structures, water retaining and hydraulic structures, the property of impermeability in concrete plays very vital role. Thus for **better impermeability** of concrete, it is necessary to have cement concrete with:

- **Low water-cement ratio** for minimum capillary pores;
- **Sound, dense and well graded aggregate** for minimum voids and pore spaces;
- **Proper compaction** for minimum voids and maximum density;
- Adequate **continuous moist curing** at low temperature to ensure proper hydration of cement for minimum capillary pores and shrinkage cracks.

The permeability of concrete can be measured by a simple test. In this test the rate of water flow through a given surface area and given thickness is measured under a given water head. The permeability is expressed as **coefficient of permeability** (K). K is measured in mm/sec.

### 2.4.4 Dimensional Changes

The cement concrete elements also undergo change in dimensions under various conditions of loading, temperature changes, and cement hydration. Various dimensional changes in concrete members occur due to:

- Elasticity
- Shrinkage
- Creep, and
- Thermal Changes

#### *i. Elasticity*

When concrete specimen is loaded it undergoes deformation. On removal of load, the deformation disappears to some extent. This portion of deformation which disappears on unloading is known as elastic deformation. This property of concrete by virtue of which **deformation occurs on loading and disappears on unloading** is called elasticity of concrete. Concrete does not exhibit the perfect elasticity property with higher and sustained loading. Concrete may be considered **elastic within certain limits only.** The **elasticity** is measured by modulus of elasticity and is defined as the change of stress with respect to elastic strain (unit deformation). It can be calculated as:

$$\text{Modulus of Elasticity} = \text{Unit Stress/Unit Strain}$$

It represents the resistance of concrete to deformation.

From a stress-strain diagram of concrete specimen loaded in compression, it is observed that within working stress (initial portion) the stress-strain curve is straight line to some extent (Fig. 2.7). For higher stresses, the stress-strain relationship becomes curved. The modulus of elasticity is generally applicable to this **initial straight portion of stress-strain diagram.** In case, there is no straight portion, the modulus of elasticity (tangent modulus) may be considered as **slope of tangent to the Stress-Strain Curve at the origin.** Tangent modulus of concrete may also be determined as slope of tangent to stress-strain curve at any other point of stress but such a value shall be useful only for those loads which are very near the loads at which the modulus has been measured.

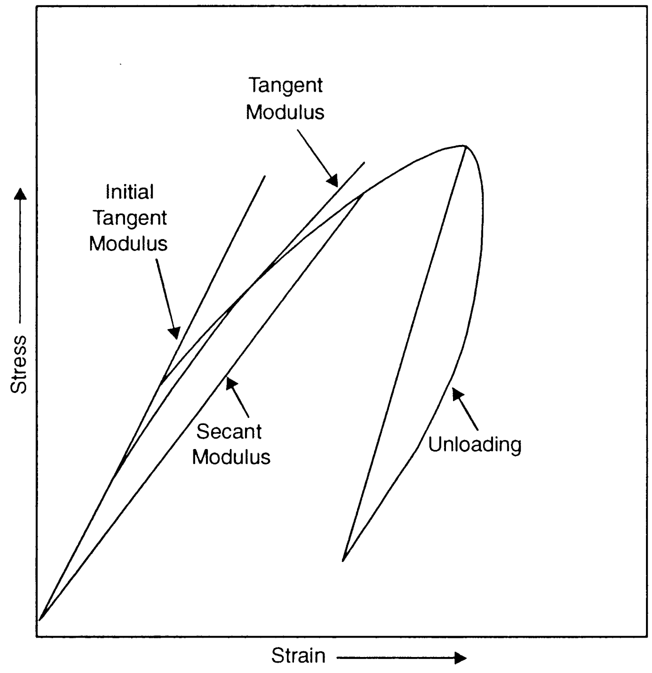


**Fig. 2.7.** Typical Stress-Strain Curve for Concrete

The deformation in concrete increases with time (i.e. with sustained loading) and the stress-strain relation does not remain straight with respect to total strain but remains approximately straight with respect to **initial instantaneous strain** (considered as elastic). The increase in strain with time under sustained loading is due to **property of creep** in concrete. Another method of measuring elastic modulus in concrete is by way of "**Secant Modulus**". The secant modulus is represented by the slope of a line drawn from the origin to any point on the curve at a certain standard stress or strain.

Many concretes exhibit a slight curvilinear relation of stress-strain even at working loads. The tangent modulus cannot be determined accurately because the stress-strain curve and tangent are drawn only by eye judgment. The secant modulus is the most practical and commonly used because there are no uncertainties in actual deformation. The secant modulus may be measured at stresses ranging from **15 to 50% of its ultimate strength.** The secant modulus decreases with an increase in stress level and hence the **stress level at which the modulus has been determined, should always be stated.** Secant modulus is determined from the experimental stress-strain relation. The secant of stress-strain curve on unloading is often parallel to the initial tangent to the loading curve. The **secant modulus** is also known as **static modulus.**

Repeated loading and unloading reduces the creep in subsequent loadings and the stress-strain curve becomes straight after 3rd or 4th loading. In **dynamic modulus** of concrete, the specimen is subjected to a **very small stress** and the modulus so obtained is similar to tangent modulus at zero stress, and therefore higher than any Secant Modulus. The dynamic modulus of elasticity takes into account mainly the elastic strain only.

The concrete exhibits a peculiar phenomenon that the maximum strain at failure in compression is higher for the lower grades of concrete while at lower stress than ultimate strength, the higher concrete grades show higher deformations. This is because the strength of cement paste is governed by the gel/space ratio. Generally the secant modulus of elasticity, as **measured at a stress of 15 to 50% of ultimate strength,** is higher in case of higher grades of concrete in comparison to lower grades of concrete. The **ratio of static to dynamic modulii** is also higher for higher grades of concrete.

The modulus of elasticity of concrete increases approximately with the **square root of its characteristic strength,** although the modulus of elasticity is influenced by the saturation condition of the specimen. Modulus of elasticity is also affected to some extent by the nature of aggregate and by the mix proportions. The modulus of elasticity of concrete is not affected by temperature upto about 23°C. The value of modulus of elasticity for concrete generally varies from **50,000 N/mm$^2$** to **30,000 N/mm$^2$.**

As per IS: 456-2000, the static modulus of elasticity of concrete ($E_c$) is approximately related to its characteristic cube strength (**$f_{ck}$ N/mm$^2$**) as:

$$E_c = 5000\sqrt{f_{ck}}\ \text{N/mm}^2 \qquad \text{(Ref: § 6.2.3.1 of IS 456-2000)}$$

Dimensional changes occur due to loading of concrete members due to the property of elasticity of concrete. Concrete also exhibits property of lateral strains due to application of longitudinal stresses. **Within elastic limits the ratio of the lateral strain to longitudinal strain is called Poisson's ratio and varies from 0.10 to 0.25** for concrete. Most common values lie between **0.15 to 0.20.** It is higher for lower grades of concrete in most cases.

Generally the factors which **increase the modulus of elasticity** for concrete are summarized as:

- **Low water-cement** ratio
- **Richness** of mixes
- **Longer curing** periods
- Quality, type and **grading of aggregate**

### *ii. Shrinkage*

The volume of concrete specimen also changes during the hydration process in cement (i.e. reaction of cement with water). The evaporation and change in water content of the mix also causes change in volume of the concrete. The chemical combination of cement and water results in reduction of volume causing shrinkage in concrete. Some times cement reacts with certain aggregate (reactive aggregate) and causes large expansion. The concrete in general, **shrinks on drying and expands on wetting.**

Cement, after hydration, consists of crystalline material plus calcium silicate gel resulting from the combination of cement and water. The quantity of the gel increases with the age of hydration and is greater for higher water-cement ratios and for finer cements. The quantity of gel also depends on the chemical composition of the cement, because **hydrated dicalcium silicate is mostly** gel, while hydrated **tricalcium silicate** is more than half gel. For most commonly used water-cement ratios in concrete, **the gel occupies larger volume than crystalline portions.** The gel is finely porous and undergoes larger volume changes on wetting and drying and thus the quantity of **calcium silicate gel determines the extent of shrinkage** upon drying of hydrated cement. Water is held in the pores of the gel and the concrete is subjected to some moisture volume changes.

While in the plastic state, **fresh concrete undergoes an appreciable reduction in volume.** This occurs due to settlement of the solids and bleeding of free water to the top where it may be lost by evaporation. Most of this settlement and bleeding occurs within an hour or so after placement of concrete. This total volume change may be **about 1%** and is not of great importance, as the concrete is still in a plastic or semi plastic state.

The **products of hydration** have a **lesser volume** than the total volume of the original components (i.e. **cement plus water**), and hence the **cement gel shrinks** as the hydration continues. After the cement paste has set, the solids form a structure having system of pores containing free water. The total volume of hardened solid mass expands, due to formation of new solids and expansion of gel although the volume of cement plus water decreases. The free water available in the pores and loosely held water in the gel is utilized by continuation of hydration of cement. The loss of water from the gel causes the **gel structure to contract**, resulting in decreased volume of the concrete mass. With the two contradictory factors of expansion and contraction in volume of concrete, the contraction becomes more dominant at later stage of hydration. Thus concrete exhibits the property of **shrinkage** (i.e. reduction in volume with hydration of cement).

Various factors which influence the behaviour of a particular concrete are:

- Cement **composition and fineness** (affecting the nature, rate and products of hydration);
- Quantity of **mixing water and water-cement ratio** (affecting the rate of hydration, porosity of paste, and free pore water);
- Type, nature and **grading of aggregate** (affecting the rate of hydration, porosity of the paste and free pore water);
- **Temperature** and moisture conditions (influencing the rate and quality of hydration);
- Absorptiveness of forms (affecting the moisture movement during the plastic stage);
- **Age of concrete and curing** method (affecting the extent and rate of hydration);
- Use of **admixtures** (affecting the rate, and products of hydration); and
- Quantity and distribution of reinforcement (affecting the volumetric strains and resistance to deformations).

It is observed that the shrinkage is mainly affected by physical structure of the cement gel. **Higher** the aggregate-cement ratio, **less is the shrinkage** of concrete. With lower aggregate-cement ratio (i.e. for richer mixes) the concrete exhibits about 50% higher shrinkage compared to lean mixes after about 4 months keeping the same water-cement ratio. Aggregate containing clay particles increases shrinkage. Similarly, higher the water-cement ratio, greater is the shrinkage. Although cement composition and fineness of cement has sufficient effect on shrinkage of neat cement paste but there is minor effect in case of shrinkage of concrete. Total shrinkage of concrete made with aluminous cement is not much different from ordinary portland cement concrete except that it is much faster in case of aluminous cement concrete.

The addition of calcium chloride increases shrinkage by 10 to 15% due to faster gel formation. It is generally observed that the concrete made with portland pozzolana cement exhibits about **20% lesser shrinkage** after 4 months than the concrete made with ordinary portland cement. The concrete prepared **with low heat portland cement** exhibits 20% more shrinkage than ordinary portland cement concrete due to slow strength gain.

Prolonged moist curing delays the shrinkage and also reduces the shrinkage cracking because of increased strength of concrete. In fact the shrinkage of neat cement paste increase with the hydration of all the cement grains but the strength also increases. The age of curing does not affect shrinkage too much.

The final magnitude of shrinkage is largely independent of the rate of drying. Very rapid rate of drying does not allow the relief stress by creep and hence may lead to initial cracking. The relative humidity of the medium surrounding the concrete greatly affects the magnitude of shrinkage. Shrinkage increases with lesser relative humidity during curing.

The shrinkage is determined with the help of frame fitted with a micrometer gauge or extensometer or strain gauges using concrete bars. Drying of surface occurs more than the inside and hence causes differential shrinkage which shall be dependent on the size and shape of the specimen, being a function of the surface/volume ratio.

If the concrete is placed in water (or at a higher humidity) after drying in air at a relatively lower humidity, it will swell and part of the shrinkage (0.30 to 0.60 of the drying shrinkage) gets reversed. If drying is accompanied by carbonation, the cement paste becomes insensitive to moisture movement and the residual shrinkage is more. It has been observed that **$CO_2$** present in atmosphere reacts, in the presence of moisture, with hydrated cement compounds. **$Ca(OH)_2$** changes to calcium carbonate **($CaCO_3$)** and other cement compounds are also decomposed. Carbonation is accompanied by shrinkage. Carbonation shrinkage is maximum at 50% relative humidity. **Alternate wetting and drying** in air containing **$CO_2$**, carbonation shrinkage increases progressively and also results in **increase of irreversible shrinkage** and crazing on the surface of concrete. **Carbonation** of concrete also **results in increased strength** and reduced permeability.

The shrinkage varies with mix proportions but in general, **total shrinkage** may be assumed as **0.0003** for most of the concrete. It may be noted that half of the total shrinkage occurs during the first month and that about **three quarters of the total shrinkage** takes place in the **first six months.**

The shrinkage before the concrete sets can be minimized by prevention of water absorption by form work and by proper prevention of evaporation. **Shrinkage during setting** is mainly because of **cement gel**, and can be minimized by:

- Keeping quantity of **cement to a minimum;**
- Keeping water-cement ratio and **water-content minimum;**
- Maintaining **adequate humidity** around concrete during curing and keeping minimum exposed surface;
- Using a **coarse grading of sand,** and avoiding over sanding and excessive silt;
- Using **non-porous aggregate** capable of resisting compression and change of volume;
- Providing suitable and well **distributed reinforcement** which may reduce shrinkage cracking by 50%;

- Curing under **low temperatures and maximum humidity** and avoiding sudden change of humidity;
- Placing **suitable** contraction and expansion **joints** in large slabs, roofs, roads, and wall.; and
- Using admixtures which reduce the water requirement but do not affect the strength.

The property of shrinkage is important in structures which cannot expand and contract freely. It is also **important** in structures with large exposed surfaces from **durability, impermeability,** and **strength** point of view.

### *iii. Creep*

The relation of stress and strain is dependent on time. The strain continues to increase with time for the same stress. This **increase in strain under sustained loading** is called **creep.** Creep may be several times as large as the elastic strain obtained on loading. Creep in concrete is due to yielding of concrete which may be caused by viscous flow of the cement-water paste, closure of internal voids, crystalline flow in aggregates and seepage of colloidal (absorbed) water from the gel formed during hydration of the cement. Seepage of colloidal water from the gel is the major cause for the creep. The rate of expulsion of the colloidal water is a function of the applied compressive stress, and the friction in the capillary channels. The greater the stress, the higher the rate of moisture expulsion and deformation. The phenomenon is associated with that of drying shrinkage.

Under normal conditions of loading, the instantaneous strain recorded depends on the rate of loading and the strains include part of creep in addition to the elastic strains. The modulus of elasticity increases with age, but generally its value is measured initially only. The creep is therefore, for convenience considered as an increase in strain above the initial elastic strain. Creep occurs similarly under both compressive and tensile stresses in concrete.

When the loaded concrete specimen is also drying, it undergoes shrinkage as well as creep strains which are both additive. Creep is calculated as the difference between the total time deformation of the loaded specimen and the shrinkage of similar unloaded specimen stored under the similar conditions through the same period.

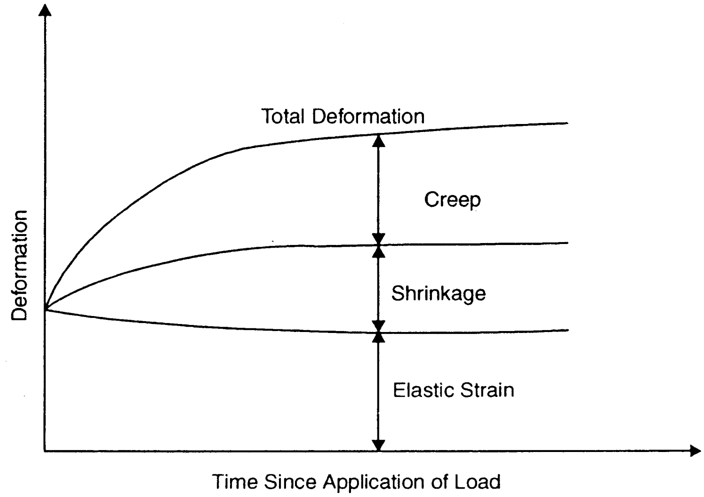


**Fig. 2.8(a).** Time dependent deformation in concrete subjected to a sustained load

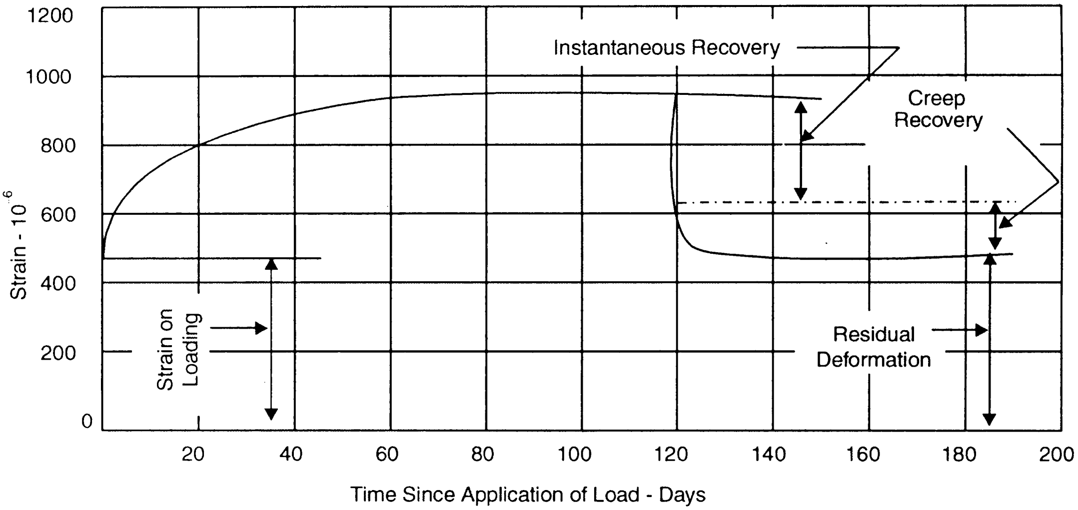


**Fig. 2.8(b).** Creep and recovery of a mortar specimen stored in air at a relative humidity of 95%, subjected to a stress of approx. 15 $N/mm^2$ and then released

The rate of creep is relatively rapid at early ages after loading and then decreases gradually, until after a few years it becomes negligible. About **one-fourth** of the ultimate **creep** occurs within **first month**, and **one-half** occurs within the **first year.** On releasing of the sustained load, the strain decreases immediately equal to elastic strain of the given age, generally less than the initial elastic strain. This instantaneous recovery is followed by a gradual decrease in strain, called creep recovery. The creep recovery occurs much rapidly. The creep recovery is not complete, and creep is not a fully reversible phenomenon (Fig. 2.8 (a).and (b)).

It is observed that the greater the degree of hydration of cement at the time of loading, the lower is the rate and total quantity of creep. Since degree of hydration reflects strength of a given concrete, it can be said that the **creep varies inversely as the strength** for a given concrete. Hence creep is related to the water-cement ratio. A higher water-cement ratio increases the size of the pores in the paste structure, so that the water of absorption may be expelled easily under a sustained loading to cause a high rate of creep. **Lean mixes exhibit greater creep** than rich mixes.

Degree of hydration is better with greater fineness of cement and hence there is reduction in creep strain at a given time in a given concrete. It is also observed that the **slow-hardening cement such as low heat portland** and **portland pozzolana cement creep more than ordinary** and **rapid hardening cement** which hydrate rapidly. Because of higher creep, the low heat portland and portland pozzolana cements have served better in relieving stresses in large dams on cooling and have shown high resistance to cracking.

Using coarser grading or higher fineness modulus of aggregates results in reduction of water-cement ratio for a given concrete mix and hence it leads to reduction in creep with increase in size of aggregate.

The storage of concrete specimen in higher relative humidity reduces the flow of moisture and hence reduces the creep in concrete. Concrete specimen stored for 28 days in 70% relative humidity exhibits almost double the creep in comparison with the same concrete specimen stored under water for the same period when subjected to a stress of about 5 N/mm$^2$. In general the creep is higher for lower relative humidity. At an advance age of loading the ambient relative humidity has little influence on the creep. Alternate wetting and drying results into increased magnitude of creep.

For specimens of larger size, the creep reduces because of more resistance to seepage of expelled pore water in longer pore passages and also due to effects of shrinkage.

Upon release of a sustained load, there is an immediate elastic recovery of length followed by a further creep recovery which continues for a period of several days. The magnitude of this creep recovery depends on the period of the sustained load and pervious creep. **Longer the loading period, lesser is the creep recovery.** Recovery of creep reaches its maximum value faster than the maximum creep attainment period.

Creep in concrete is sometimes beneficial as it reduces the tendency of cracking due to shrinkage in restrained structures by relieving stress. **Creep is disadvantageous** in case of **prestressed concrete** structures because creep reduce tension in steel wires.

### *iv. Thermal Changes - Coefficient of Expansion*

Temperature change in concrete causes change in dimensions of concrete. Cement concrete has positive coefficient of thermal expansion but its value depends on the composition of the mix and on its hygral state at the time of the temperature change. Two main constituents of concrete i.e. cement paste and aggregate have different thermal coefficients, and hence the coefficient for concrete is a resultant of the two values.

The coefficient of thermal expansion of cement paste varies between about $11 \times 10^{-6}$ and $13 \times 10^{-6}$ per°C and is generally higher than the coefficient of aggregate $5 \times 10^{-6}$ to $13 \times 10^{-6}$ per°C). The coefficient of thermal expansion of concrete depends on the quantity of aggregate and the coefficient of thermal expansion of aggregate itself. Thus if the coefficients of thermal expansion of the coarse aggregate and of the cement paste differ too much, it will cause differential movement and break bond between aggregate and paste. Due to differential coefficients the concrete mass may be subjected to a severe thermal stress when the concrete is exposed to high temperatures.

The coefficient of thermal expansion of paste depends on the saturation condition. For the paste which is **completely dry or fully saturated**, the coefficient of **thermal expansion is less** than when the paste is partially saturated. These coefficients are maximum at relative humidity of 50 to 70%. The **coefficient also decreases** with the **age of hydration** due to increase in crystalline material in the hardened paste. These variations in the coefficient of thermal expansion are not found in steam cured pastes. Some times the increase in temperature is associated with drying shrinkage also and hence results in lesser expansion.

Thermal changes in concrete are due to two reasons:

- Internal (chemical combination of water and cement)
- External (due to change of temperature in environment).

The internal heat generated by chemical reaction in mass concrete dissipates quickly at the surface in comparison to the interior and thus creates temperature gradient which may cause thermal cracks. The rise in temperature causes expansion of concrete and result into thermal stress and cracks if restrained. These cracks become more prominent if the coefficient of expansion of aggregate and cement paste differs too much.

The thermal coefficient of expansion of concrete is the change in unit length of concrete member due to unit degree of change in temperature. For plain cement concrete using normal aggregate the coefficient of thermal expansion generally varies between $7 \times 10^{-6}$ to $11 \times 10^{-6}$ per degree Celsius. IS:456-1978 proposes the following values:

a) Plain cement concrete : $10.6 \times 10^{-6}$ per°C
b) Reinforced cement concrete : $11.7 \times 10^{-6}$ per°C

As already explained the coefficient of thermal expansion is mainly influenced by the quantity and nature of aggregate, condition of saturation, and age of concrete. Aggregates derived from gravel and quartzite have higher coefficients of thermal expansion as compared to lime stone, granite and sand stone.

Thermal expansions are important in concrete structures which are restrained. With the rise in temperature, the restrained concrete is subjected to compressive stresses. Similarly on fall of temperature, the restrained concrete is subjected to tensile stresses and may cause cracking if the temperature change is high. Thus to avoid development of severe tensile stresses and cracking, the concrete should be placed comparatively at low temperatures and low heat or portland-pozzolana cements should be used especially in mass concrete. Suitable expansion and contraction joints should be provided to allow for free movement of concrete due to temperature changes. The concrete with higher coefficient of thermal expansion are less resistant to temperature changes than concrete with a lower coefficient.

### *Thermal Conductivity*

Thermal conductivity is important in mass concrete, and also for insulating properties of concrete walls and floors. Structural concrete made of normal aggregates conduct heat easily in comparison to light weight concrete, and other non-structural concretes. Conductivity, is low with use of light weight aggregates, and in case of air entrained concrete. To avoid heat losses in air conditioned rooms the walls, floors, and roofs should be made of concrete having low conductivity of heat. Concrete made with pumice and cinder has low thermal conductivity. Saturation of concrete also improves conductivity compared to dry concrete containing air voids. Since conductivity of water is about half of the cement paste, conductivity of hardened concrete is much better with low water-cement ratio.

Thermal conductivity is usually calculated from the diffusivity which represents the rate at which temperature changes within a mass.

### *Specific Heat*

Specific heat represents the heat capacity of concrete. Specific heat of concrete is the quantity of heat required to heat a unit mass (kg) of concrete through a unit temperature (°C). Specific heat increases with increase in moisture content of the concrete.

## 2.4.5 Unit Weight

The weight of concrete becomes important from various quality control point of view during preparation of fresh concrete and functional requirements during hardened concrete.

The unit weight of concrete depends mainly on unit weight, quantity, and size of aggregate in the mix. Unit weight of concrete is also influenced by air entrainment. For ordinary concrete, nominal natural aggregate is used. For light weight concrete, light weight aggregate is used. For high density concrete, special high weight aggregate such as iron ore, magnetite, steel, and lead are used. Unit weight increases with use of bigger size aggregates. For plain cement concrete, the unit weight is normally assumed as 2400 kgf/m$^3$ (24 KN/m$^3$).

For reinforced cement concrete, the unit weight is considered as 2500 kgf/m$^3$ ($\approx$25 KN/m$^3$). Unit weight of reinforced cement concrete increases with increase in percentage of steel reinforcement.

Unit weight of concrete is also influenced by degree of compaction at the time of placing. Higher air content or air voids in concrete results into lower unit weight of fresh concrete. The unit weight of fresh concrete is useful for determination of yield of concrete.

## 2.5 SUMMARY

Cement concrete is the most common and important material of construction. Quality and economy in any construction project depends largely on cement concrete construction. For managing and controlling quality and economy it is necessary to understand the properties and behaviours of cement concrete both during **fresh** and **hardened** states.

Cement concrete in its fresh state is required to exhibit property of good **workability**, freedom from **segregation**, and freedom from **bleeding** and **harshness. Workability is defined as the ease with which fresh concrete can be placed and compacted fully without segregation.** Segregation is defined as separation of the constituents (specially coarse aggregate) to make concrete composition non-uniform. The separation of water from cement and sand or separation of cement paste from the mortar allowing the water or cement paste to appear at the surface is called **bleeding.**

**Bleeding** in concrete can be prevented by using finer cement and finer grading, and controlling water content, compaction and finishing. Workability and segregation can be controlled by proper grading of aggregate and proportion of water. Overall phenomenon of workability includes bleeding and segregation controls. Workability can be measured by **slump, compacting factor, flow, remoulding, Vee-Bee degrees,** and ball penetration characteristics of concrete. Slump is the most common site test for control of workability. Slump test does not provide correct measure of workability specially for very rich and very lean mixes. Compacting factor and Vee-Bee degrees represent workability fairly well for various concrete mixes except for very fluid concrete.

Hardened concrete exhibits properties of **strength, durability, impermeability, dimensional changes,** and unit weight. Various type of strengths are mostly governed by its basic compressive (crushing) strength which in turn depends on cement, W/C ratio, aggregate grading and size, and concreting operations (compaction, curing, etc.). Flexural strength $f_{cr} = 0.7\sqrt{f_{ck}}$ N/mm$^2$. Durability of concrete depends on impermeability, resistance to weathering corrosion and chemical attack. Impermeability is affected by W/C ratio, adequate compaction and curing and dense grading of aggregate. Dimensional changes occur due to elasticity, shrinkage, creep and thermal variations. Creep occurs due to sustained loading and affects prestressed concrete adversely. Appropriate joints are constructed to avoid excessive stresses in restrained structures. Unit weight of concrete represents its **mass per unit volume** (m$^3$) and depends on the sp. Gravity of aggregates.

The concrete in various engineering structures had to withstand different types of forces and exhibit appropriate behaviour. In concrete structures failure of concrete occurs due to:

Lack of **durability**
Lack of **strength**
Lack of **impermeability**
Lack of resistance to **dimensional changes**

Concrete structures fail due to **inadequate cover** leading to **corrosion** of reinforcement, **over stressing** of weak and/or porous concrete, cracking as a result of bad construction and expansion joints, and deterioration due to use of inappropriate concrete ingredients. For avoiding failure, the concrete of appropriate characteristics should be developed according to the functional requirements of the structure, its exposure conditions and strength requirements.

All structures are required to resist forces and loads, and therefore, it is necessary for structural concrete to exhibit certain desired strength. Some concrete structures are exposed to atmospheric and weathering forces of wind, rain, water, chemicals, temperature, fire and requires the concrete to be durable against such conditions.

The quality and characteristics of concrete mix should therefore, be designed optimally to exhibit suitable properties and functions in given conditions of exposure.

## PRACTICE QUESTIONS

2.1 Define each in not more than 50 words : grade of concrete, workability, strength, bleeding, harshness, and impermeability.
2.2 List main properties of cement concrete in (a) plastic state (b) hardened state
2.3 Explain the importance of workability in quality control of cement concrete.
2.4 Differentiate between :
  - bleeding and segregation,
  - strength and durability
  - creep and shrinkage
  - coefficient of expansion and elastic modulus
2.5 Explain the steps of controlling bleeding in cement concrete.
2.6 Explain each of the method for workability measurement in not more than 100 words
  - Slump test
  - Compacting factor test
  - Vee-Bee test
  - Flow test
2.7 Explain various conditions of fresh cement concrete mix in relation to Vee-Vee degrees
2.8 Explain strength characteristics of cement concrete.
2.9 Explain Impermeability and durability for cement concrete
2.10 Explain mechanism of chemical attack on cement concrete.
2.11 Explain importance of properties in plastic stage to control concrete properties in hardened state.
2.12 Differentiate between:
  - Elasticity and durability
  - Impermeability and conductivity of heat
  - Chemical attack and corrosion
  - Compressive and flexure strengths
2.13 Explain role of cement concrete properties in management of its quality in not more than 100 words.
2.14 List five most critical properties of cement concrete essentially considered for controlling and managing its quality.

## CHAPTER 3

# *Influence of Basic Ingredients on Quality of Concrete*

## LEARNING OBJECTIVES

After studying this chapter the learner **understands the influence of basic ingredients** on the quality of concrete and will be able to:

- **List characteristics** of cement and its influence on concrete;
- **Explain the influence** of **fineness, strength, soundness, heat of hydration** and **hardening** of cement on the quality of concrete;
- **Specify Indian standard specifications** of ordinary portland cement;
- **Explain characteristics** of aggregate;
- **Explain the effect of size, shape, strength** and **texture** of aggregate on the properties of cement concrete;
- **Explain the effect of aggregate grading** on the quality of cement concrete;
- **Explain bulking** of sand;
- **Explain fineness modulus** of aggregate;
- **Explain Alkali-aggregate** reaction;
- **Explain the influence of sand grading zone** on cement concrete property;
- **Explain the quality of water** in relation to the quality of cement concrete.
- **Explain the importance** of basic **ingredients** in achieving the quality of cement concrete.

## 3.1 INTRODUCTION

Normal cement concrete is produced by using basic ingredients: **cement, aggregate** (fine and coarse) and **water.** To control the quality of concrete it is essential to understand the influence of each ingredient on the property and behaviour of cement concrete. **Cement act as binding material, water reacts chemically** with cement, **aggregate as inert material** to increase the bulk (coarse aggregate as crushed rock or gravel for **volumetric stability** and sand **as fine aggregate for cohesiveness**) in the mass. For achieving the final concrete each of these basic ingredients shall be selected, measured and prepared to undergo a suitable process of concrete making. In addition to these basic materials, sometimes **special admixtures** may also be used to modify certain properties of concrete. These admixtures have been dealt separately in chapter-4. The quantity and quality of these basic ingredients influence the properties of concrete both during plastic and hardened states. Characteristics of these basic ingredients and their influence on concrete are discussed in subsequent paras.

## 3.2 CEMENT

**Cement** is most important ingredient and acts **as a binding material** (having adhesive and cohesive properties). Cement is obtained by **pulverising clinker formed by calcining** raw materials primarily comprising of **lime (CaO), silica ($SiO_2$), alumina ($Al_2O_3$)** and **ferric oxide ($Fe_2O_3$)** alongwith some minor oxides. **Joseph Aspdin**, a brick layer in England, developed **portland cement in 1824.** Further improvements lead to the present form of portland cements exhibiting a variety of properties suitable for variety of functional requirements of **strength, durability, impermeability** and other dimensional constraints. Cement when mixed with water forms a **paste which sets and hardens under water and binds the aggregate** together to produce a continuous compact mass. The characteristic behaviour of this concrete mass in a given condition depends on the **type, grade, quality** and **quantity** of cement.

The portland cements comprise of four principal compounds such as **tricalcium silicate ($3CaO. S_iO_2$), dicalcium silicate ($2CaO. SiO_2$), tricalcium aluminate ($3CaO. Al_2O_3$)** and **tetra calcium alumino ferrite ($4CaO. Al_2O_3. Fe_2O_3$).** The composition of these principal compounds is affected by the proportions of basic raw material oxides. The composition of these principal compounds affect the behaviour of cement in concrete. The actual proportions of these principal compounds differ from cement to cement and accordingly forms the basis of suitability under different conditions and requirements of a structure. Apart from variety of portland cements, there are other special cements which are suitable under special conditions of placement, environment and special structural requirements.

Different portland cements have different basic raw material oxide composition and is specified in Table 3.1.

Cements are selected for preparation of desired concrete required for structures placed under special conditions of loading, and environmental exposure on the basis of its characteristics. Various physical properties of cement are:

- **fineness;**
- **setting** and **hardening;**
- **strength;**
- **soundness;** and
- **heat of hydration.**

**Table 3.1** Basic Raw Material Oxide Composition and Principal Compounds Formed

| *Oxides/Compounds* | *Ordinary* | *Rapid Hardening* | *Low Heat* | *Sulphate Resisting* |
|---|---|---|---|---|
| Basic Oxides Lime (CaO) | 63.1 | **64.5** | **60.0** | **64.0** |
| Silica ($SiO_2$) | 20.6 | 20.7 | **22.5** | 24.4 |
| Alumina ($Al_2O_3$) | 6.3 | 5.2 | 6.2 | **3.7** |
| Iron oxide ($Fe_2O_3$) | 3.60 | 2.9 | 4.6 | 3.0 |
| Principal Compounds (CaO-C, $SiO_2$-S, $Al_2O_3$-A, $Fe_2O_3$-F) | | | | |
| **$C_3S$** | **40** | **50** | **25** | **40** |
| **$C_2S$** | **30** | 21 | 45 | 40 |
| **$C_3A$** | **11** | 9 | **6** | **5** |
| **$C_4AF$** | 11 | 9 | 14 | 9 |

### 3.2.1 Fineness

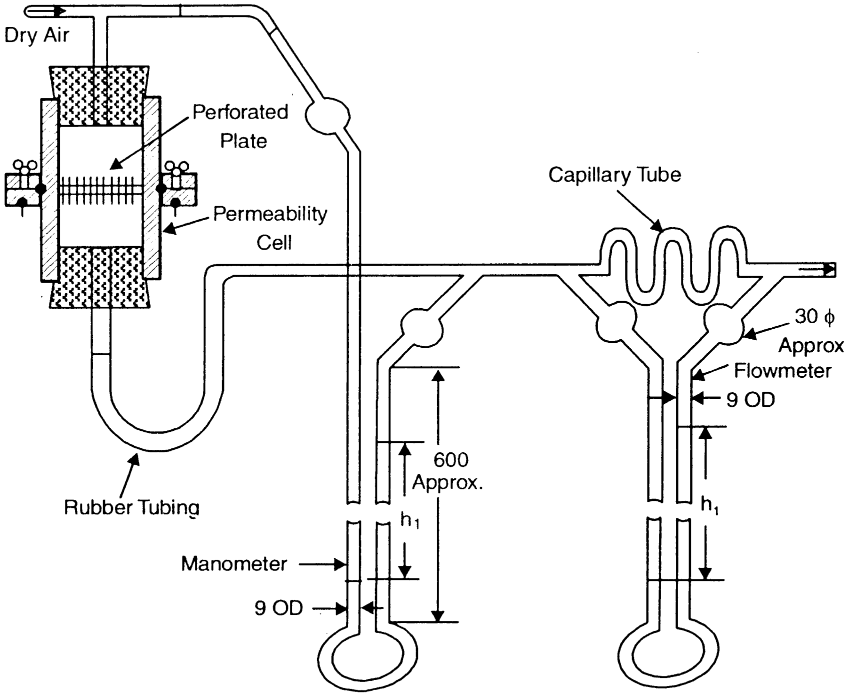
It may be recalled that cement is obtained by **grinding clinker mixed with gypsum.** The hydration of cement particles occurs immediately at its surface and hence it is the total surface area of cement particles that represents the material available for immediate hydration. Fineness of cement is determined by the particle size and its distribution. This is generally determined in terms of percentages of particles retained and **passing through 90-micron sieve.** This provides only indication of percentage of particles larger and smaller than 90 microns and does not provide the full detail of particle size distribution. This method is simple and can be used in the field.

Another method is developed which is based on **specific surface area ($cm^2$ or $m^2$) of cement particles per unit mass** (gram or kg). Particle size distribution of cement depends on the method and extent of grinding. During recent past air permeability (Refer Fig. 3.1) method of determining **specific surface area** was developed by **Lea and Nurse** and **Blaine** and is adopted by most of the countries as a standard method. It is based on the relation between the **flow of a fluid** (air) through a granular **cement bed** and the surface area of the particles comprising the bed. The surface area per unit mass of cement bed material is related to the permeability of the bed. The surface area per unit mass depends on the porosity (volume of pores in total volume of bed) of a given cement bed. Pressure difference is created and a stream of dry air is passed through the bed of cement at a constant velocity and the resulting pressure drop is measured by a manometer. Specific surface area is calculated by a suitable formula which provides a good guidance of relative fineness of the sample. Greater specific surface area represents greater finess.

Fineness of various cements is specified as:

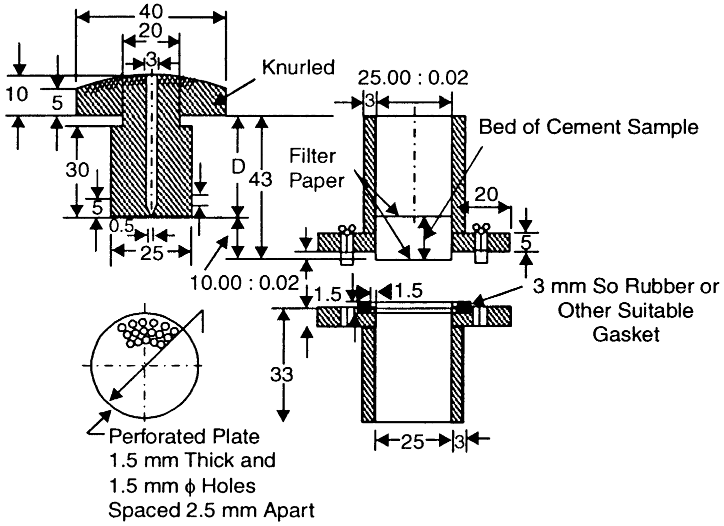
| | | |
|---|---|---|
| Ordinary portland cement (OPC) | 225 $m^2$/Kg | (2250 $cm^2$/g) |
| Rapid hardening portland cement (RHPC) | 325 $m^2$/Kg | (3250 $cm^2$/g) |
| Portland blast furnace slag cement (PBFSC) | 225 $m^2$/Kg | (2250 $cm^2$/g) |
| Low heat portland cement (LHPC) | 320 $m^2$/Kg | (3200 $cm^2$/g) |
| Portland pozzolana cement (PPC) | 300 $m^2$/Kg | (3000 $cm^2$/g) |

Since the reaction of water and cement particles starts at the surface of cement particles, the total surface area of cement plays an important role in rate of hydration and strength development. Thus **finer the cement, rapid will be the rate of hydration** and **gain of strength.**



All Dimensions in mm

**Fig. 3.1(a).** Permeability Apparatus with Manometer and Flowmeter



All Dimensions in mm

**Fig. 3.1(b).** Details of Permeability Cell

With rapid rate of hydration, the heat evolution will also be rapid. The cost of grinding will also be higher for higher fineness. Further **deterioration** of cement due to exposure to atmosphere during storage shall be **rapid in case of finer cements.** The **shrinkage** of cement paste also **increases with increase in fineness.** Finer cements have **lesser tendency to bleed.** With finer cements **higher percentage of gypsum is needed** to balance the effect of $C_3A$ to retard setting. Quantity of water required for a paste of **standard consistency is higher for finer cements.** Workability of concrete mix improves slightly with increase in fineness of cement. **Fineness** is therefore an important property **of cement for controlling the quality** of concrete.

### 3.2.2 Setting and Hardening

When water is added to cement to form paste, the reaction starts and the paste loses plasticity gradually with time and finally becomes stiff. During this reaction **$C_3A$ tends to react quickly** to produce a jelly like compound which starts solidifying. Due to addition of **gypsum** during manufacture of cement, the **reaction of $C_3A$ delays** and $C_3S$ starts setting first. If $C_3A$ is allowed to set first, a **porous calcium aluminate hydrate forms** and the other compounds hydrate within this porous framework and affects the strength characteristics of cement paste adversely. The term **setting is used to describe the stiffening (loss of plasticity)** of the cement paste capable of withstanding an arbitrarily defined pressure. During this, the fluid state of the cement paste changes to rigid or solid state. Cement paste **acquires very little strength during setting** and should be neglected. With further **continuance of hydration of $C_3S$ and $C_2S$, the cement paste gains strength** which is **referred as hardening.** The first part of hydration which causes **loss of plasticity or fluidity is termed as setting** while later part of hydration which causes gain of strength is termed as hardening.

Setting is described at two stages arbitrarily chosen as **initial setting** (beginning) and **final setting (ending)**, and are measured as times from the moment of adding water to cement. It is difficult to measure these exactly and hence arbitrary method is employed to locate these stages. It is important that the setting should neither start very early nor takes too long. The concreting operations of mixing, transporting, and placing should be completed before the concrete mix loses plasticity and the initial set begins. Various standards, therefore, specify a minimum initial setting time for cement. Once the initial setting has commenced, it is desirable that it should harden or gain rigidity as rapidly as possible, so as to remove side shuttering. Standards of various countries, therefore, specify the maximum time limit for final setting and minimum time for initial setting.

The water content of a paste has a marked effect upon the time of set as well as on other properties of cement paste. For acceptance tests of cement, the water content is regulated by bringing the cement paste to a standard condition of plasticity, called **normal** consistency. Generally, the water required for normal consistency varies from 25 to 32% by weight of cement in most of portland cements. The quantity of water required to make a paste of normal consistency is determined on the basis of penetration of a plunger of 10 mm diameter and a standard weight, in a neat cement paste test block in Vicat apparatus. The percentage of water by weight of cement at which the standard plunger is capable of penetrating the cement paste test block upto **5 mm to 7 mm from the base** of the mould is called the percent of water required for the **paste of normal consistency.**

The Indian standard specifies two arbitrary points which relate to the setting of cement. The initial setting time is defined as the period elapsing between the time when water is added to cement and the time at which **a needle of 1 mm square section fails to pierce the cement paste test block to a depth of about 5 to 7 mm from the bottom** of the mould. A period of **30 minutes** is the minimum initial setting time specified for ordinary and rapid hardening portland cements. Final setting time is defined as the period elapsing between the time when water is added to cement and the time at which **the needle of 1 mm square section (with 5 mm diameter attachment) makes an impression on the cement paste test block, but the attachment fails to make an impression** on the test block (Refer Fig. 3.2). A period of **600 minutes** is the maximum time specified for the final set for various portland cements. Setting times are controlled by using appropriate percentage of gypsum during grinding of clinker (2 to 3%).

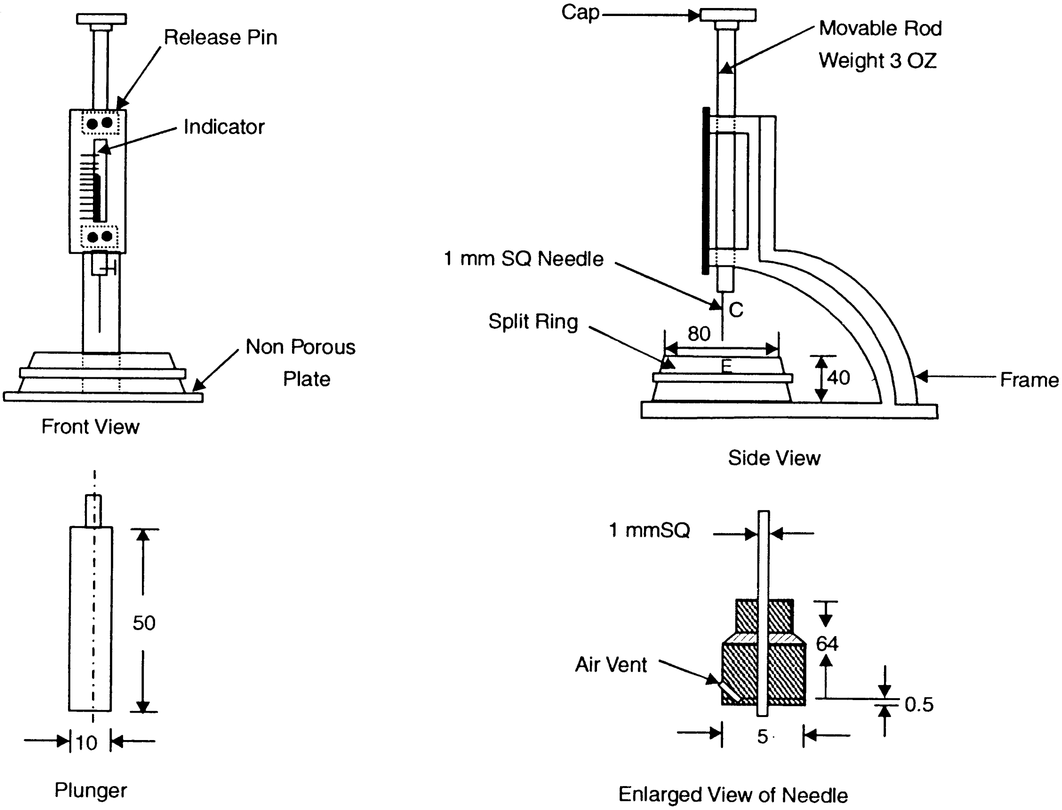


Fig. 3.2. Vicat's Mould

The time of setting of cement depends on **chemical composition, fineness, water content** of paste, and **storage temperature of paste. Fineness reduces the time of setting. Higher quantity of water delays setting.** High temperature of environment of cement paste reduces the setting time.

### 3.2.3 Strength

The resistance of cement paste to deformation under loads and pressures is called its strength. This gain of strength of cement paste is due to formation of products of hydration. According to H. Lechatelier the strength is due to **high cohesive and adhesive properties of interlaced elongated crystals** produced during hardening of cement paste. According to W Michaelies the strength is due to gelatinous mass of **calcium silicate hydrate** formed during hardening of cement paste. The gel mass gradually hardens and exhibits property of cohesion due to loss of water by external drying and hydration of inner core of cement grains. The gel contains some crystals of **calcium silicate hydrate** including calcium hydroxide. The strength of the gel is due to cohesive bonds created by **physical attraction and chemical bonds.** The cement gel consists of microscopic pores containing gel water and free water. Gel also contains chemically combined water (non evaporable) which reflects the degree of hydration.

The quality of gel and its rate of hydration depends mainly on the compound composition of cement gel and other surrounding conditions. It is found from research that primarily calcium silicate hydrates ($C_3S$ and $C_2S$) are responsible for the strength of cement paste. $C_3S$ is responsible for an **early strength** (first 4 weeks) while **$C_2S$ influences later strength.**

Cement has the maximum strength in compression but has very little strength in tension (both direct and flexural). Thus it is the compressive strength of hardened cement which forms important consideration for the properties of hardened cement concrete. Since moulding of neat cement paste specimen is difficult, tests are conducted on **standard cement-sand mortar cubes** for determining cement strength. The strength of mortar or concrete depends on the cohesion of cement paste, adhesion of cement paste to the aggregate particles (bond), and on the strength of aggregate particles itself. Test shall, therefore, be conducted with mortars using **standard sand** (as aggregate) and **eliminating the possibility of failure due to poor bond or poor strength of aggregate.** According to Indian Standards mortar cubes are prepared by taking **one part of cement** and **three parts of standard Ennore sand** by adding suitable quantity of water on the basis of the normal consistency of neat cement paste. The mortar cubes are compacted, cured and tested under standard conditions. Standard sand is used to eliminate the effect of variation in properties of sand in determining the compressive strength of cement sample.

The strength of hardened cement concrete is the property required for various structural purposes. The strength tests are, therefore, important to specify the cements. The **compressive strength of cement serves as a guide** and check on the quality of cement and helps to classify the cement as ordinary, rapid hardening, low heat, or pozzolanic portland cement. Cements can also be classified by its grade of strength as **33, 43** or **53 grades.** Grade represent 28 days compressive strength. The compressive strengths are determined at the ages of 1 day, 3 days, 7 days or 28 days depending on the type of cement. The tensile strength test is not considered important for cement and hence it is not specified in standard specifications.

### 3.2.4 Soundness

Cement paste after it has set, should not undergo a large change in its volume specially when the concrete structure is restrained for movement. These changes in volume induce stresses due to restraint in structures. The volumetric expansion of cement paste after setting causes **cracks, disruption,** and **disintegration of mass** and is called **unsoundness** of cement. These volumetric changes are caused by slow hydration or reaction of free lime, magnesia, and calcium sulphate with water. The volume of products of these reactions increases in relation to the original volume of compounds.

During the burning of raw materials in the kiln, if raw materials contain more lime and magnesia than that which can combine with acidic oxides, these remain in free state. These hard burnt lime and magnesia (specially periclase) slake (hydrate) very slowly and the **volume** of compounds formed after slaking is **very large as compared to the original volume** and hence results in large scale cracks. Thus the cements which exhibit such expansions are called unsound.

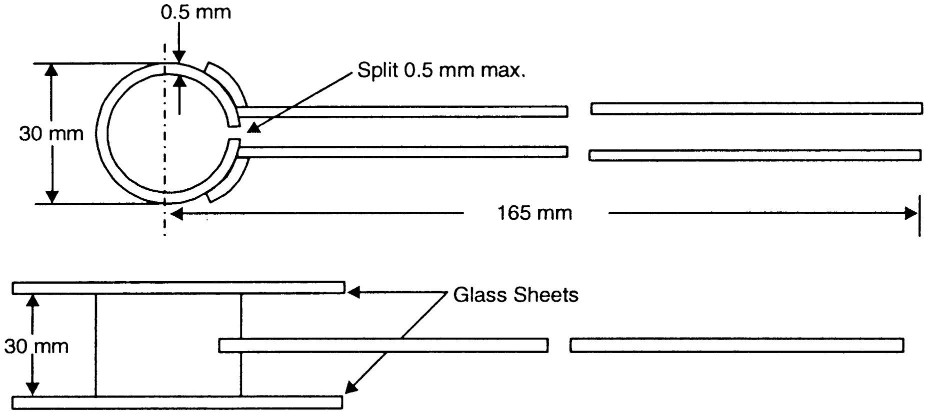


**Fig. 3.3.** Lechatelier Mould

Lime added to cement does not produce this delayed expansion because it hydrates rapidly before the cement paste has set. Free **lime and magnesia present in clinker get intercrystalized** with other compounds and cannot be fully exposed to water for its hydration before the cement paste has set. Presence of such **crystalline lime and crystalline magnesium oxide is harmful.** Calcium sulphate present in excess of that required for retarding setting action also causes expansion due to formation of calcium sulphoaluminate at a later stage. These **delayed reactions and volumetric expansions** may occur after quite long periods, sometimes, extending to many months or years.

Fine grinding of raw materials brings them into more intimate contact when burned, so that there is less chance of free lime existing in clinker. Thorough burning of raw materials further reduces the quantity of free lime. Fine grinding of the clinker tends to expose the fine particles of free lime for hydration quickly before hardening of cement gel, thus rendering the cement sound.

The method of detecting unsound cements is by **Lechatelier** apparatus (Fig. 3.3) or autoclave test. In case of Lechatelier test, the specimen of cement paste is prepared and cured by boiling in water. The expansion of specimen is measured in the apparatus and expressed in mm. Generally this expansion does not exceed 10 mm for sound cements. In autoclave (steam boiler) test, cement paste bars are prepared and cured at high pressure and temperature **after 24 hours of casting for 3 hours.** The lengths of these bar specimen are compared with the original gauge lengths and the expansion is expressed as percentage. The cements exhibiting not more than 0.50% expansions are considered within sound limits.

### 3.2.5 Heat of hydration

The chemical **reaction of water and cement** is known as **hydration.** This chemical reaction of hydration of cement is **accompanied by liberation of heat.** This heat liberated during setting and hardening of cement is called heat of hydration. The rate and the quantity of heat of hydration depend on the compound composition of cement and surrounding environment of cement mass. Concrete has a low thermal conductivity and hence in a large concrete mass such as dams, the heat generated in the interior during setting and hardening is not readily dissipated. This causes immediately expansion of concrete mass due to heat of hydration and later contraction on cooling. This expansion and contraction results into cracks in the concrete mass due to restraints in the structure.

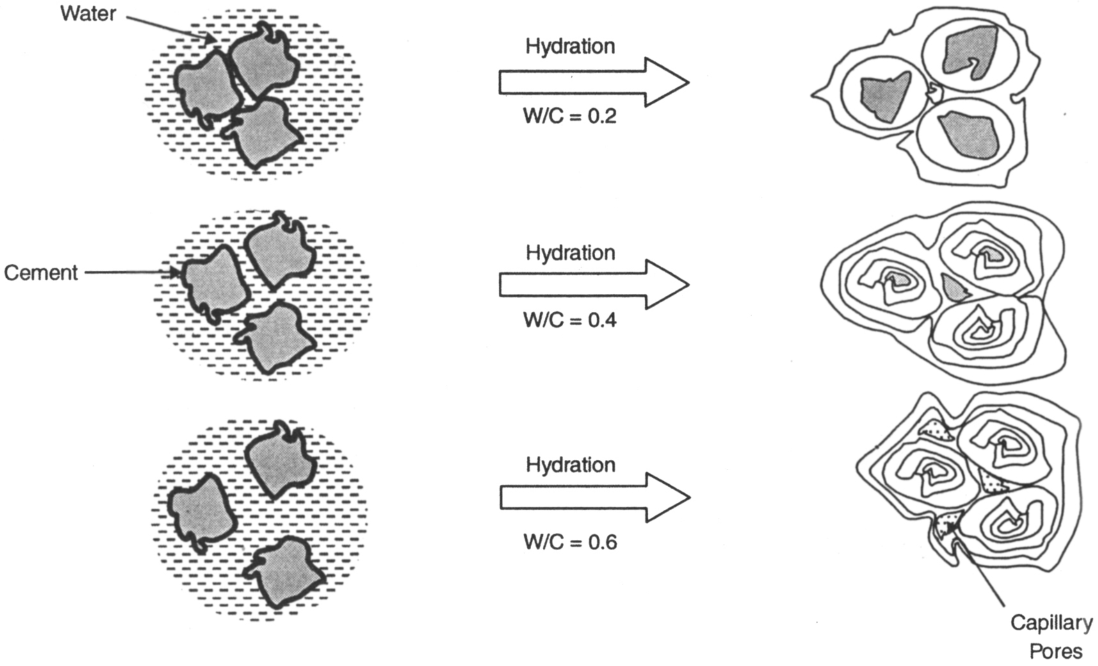


**Fig. 3.4.** Schematic Representation of Hydration of Cement With Insufficient (W/C = 0.2), Sufficient (W/C = 0.4) And Excess (W/C = 0.6) Water

In construction of massive concrete structures, the temperature of concrete is controlled by using a system of embedded interior cooling pipes and by rate of placement of concrete from the known value of heat of hydration of cement. The amount of heat generation can also be reduced by modifying the cement composition. Tricalcium aluminate ($C_3A$) and tricalcium silicate ($C_3S$) are mainly responsible for **rapid generation of heat** and hence by limiting the proportions of these compounds in cement, the heat generation rate and quantity can easily be controlled. During very cold weathers, the heat of hydration of cement can be utilized advantageously to prevent the capillary pore moisture from freezing. Thus **rapid hardening portland cement is more suitable in cold weather** concreting.

The heat of hydration in case of ordinary portland cement normally varies from 85 to 100 calories per gram, while that of low heat portland cement varies from 60 to 70 calories per gram.

### 3.2.6 Influence of cement on concrete properties

There is increasing use of cement concrete as a construction material for structures serving a variety of functions and subjected to various exposure conditions. These concrete structures in course of time may develop cracks, spalls, or disintegrate due to the action of severe weathering or aggressive chemically charged waters or soils or gases.

Cement reacts with water and forms plastic paste which hardens to impart strength to concrete. The reaction of cement is also responsible for shrinkage. For achieving concrete of desired strength and durability, a suitable type, quality and quantity of cement has to be selected. The selection of **type of cement** is governed mainly by the nature of **exposure of concrete,** while the **quantity of cement** is mainly determined on the basis of **workability, strength,** and **economy** in concrete. For minimizing shrinkage a minimum quantity of cement and minimum optimum water-cement ratio are recommended for concrete proportioning. The **quality, type,** and **quantity of cement** is therefore important for obtaining concrete of desired **strength and durability.**

Cement is a very fine and hygroscopic material and hence it should be stored properly in dry place and handled carefully to avoid any loss and damage to its quality. For correct proportioning, the cement is always measured by weight (mass). Cement bags are supplied in packing of 50 kg mass and should be weighed and checked for important construction jobs.

Since the properties of cement directly influences the properties of concrete, the selection of correct quality and quantity of cement is a key factor in obtaining the desired quality of concrete for the given structure. Cement should be tested for its properties before it is being used in the concrete. The cement should satisfy requirements of Indian standards before it is accepted for any concreting job for a specific structure subjected to specific conditions and stresses. For optimum use of cement properties, various concreting operations should be completed before the initial setting time of cement. The Indian Standard specifications are given in Tables 3.2 and 3.3.

## 3.3 AGGREGATE

Concrete comprises of a very large proportion of inert rock fragments or gravel called aggregate and hence it forms very important consideration in concrete properties. Cement and water forms paste which combines with aggregate by developing mechanical bond to form hard mass called concrete. Although, earlier, the aggregate was considered as inert material dispersed in the cement paste, but in fact it is not truly inert and its physical, thermal, and sometimes also chemical properties influence the performance of cement concrete. The **aggregate** imparts greater **volumetric stability** to concrete mass by offering greater resistance to deformations caused by shrinkage of cement paste. The aggregate limit the strength of cement concrete as weak aggregate cannot produce strong concrete. The properties of aggregate greatly affect the durability and structural performance of cement concrete. The aggregate is very cheap compared to cement and hence for economical production of cement concrete, maximum (optimum) quantity of aggregate and minimum (optimum) quantity of cement should be used. The selection of **type, size, quantity,** and **grading** of aggregate is done on the basis of **workability requirements** in fresh state, **strength and durability** in hardened state, and **economy** in concrete production.

A suitable grading is done from fine to coarse particles to achieve maximum density of concrete mass. Grading of aggregate particles also affects the workability of fresh plastic concrete and should be selected suitably for optimum **workability, strength,** and **economy** in concrete mass.

**Table 3.2** Specifications for Physical Properties of Cements (as per Indian Standard)

| *Properties* | *Type of Cement and Relevant IS Code Requirements* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *OPC* | *RHPC* | *LHPC* | *HSPC* | *PPC* | *PSC* | *SSC* | *HAC* |
| | *(i)* | *(ii)* | *(iii)* | *(iv)* | *(v)* | *(vi)* | *(vii)* | *(viii)* |
| | *IS: 269-1989* | *8041-1990* | *12600-1989* | *8112-1989* | *1489-1991 (Pt. I)* | *455-1989* | *6909-1990* | *6452-1989* |
| 1. Fineness | | | | | | | | |
| a) Residue (90mic) not to exceed % | 10 | 5 | — | — | — | — | — | — |
| b) Sp.surface($m^2$/Kg) not less than | 225 | 325 | 320 | 350 | 300 | 225 | 400 | 225 |
| 2. Setting Time (min) | | | | | | | | |
| a) Initial not less than | 30 | 30 | 60 | 30 | 30 | 30 | 30 | 30 |
| b) Final not more than | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| 3. Strength (N/$mm^2$) | | | | | | | | |
| a) At 1 day (24±0.5 hrs) | — | 16 | — | — | — | — | — | 30 |
| b) At 3 days (72±1 hr) | 16 | 27 | 10 | 23 | 16 | 16 | 15 | 35 |
| c) At 7 days (168±2 hrs) | 22 | — | 16 | 33 | 22 | 22 | 22 | — |
| d) At 28 days(672±4hrs) | 33 | — | 35 | 43 | 33 | 33 | 30 | — |
| 4. Soundness | | | | | | | | |
| a. Lechatelier expansion not more than (mm) | 10 | 10 | 10 | 10 | 10 | 10 | 5 modified | 5 |
| b. Auto-Clave Expansion not more than (%) | 0.8 | — | 0.8 | 0.8 | 0.8 | — | — | — |
| 5. Max. Heat of Hydration (calories/g) | — | — | — | — | | | | |
| a) At 7 days not more than | — | — | 65 | — | — | — | — | — |
| b) At 28 days not more than | — | — | 75 | — | — | — | — | — |

*(Contd.)*

**Table 3.2** Specifications for Physical Properties of Cements (as per Indian Standard)

| *Properties* | *Type of Cement and Relevant IS Code Requirements* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *OPC* | *RHPC* | *LHPC* | *HSPC* | *PPC* | *PSC* | *SSC* | *HAC* |
| | *(i)* | *(ii)* | *(iii)* | *(iv)* | *(v)* | *(vi)* | *(vii)* | *(viii)* |
| | *IS: 269-1989* | *8041-1990* | *12600-1989* | *8112-1989* | *1489-1991 (Pt. I)* | *455-1989* | *6909-1990* | *6452-1989* |
| 6. Specific gravity (Bulk Density Kg/l) | — | — | — | — | — | — | 2.8-2.9<br>(1.30) | — |
| 7. Drying shrinkage (max percent) | — | — | — | — | 0.15 | — | — | — |
| 8. Chemical Requirements | | | | | | | | |
| a) Loss on ignition max. % | 5.0 | 5.0 | 5.0 | 4.0 | — | 4 | Insoluble Residue (max. 4.0%) | — |
| b) Wt. of MgO (max.%) | 6.0 | 6.0 | 6.0 | 6.0 | — | 8 | 10.0 | — |
| c) Sulphuric anhydrate (max.%) | 2.75 | 2.75 | 2.75 | 2.75 | — | 3 | 6.0 Sulphide Sulphur max. | — |
| d) Insoluble material (max. %) | 2 | 2 | — | 2 | — | 2.5 | 1.5 % | — |
| e) Lime Saturation factor % | 0.66 – 1.02 max. | 0.66 – 1.02 max. | —<br>— | —<br>— | —<br>— | —<br>— | —<br>— | —<br>— |

OPC - Ordinary Portland Cement
RHPC - Rapid Hardening Portland Cement
LHPC - Low Heat Portland Cement
HSOPC - High Strength Ordinary Portland Cement
PPC - Portland Pozzolanic cement
PSC - Portland Slag Cement
SSC - Super Sulphated Cement
HAC - High Alumina Cement

For durability of concrete, the aggregate should be **resistant to weathering action**, should not react with cement compounds, and should not contain impurities which affect the strength and soundness of cement paste in the concrete. There may be some interaction, over a long period of time, between cement paste and surface of aggregate particles which may promote bond with concrete mass and may not be harmful in all the cases. For preparing concrete required to exhibit special properties, aggregates of special characteristics (viz. heavy weight, light weight) are used.

Thus for production of concrete of desired **strength, durability,** and **economy,** the aggregate should be considered for its:

- **Physical characteristics** and mix proportions useful for **strength** and **workability**;
- Properties which affect the **durability** of concrete; and
- Properties which offer **special characteristics** to concrete.

### 3.3.1 Classification of aggregate

Aggregate may be generally classified on the basis of its source, mineralogical composition, mode of preparation, and size. Such classification helps in identifying and selecting suitable aggregate for the desired concrete job. The acceptance of aggregates for use on the required job is done after getting specific information regarding their qualities.

According to source, aggregate may be called **natural** or **artificial** depending on whether the aggregate particles are formed by natural processes, or artificial industrial processes. Natural sands and gravel are produced by weathering and the action of running water, while crushed stones and stone sands are reduced from natural rock by crushing and screening. The rocks may be igneous, sedimentary or metamorphic and may or may not provide good aggregate. The mineral composition of these rocks are mainly siliceous or calcareous alongwith certain secondary minerals. The form in which these minerals are present, makes the aggregate responsible to exhibit certain specific (good or harmful) behaviours in concrete.

Artificial aggregates are produced for some special purposes. Light weight concrete aggregates are produced by burning clay nodules, cinders, and industrial bye products such as blast furnace slag and fly ash. For production of heavy weight concrete, steel nodules, steel balls may be used. Natural aggregate such as pumice is used for light weight concrete, while magnetite (iron-ore) may be used for heavy weight concrete. At some places natural pit run aggregates are also available and may be used for normal concrete preparations after proper washing. According to size, the aggregate is classified as **fine** aggregate (particles **passing 4.75 mm** sieve and **retained on 75 micron** sieve), and **coarse** aggregate (particles passing **80 mm** sieve and **retained on 4.75 mm** sieve). Further the aggregate may be classified as **single size** (containing mostly particles of one size) and **graded** (containing particles of various sizes).

The aggregate should satisfy the required specifications and qualities before used in preparation of cement concrete. Various characteristics of aggregate important for preparation of concrete are studied in subsequent paragraphs.

### 3.3.2 Aggregate Characteristics

Aggregate has many characteristics which influence the properties of fresh or hardened cement concrete directly or indirectly and forms useful data for the design of mix proportions. These characteristics are listed below:

(i) **Size;**
(ii) **Shape;**
(iii) Surface **texture;**
(iv) **Strength;**
(v) Water absorption and **surface moisture;**
(vi) **Bulking** of sand;
(vii) Unit weight and **bulk density;**
(viii) **Specific gravity;**
(ix) **Thermal properties;**
(x) **Deleterious impurities;**
(xi) **Soundness;**
(xii) **Alkali-aggregate reaction** and durability; and
(xiii) **Gradation** of aggregate.

### 3.3.3 Size of Aggregate

Size of aggregate is designated by its size of particles. Size of individual particles is defined by **standard sieve size through which particles pass if these are retained on the next lower standard sieve.** An individual particle is said to be 20 mm size, if it passes through a 20 mm sieve and is retained on the next lower standard sieve in the set (i.e. 16 mm sieve). An aggregate heap containing particles of one or many sizes is designated by the **maximum size** of the **particles present in substantial quantity.** For example, the aggregate containing particles of 40 mm, 20mm, and 16mm in sufficient quantities shall be designated as 40 mm size aggregate.

According to IS: 460-1962, the standard set of sieves commonly used in concrete technology are:

**80 mm, 63mm, 50 mm, 40mm, 20mm, 16mm, 12.5 mm, 10mm, 6.3 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron, 150 micron,** and **75 micron**
(1 micron = $10^{-6}$ m = $10^{-3}$ mm)

Particle sizes in aggregate varies from **80 mm down to 75 micron.** Particle **sizes from 60 microns down to 2 microns are classified as silt,** while particle sizes **below 2 micron are classified as clay and does not form part of aggregate.** Silt and clay are harmful to concrete. For the sake of convenience, the aggregate is further classified into **coarse aggregate** and **fine aggregate** according to the **size of particles.** The aggregate particles which are **retained on 4.75 mm sieve and are below 80 mm** sieve size are grouped as **coarse aggregate.** The aggregate particles which **passes through 4.75 mm sieve and retained on 75 micron sieve** are grouped as **fine aggregate.** All-in-aggregate is the combination of both coarse and fine aggregate and the particles range from **75 micron to the maximum size.** Single size aggregate comprises of mainly particles of one and the same size. A graded aggregate comprises of particles of various sizes in different proportions.

**Plums** (boulders) have 160 mm and upto a reasonable size may be used in plain concrete work upto a maximum limit of 20% by volume of concrete when specially permitted in a particular job. The plum shall be distributed evenly and shall not be closer than 150 mm from the surface. This indicates that plums can be used only for thick layers of concrete more than 300 mm.

The **surface area of particles per unit volume increases** as the **size of particles reduces.** This can be explained by considering a simple cuboid of 20 mm size and reducing it to 8 cuboids of 10 mm size each **(Fig. 3.5).**

20 mm cuboid:

Volume $V_o = 8000\ mm^3$, surface area $S_o$ = **2400 mm²**, while

8 cuboids of 10 mm:

Volume $V_1 = 8 \times 1000\ mm^3 = 8000\ mm^3$, surface area $S_1 = 8 \times 6 \times 100\ mm^2$ = **4800 mm²**.

Because of change in surface area with size of aggregate, the quantity of cement paste required for certain desired workability also changes. Thus size of aggregate plays very important role in properties of fresh concrete spcially **workability.**

### 3.3.4 Particle Shape of Aggregate

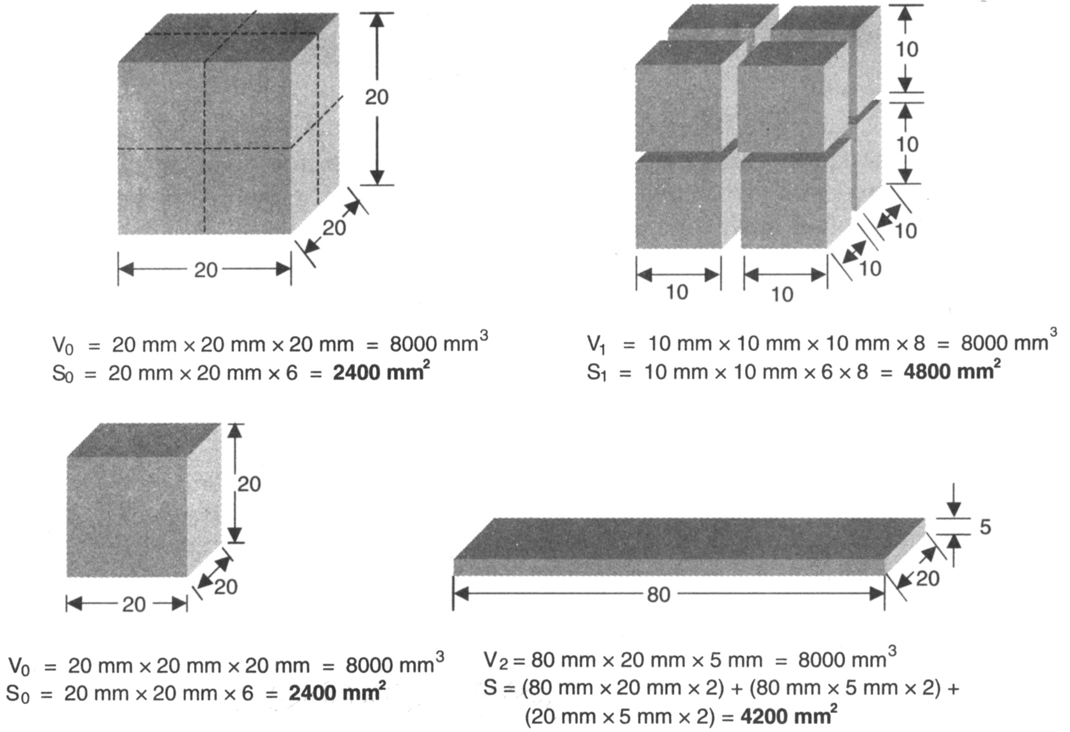
Particle shape is described in terms of geometrical characteristics. The geometrical characteristics of particles are based on the method of their formation, and strength and abrasion of the parent rock. The shape is measured in terms of **roundness** or **angularity** of the edges and corners of a particle.

According to IS: 383-1970, the **particle shape** can be classified as given in Table 3.4 (Refer **Fig. 3.6**). The degree of packing of particles of one size depends on their shape. The **angularity of aggregate** can be estimated from the **percentage of voids** in a compacted sample. The **angularity number** is defined as the **percentage of voids in a standard compacted aggregate** in excess of that in the rounded gravel (i.e. 33%). **Angularity number** (as well as voids in well compacted aggregate) **increases as the angularity of the aggregate increases.** Angularity number (as well as voids in well compacted aggregate) decreases as the angularity of aggregate decreases or roundness increases. The **angularity number** practically ranges from 0 for completely round to about 11 for completely angular aggregate. **Angularity influence** the total surface area of particles per unit volume and hence the **workability** of the mix.

**Table 3.4** Particle Shape

| *Classification* | *Description* | *Example* |
|---|---|---|
| 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 and having rounded edges | Pit sands and gravels; dug flints; cuboid rocks |
| Angular | Possessing well defined edges formed at the intersection of roughly planar faces | Crushed rocks of all types; Talus; screes; crushed slag |
| Flaky | Material of which the thickness is small relative to the width and/or length | Laminated rocks |
| Elongated | Material, usually angular in which the length is considerably larger than the width and thickness | — |

The particles may also be elongated and flaky type. **Flaky** particles are those **whose thickness is less than 0.6 times the average sieve size** (average of sieve sizes through which



$V_0 = 20\text{ mm} \times 20\text{ mm} \times 20\text{ mm} = 8000\text{ mm}^3$
$S_0 = 20\text{ mm} \times 20\text{ mm} \times 6 = \mathbf{2400\text{ mm}^2}$

$V_1 = 10\text{ mm} \times 10\text{ mm} \times 10\text{ mm} \times 8 = 8000\text{ mm}^3$
$S_1 = 10\text{ mm} \times 10\text{ mm} \times 6 \times 8 = \mathbf{4800\text{ mm}^2}$

$V_0 = 20\text{ mm} \times 20\text{ mm} \times 20\text{ mm} = 8000\text{ mm}^3$
$S_0 = 20\text{ mm} \times 20\text{ mm} \times 6 = \mathbf{2400\text{ mm}^2}$

$V_2 = 80\text{ mm} \times 20\text{ mm} \times 5\text{ mm} = 8000\text{ mm}^3$
$S = (80\text{ mm} \times 20\text{ mm} \times 2) + (80\text{ mm} \times 5\text{ mm} \times 2) + (20\text{ mm} \times 5\text{ mm} \times 2) = \mathbf{4200\text{ mm}^2}$

**Fig. 3.5.** Influence of Particle Size and Shape on Surface Area for a Given Volume

it passes and on which it is retained). **Elongated** particles are those **whose length is more than 1.8 times** the average sieve size. **Flakiness index** is the **percent by weight of flaky particles** in the aggregate. **Elongation index** is the **percent by weight of elongated particles** in aggregate. Generally flaky and elongated particles in excess of **10 to 15 %** of coarse aggregate **affects the workability and durability** of concrete adversely due to orientation of such particles in one plane and forming **air voids** and **water pockets.** No limit of flakiness is specified in Indian standard but British Standard BS: 63 specifies a maximum limit of **35 and 40 % flakiness** for aggregates of 6.3 mm to 25 mm and 25 mm to 50 mm respectively.

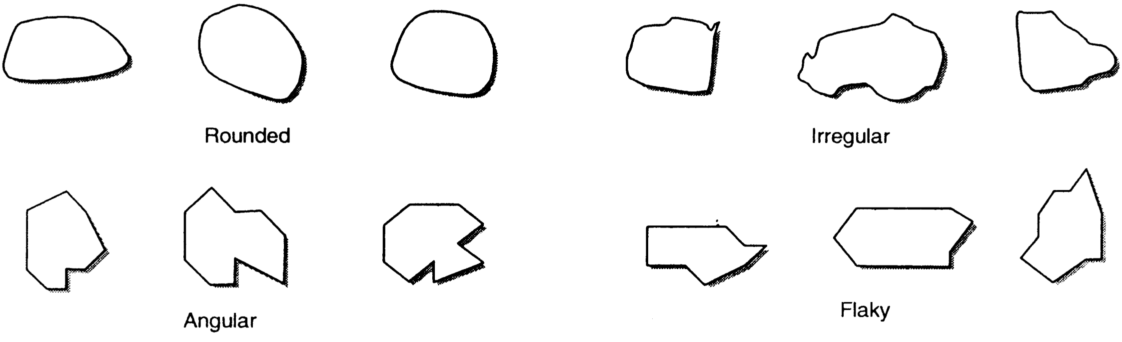


**Fig. 3.6.** Particle Shape

### 3.3.5 Surface Texture

**Surface texture** of aggregate particles describe the **nature of the surface.** It depends on the **hardness**, the **grain size** and **pore characteristics** of the parent rock material. Table 3.5 specifies surface textures as given in IS: 383-1970 and BS: 812-1960.

**Table 3.5** Surface Texture of Aggregate

| *Surface Texture* | *Characteristics* | *Example* |
|---|---|---|
| Glassy | Conchoidal fracture | Black Flint, Vitreous Slag |
| Smooth | Water worn or smooth due to fracture of laminated or fine grained rock | Gravel, Chert, Slate, Marble, Stone, Rhyolite |
| Granular | Fracture showing more or less uniform rounded grains | Sand Stone, Volite |
| Rough | Rough fracture of fine or medium grained rock containing no easily visible crystalline constituents | Basalt, Felsite, Lime Stone |
| Crystalline | Containing easily visible crystalline constituents | Granite, Gabbro, Gneiss |
| Honeycombed and porous | With visible pores and cavities | Brick, Pumice, Foamed Slag, Clinker, Expanded Clay |

The **surface texture influences** the surface area and hence the **workability and strength. Rougher** the surface, **greater is its area** and results in a greater adhesive force between the particles and the cement matrix thus **reducing the workability.** Due to roughness of surface better bond between cement paste and aggregate is realised. Sometimes the bond is developed due to chemical composition of aggregate particle's surface and cement paste. It is difficult to measure this bond of aggregate and cement paste directly but judged indirectly from the fractured surface of concrete. Surface texture becomes important in high strength concrete specially in air field pavements.

### 3.3.6 Strength

The compressive strength of concrete depends on the strength of the bulk of aggregate. It is not easy to directly measure the crushing strength of aggregate.

The strength of aggregate is measured by indirect methods so as to check its suitability in concrete. These indirect methods are:

- Compressive strength of prepared prismatic sample from the **parent rock** of aggregate;
- **Aggregate crushing** value or **aggregate impact** value; and
- **Performance** of aggregate **in concrete.**

Preparing parent rock samples are costly and difficult and hence this method is not very commonly used. Performance of aggregate in concrete is judged from the previous experience of using a particular aggregate in a given concrete or by trial use of such aggregate in desired concrete. If the aggregate under test leads to a lower compressive strength of concrete, and there are number of fractured aggregate particles, it indicates that the aggregate strength is less than the normal strength of concrete mix. Although there is no direct relationship of **aggregate crushing value**, or **impact value** and compressive strength, but **qualitatively** there is sufficient agreement in the two tests. The aggregate crushing value or impact value represent indirectly the value of compressive strength. These tests can also be carried out easily. The aggregate crushing value, impact value and abrasion value tests are described in IS: 2386 (part iv)-1963 (Fig. 3.7).

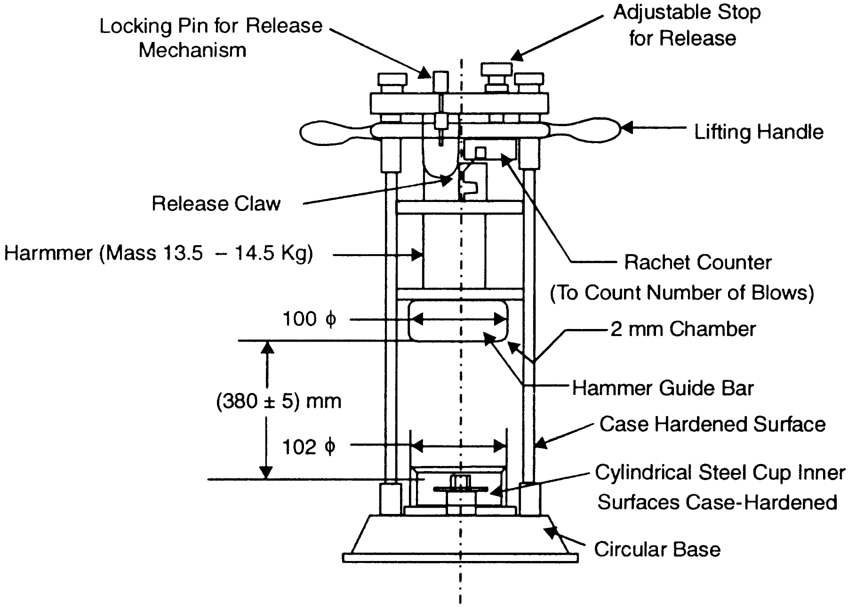


**Fig. 3.7.** Aggregate Impact Test Machine

To determine the aggregate impact value, a sample is obtained from the aggregate passing through **12.5 mm sieve and retained on 10mm sieve.** The same is cleaned and dried upto 100 $^0$C, cooled, and filled in a standard cylindrical mould and tamped as specified in the code.

The sample is subjected to **15 blows of standard hammer** and then sieved through a 2.36 mm IS sieve and the material passing is weighed. The **aggregate impact value** is defined as the **fraction of material passing 2.36 mm IS sieve by mass of the total sample** (passing 12.5 mm and retained 10 mm). Similarly **aggregate crushing value** is also represented as the **fraction of material passing 2.36 mm Sieve** after subjecting the sample to a **compression of 40000 kgf (400KN)** by mass of total sample (passing 12.5mm and retained 10mm). Another test of strength of aggregate is conducted through **LOS Angeles** test of abrasion. In this test the sample of aggregate is placed in cylindrical drum alongwith a charge of **steel balls** and the drum is rotated for specified number of revolutions. The falling of aggregate and steel balls causes abrasion which is measured as **percentage by mass of material passing 2.36 mm sieve** with respect to the mass of the sample.

As a general guide, **higher crushing values**, impact values or abrasion values **represent lower compressive strength** of aggregate. IS: 383-1970 specifies that the aggregate used in concrete shall satisfy the following requirements:

| | *Aggregate Crushing Value* | *Aggregate Impact Value* | *Aggregate Abrasion Value* |
|---|---|---|---|
| (i) Concrete in Wearing surfaces (shall not Exceed) | 30 % | 30 % | 30 % |
| (ii) Concrete in other than Wearing surface (shall not Exceed) | 45 % | 45 % | 50 % |

### 3.3.7 Water Absorption and Surface Moisture

Aggregate particles have minute **permeable and impermeable pores** of various sizes which influence the water absorption and **permeability** characteristics of aggregate. These characteristics in turn affect the **bond** between cement paste and aggregate, **resistance of concrete to freezing and thawing**, and **chemical stability.** The pores in aggregate may exist as closed one (inside the solids) or as open to surface of the particles. Water can enter or evaporate from permeable pores. The moisture condition of aggregate can be determined according to tests prescribed in IS: 2386-1963 (part iii).

According to the moisture condition of aggregate various states are described as given below:

- **(i) Bone dry** (or oven dry): In this condition the moisture from all permeable pores is completely evaporated. This state is reached if aggregate is heated in an oven at 100°C for about 24 hours.
- **(ii) Air dry**: When moist aggregate is allowed to dry in air, part of the moisture from the permeable pores evaporates, and such a state of aggregate is called air dry.
- **(iii) Saturated surface dry**: When the permeable pores are completely filled with moisture, but there is no free moisture on the surface of aggregate, such a state is called saturated surface dry. This is an important balanced state of moisture in aggregate for its performance in concrete.
- **(iv) Damp** (or wet): In this state, aggregate have all the pores fully saturated and also contains some free moisture on the surface.

These four states of aggregate are shown diagrammatically in **Fig. 3.8.**

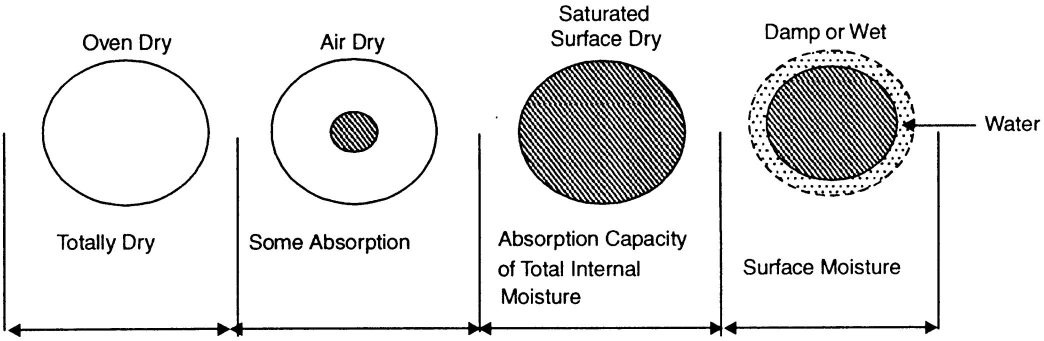


**Fig. 3.8.** Moisture State of Aggregate

The knowledge of moisture condition of aggregate at site is an important consideration in proportioning of concrete mix and quality control. Based on the moisture condition of aggregate the mix proportions (including quantity of mixing water) are adjusted at site so that correct workability and cement hydration are achieved as envisaged in the mix design. IS: 456-1978 specifies approximate amount of surface moisture carried by aggregate in its different conditions of wetness in Table 3.6.

**Table 3.6** Approximate Surface Water Carried by Aggregate

| | *Condition of Wetness Percent by mass* | *Quantity of surface water litre/m³* |
|---|---|---|
| i. Very wet sand | 7.5 | 120 |
| ii. Moderately wet sand | 5.0 | 80 |
| iii. Moist sand | 2.5 | 40 |
| iv. Moist gravel or crushed aggregate | 1.25 to 2.5 | 20 to 40 |

The aggregate shall be used in its saturated surface dry condition. The coarse aggregate can be brought to the saturated surface dry condition by sprinkling water 24 hours before using in concrete. If it is not done, necessary adjustments in the quantity of water must be made depending on the moisture condition of aggregate. The approximate moisture condition of aggregate can be determined at site by visual inspection or accurately by laboratory tests depending on the importance and quality of the concrete job. The moisture condition may be estimated as percent by mass of water in relation to aggregate mass.

Completely dried or oven dried aggregate needs certain additional quantity of water to become saturated surface dry. This quantity of water can be found by tests. Similarly water requirement or excess of surface water available can be determined and estimated for suitable adjustments in water in mix proportions. The presence of moisture in fine aggregate or sand causes certain volumetric changes which should be studied properly.

### 3.3.8 Bulking of Sand

When sand is **moist**, its **volume is more than its actual volume.** The increase in volume of sand is due to formation of film of water around sand particles which push these sand particles apart by surface tension. The phenomenon of **increase in bulk volume of sand due to presence of water is called bulking** of sand. The bulk volume of sand goes on increasing as its moisture content increases upto a certain limit. In most of sands there is **maximum bulking at 5 to 6%** moisture content, and then this bulking effect reduces with increase in moisture content and becomes **zero around 20% and more** moisture content. This maximum increase in bulk volume is highest **(35-40%) in case of fine sands,** while it is lowest **(15-20%) in case of coarse sands.** IS: 2386-1963 (part iii) describes the method of determining bulking of sands. Table 3.7 gives bulking of sand corresponding to various moisture contents.

Sand available at site should be checked if it is dry or wet and the bulking should be assessed by test. Sample of sand should be taken from the site and filled in a graduated glass jar upto certain height loosely and record the height ($h_1$). Add water in the jar till sand is fully submerged. Stir the jar and keep for some time. Due to excess water sand comes to its original volume without bulking. Measure the level of sand ($h_2$).

$$\boxed{\textbf{Bulking} = \frac{100(h_1 - h_2)}{h_2}\%}$$

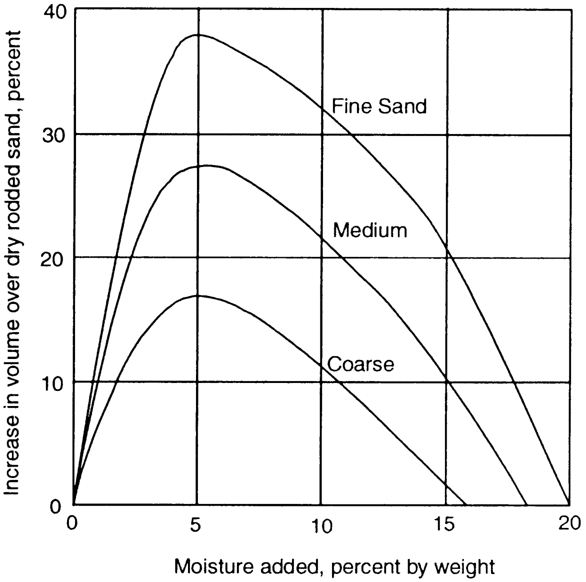


**Fig. 3.9.** Bulking of Sand

**Table 3.7** Bulking of Sand for various Moisture Contents

| *Moisture Percent* | | *Percentage Bulking* | |
|---|---|---|---|
| | *Fine Sand* | *Medium Sand* | *Coarse Sand* |
| *(i)* | *(ii)* | *(iii)* | *(iv)* |
| 1 | 16 | 8 | 6 |
| 2 | 16 | 16 | 12 |
| 3 | 32 | 22 | 15 |
| 4 | 36 | 27 | 17 |
| 5 | 38 | 29 | 18 |
| 6 | 37 | 28 | 18 |
| 8 | 35 | 26 | 16 |
| 10 | 32 | 22 | 12 |
| 12 | 28 | 19 | 8 |
| 15 | 22 | 12 | 2 |
| 17 | 18 | 7 | 0 |
| 20 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 |

Volume measurement of sand must be modified to account for bulking effect in moist sand at site. Water content should also be estimated and adjusted from the designed quantity of water. For example if mix proportions by volume are 1 : 2 : 5 and sand at site has 25 % bulking, the sand measurement in one bag batch shall be modified as: 2 × 35 × (1 + 25/100) = 88 litres of moist bulked sand (one bag cement contains 35 litres). Actual volume of sand shall be 88 × 1/1.25 = 70 litres, which is designed quantity of sand in the batch.

### 3.3.9 Unit Mass (Weight)/Bulk Density

The mass of material required to fill container of unit volume is called unit mass (weight) or bulk density. The unit volume is actually the bulk volume and represents the sum of volume of solids and the volume of voids. The bulk density can be easily measured by filling the containers of certain known volume V with aggregate in a standard manner levelled with the brim and determining its mass (weight-W).

Bulk density is thus calculated as $\mathbf{BD} = \frac{W}{V}$

The bulk density depends on the method of filling the container and how densely the aggregate is packed. The **shape**, and **grading** of aggregate **affects the packing** and with better packing by compaction, the density increases. The bulk density is therefore specified as **loose bulk density** and **rodded bulk density** depending on whether the container is filled loosely (without compaction) or rodded (with compaction) respectively.

Containers of different standard volume capacities are used for different sizes of aggregate and are given as under:

| | | | |
|---|---|---|---|
| Size of Aggregate: | 4.75mm and under | 4.75mm to 40 mm | over 40mm |
| Volume of Container: | 3 litres | 15 litres | 30 litres |

Method of determining bulk density is-specified in IS: 2386-1963 (part iii).

Various factors affecting bulk density of aggregate should be considered and specified while measuring the bulk density. These factors are:

| | |
|---|---|
| Degree of compaction | Higher compaction leads to higher bulk density |
| Shape of particle | With the same compaction rounded aggregate has higher bulk density than angular aggregate. |
| Grading of aggregate | Well-graded aggregate has lesser voids and hence higher bulk density compared to single size aggregate, provided the compacting effort is the same. |

Some values of bulk densities are given in Table 3.8

**Table 3.8** Bulk Densities

| *Material/Aggregate Type* | *Bulk Density (kg/litre)* |
|---|---|
| Cement | 1.44 |
| River sand: Fine | 1.44 |
| Medium | 1.52 |
| Coarse | 1.60 |
| Beach or river single | 1.60 |
| Crushed stone | 1.60 |
| Stone screening | 1.44 |
| Broken granite | 1.88 |

For batch purposes loose bulk density is used for conversion of mass (weight) of aggregate into bulk volume or vice versa. Rodded bulk density is used for detecting the uniformity of shape and grading of aggregate.

### 3.3.10 Specific Gravity

Aggregate generally contains pores, both permeable and impermeable, the term specific gravity has to be carefully defined with reference to these pores. Absolute specific gravity refers to the weight of the solids to the weight of an equal volume of distilled water both considered at the same temperature. In order to eliminate the effect of enclosed impermeable pores, the **material needs to be pulverised.** This is not very important in relation to concrete.

**Apparent specific** gravity is defined as the ratio of weight of aggregate solids to the weight of distilled water of an equal volume of solids excluding permeable pores. Specific gravity based on surface saturated condition is defined as the ratio of **weight of aggregate solids in saturated surface dry condition** to the weight of distilled water of an equal volume to that of **solids including permeable pores.**

IS: 2386-1963(part iii) specifies methods of determining the specific gravity for different sizes of aggregate.

Most of aggregates have specific gravity (SSD basis) between 2.5 and 2.90. Specific gravity of aggregate form an important parameter in design of concrete mix proportions and for determining void ratio in aggregate. Heavy weight concrete needs aggregate of high specific gravity while light weight concrete needs aggregate of low specific gravity. Values of specific gravity of some aggregates are given in Table 3.9.

**Table 3.9** Specific Gravity (Saturated Surface Dry Basis)

| *Sr. No.* | *Material* | *Sp. Gravity* |
|---|---|---|
| 1. | Cement | 3.15 |
| 2. | Traps | 2.90 |
| 3. | Granite | 2.80 |
| 4 | Gravel | 2.66 |
| 5 | Sand | 2.65 |

### 3.3.11 Thermal Properties

Thermal properties of aggregate affects the performance of concrete. These properties are coefficient of thermal expansion, specific heat, and conductivity. Specific heat and conductivity becomes important in mass concrete and where insulation characteristics are desired. The coefficient of thermal expansion of aggregate influences this coefficient of concrete directly. Higher coefficient of expansion of aggregate leads to higher coefficient of expansion for the concrete. Large difference in coefficient of expansion of aggregate and cement paste with high change in temperature leads to distress. The thermal coefficient of expansion for majority of aggregates lies between $5 \times 10^{-6}$ per °C and $13 \times 10^{-6}$ per °C while that of cement paste lies between $10 \times 10^{-6}$ and $16 \times 10^{-6}$ per °C. Quartz changes state at 573 °C and expands suddenly and hence should not be used for fire resistant concrete.

### 3.3.12 Deleterious Substances

There are three categories of deleterious substances generally present in aggregate: Impurities interfering with hydration of cement such as organic matter; Coatings preventing the development of bond between aggregate and cement paste such as silt and clays; and Individual weak and unsound particles such as shale and coal.

These deleterious substances, if present in sufficient quantities, affect the concrete strength and durability adversely. IS: 383- 1970 specifies the limits of deleterious material as given in Table 3.10.

Apart from standard tests, simple test for detection of silt impurities may be carried out with a glass measuring cylinder of 250 ml capacity. Add one percent common salt solution in the cylinder upto 50 ml mark. Add aggregate to fill the jar half full. Add some more solution, vigorously shake the contents and keep the cylinder for 3 hours for settlement of silt. Silt settles slowly and forms a distinct layer at top which can be measured. The percentage of silt should not be more than 5-6 percent, and for high silt content the aggregate should be washed thoroughly with clean water. The aggregate should not contain large quantities of weak and unsound particles.

**Table 3.10** Limits of Deleterious Materials

| *Sr. No.* | *Deleterious Substance* | *IS Code for Test* | *Fine Aggregate Percent By Mass Maximum* | | *Coarse Aggregate Percent By Mass Maximum* | |
|---|---|---|---|---|---|---|
| | | | *Uncrushed* | *Crushed* | *Uncrushed* | *Crushed* |
| 1 | Coal and lignite | IS: 2386-63 (part II) | 1.0 | 1.0 | 1.0 | 1.0 |
| 2 | Clay lumps | -do- | 1.0 | 1.0 | 1.0 | 1.0 |
| 3 | Materials finer than 75 micron sieve | IS: 2386- 63 (part I) | 3.0 | 1.50 | 3.0 | 3.0 |
| 4 | Soft fragments | IS: 2386-63 (part II) | — | — | 3.0 | — |
| 5 | Shale | -do- | 1.0 | — | — | — |
| 6 | Total percentages of all deleterious materials (except mica) | — | 5.0 | 2.0 | 5.0 | 5.0 |

### 3.3.13 Soundness

**Soundness** of aggregate is its **resistance to disintegration** by volumetric changes under physical forces such as heating and cooling, wetting and drying, freezing and thawing due to climatic changes. Aggregate is said to be unsound when volume changes occur due to above causes and result in disintegration of concrete. This may range from local scaling to extensive surface cracking and disintegration of concrete.

Unsoundness is exhibited by porous Cherts, some Shales, some lime stones containing expansive clay, some dolarite and some sand stones. Characteristics of aggregate mainly makes it sound or unsound.

Soundness can be determined as specified in IS: 2386-1963 (part v). This test popularly known as "sulphate test" consists of subjecting a graded and weighed sample of aggregate to alternate cycles of drying and chemical immersion. Alternate **immersion** of aggregate in saturated solution of **sodium sulphate** or **magnesium sulphate** and **oven drying** is carried out for determining the weight loss after specified cycles of immersion and drying. The test is not really simulation of conditions of exposure of freezing and thawing and provides only some guidance. The limits specified in IS: 383-1970 should be carefully used alongwith the actual performance of aggregate from the service-record. As a general guide, the code specifies that the limits of average **loss of weight after 5 cycles** shall not exceed the following:

| | |
|---|---|
| Fine aggregate | **10%** when tested with Sodium sulphate, and **15%** when tested with magnesium sulphate |
| Coarse aggregate | **12%** when tested with sodium sulphate and **18%** when tested with magnesium sulphate. |

Weigh the sample of aggregate passing certain sieve size and retained on the next standard sieve size before the test. The sample is subjected to alternate cycles of sulphate test and weight is taken after sieving through the same sieve. **Percentage loss of mass (weight)** is measured to indicate soundness.

### 3.3.14 Alkali-Aggregate Reaction and Durability

Durability of aggregate is its resistance to disintegration due to chemical reaction of aggregate with cement paste. This reaction takes place between **active silica or carbonate** constituents sometimes **present in aggregate** and **the alkalies in cement.** This reaction causes excessive expansion and results in cracking of concrete. Such deleterious reactions are encountered in various climatic zones and are basically due to high alkali content of cement (more than 0.6 % expressed in terms of $Na_2O$) and presence of active silica in aggregate.

Alkali-aggregate reaction is determined with the help of "mortar bar test" as specified in IS: 2386-1963 (part vii). The test measures the expansion developed by the cement-aggregate combination in mortar bar 100mm in length and 25 mm × 25 mm in section.

Although, the test results are quite useful, but it takes several months and necessitates crushing of coarse aggregate. If the mortar bar expansion exceeds **0.05 percent at 6 months** and **0.10% at 12 months,** the aggregate is considered as **potentially reactive.** Alternative test for determining the potential reactivity of aggregate is the chemical method using sodium hydroxide solution. Although the results are obtained in 3 days but the test results are not reliable and conclusive.

The problem of alkali-aggregate reaction can be overcome by using cements with low alkali content (less than 0.6% alkali calculated as $Na_2O$) or by adding finely ground suitable pozzolana to the concrete mix. Pozzolana reacts with the alkalis before they attack the reactive aggregates. Generally natural aggregate in India are not reactive except some of rock aggregates containing highly granulated quartz. Some sand stones and quartzites containing more than 5% cherts also show deleterious reactions.

### 3.3.15 Grading of Aggregate

**Particle size distribution** of aggregate is known as its gradation. The aggregate is said to be graded if it contains particles of various sizes in different proportions. The size of aggregate particles is designated by the **sieve size they pass** and is determined by sieve analysis. Set of IS sieves used for sieve analysis of aggregate are as follows:

> **80mm, 63mm, 50mm, 40mm, 31.5mm, 20mm, 16mm, 12.5mm, 10mm, 6.3mm, 4.75mm,** (square hole perforated plate type). **3.35mm, 2.36mm, 1.18mm, 600 micron, 300 micron, 150 micron, 75 micron** (fine mesh wire cloth type).

Aggregate is sieved through the set of sieves and the material retained on each of sieves is weighed. From these weights necessary grading curves are drawn and fineness modulus is also calculated for studying grading pattern.

Depending on the sieve analysis data, the grading can be called "**continuous**" or "**gap**" grading. Aggregate is said to be continuously graded when it contains all particle size groups from the maximum particle size to the minimum size in sufficient proportions and when these proportions increase or decrease progressively. These gradings are further said to be **coarser or finer** according as they contain a higher proportions of coarser or finer particles with reference to the specified grading with which comparison is being made. Aggregate is said to be gap graded when certain sizes of particles are missing in the whole lot.

The grading may also be called irregular/poor if it has **excess or deficient** proportions of certain intermediate particle sizes and the **grading is not continuous** or gap graded.

The grading of aggregate has its influence on **voids** content, **mortar** requirement, **cohesiveness** or segregation, **harshness**, **bleeding**, and **strength** of concrete.

Well-graded aggregate has less volume of voids than aggregates of single size or irregular/poorly graded aggregate. This can easily be verified by taking samples of single size aggregate, poorly graded aggregate and well graded aggregate in graduated glass jars and filling these jars, with measured quantity of water upto the surface of samples. It will be found that **well graded** aggregate require **minimum quantity of water** for filling the voids. Also the percent of voids remain approximately the same for different sizes. For continuous and **coarser grading voids are less** and hence the mortar required to fill the voids shall also be less.

Coarser grading, specially if not well graded, tends to segregate and hence for proper cohesiveness there should be sufficient finer material in the mix. Continuously graded aggregate produce smooth surface, while irregular grading produce harsh mixes specially when finer material is deficient. **Coarser grading** alongwith excessive water content leads to **bleeding.** Finer grading alongwith just sufficient quantity of water shall prevent bleeding in concrete mix.

Grading influences indirectly the strength of concrete. **Coarser grading** results in lower surface area and requires lesser quantity of water for certain desired workability and hence makes concrete **economical for the desired strength.** For low water-cement ratio, coarser grading providing lesser surface area gives better workability and compaction and higher strength. **Finer grading** having more surface area requires more water or higher water-cement ratio and hence **lower strength** of concrete mix.

The method of sieve analysis is described in IS: 2386-1963 (part i). A known mass of aggregate is sieved through a set of standard IS sieves and the material retained on each sieve is weighed and tabulated as shown in example given in Table 3.11. Cumulative percentage retained and passing each sieve are calculated from the data of sieve analysis, **grading curves are drawn from cumulative percentages passing** and fineness modulus calculated from **cumulative percentages retained.**

**Table 3.11** Example of Sieve Analysis - Sample 1000 gm

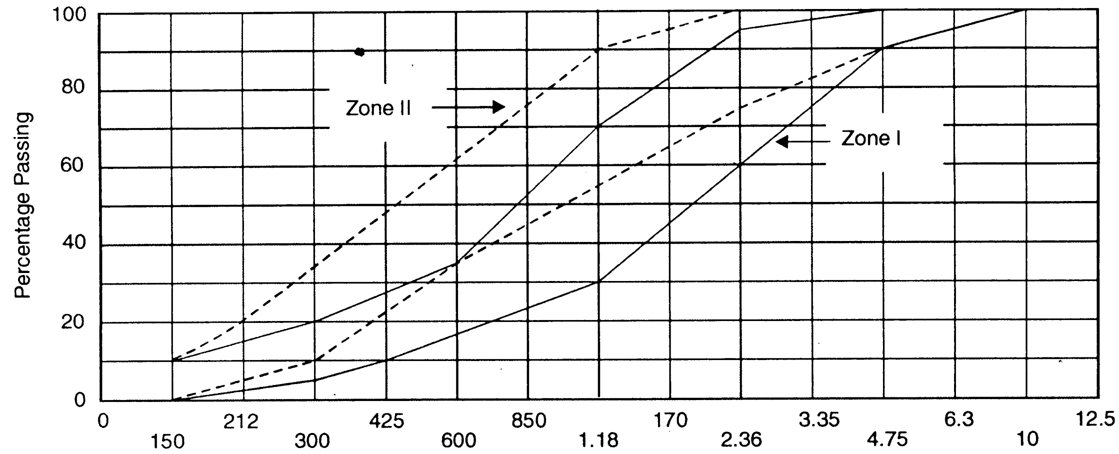
| *I.S. Sieve Size*<br>*i* | *Mass retained (gram)*<br>*ii* | *Percentage mass retained*<br>*iii* | *Cumulative Percentage retained*<br>*iv* | *Cumulative Percentage passing*<br>*v* | *Remarks*<br>*vi* |
|---|---|---|---|---|---|
| 80mm | 0.0 | 0.0 | 0.0 | 100.0 | |
| 63mm | 0.0 | 0.0 | 0.0 | 100.0 | |
| 40mm | 0.0 | 0.0 | 0.0 | 100.0 | |
| 20mm | 7.0 | 0.7 | 0.7 | 99.3 | |
| 16mm | 145.0 | 14.5 | 15.2 | 84.8 | |
| 12.5mm | 510.0 | 51.0 | 66.2 | 33.8 | |
| 10mm | 120 | 12.0 | 78.2 | 21.8 | |
| 4.75mm | 133 | 13.3 | 91.5 | 8.5 | |
| 2.36mm | 51.0 | 5.1 | 96.6 | 3.4 | |
| 1.18mm | 25.0 | 2.5 | 99.1 | 0.9 | |
| 600micron | 02.0 | 0.2 | 99.3 | 0.7 | |
| 300micron | 01.0 | 0.1 | 99.4 | 0.6 | |
| 150micron | 01.0 | 0.1 | 99.5 | 0.5 | |
| Finer than 150 micron | 05.0 | 0.5 | — | — | |
| | | | 745.7 | | |

Total Commulative % retained = 745.7

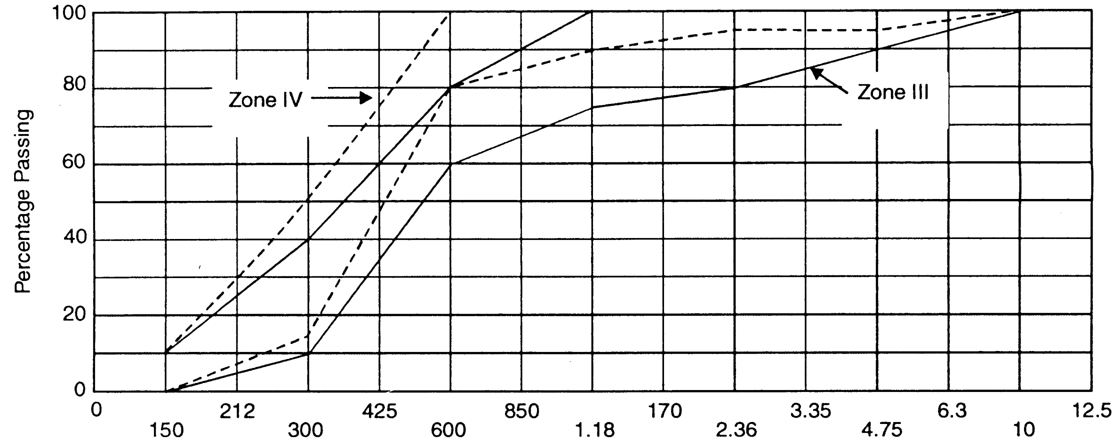
Fineness Modulus = 7.457 ≈ 7.46

**Fineness modulus** of aggregate is defined as the **sum of the cumulative percentages retained** on the standard set of sieves from smallest to the largest sieve size present **divided by 100.** The fineness modulus (**FM**) can be looked upon as a **weighted average size of sieve** on which the material is retained, the sieves being counted from the finest. For example, a **FM of 7.46** indicates that the **average size lies between 7th and 8th sieve i.e.** between 10 mm and 12.5 mm sieves. FM for coarse aggregate is higher than fine aggregate. The **fineness modulus increases with coarser grading.** The fineness modulus can not represent the distribution and the same FM may represent a large number of particle size distributions or grading curves. The fineness modulus is therefore not a good way of describing the grading of aggregate, although it is a useful tool for checking variations in the aggregate from the same source from time to time.

Grading curves are prepared on a semilog graph representing percentage passing along ordinate (on linear scale) and the sieve size along abscissa (on **logarithmic scale**). The graph provides particle size distribution of aggregate at a glance and it can be compared with standard grading curves for improvement of given sample by mixing certain sizes in the desired proportion. Steep slope of grading curve at a particular sieve size indicates greater proportion of a particular particle size, while a flat slope indicates lesser proportion of that size. It is very difficult to have exactly the same grading as specified and hence **grading zones** are specified giving **ranges of grading.** Generally, if grading curve lies within the specified zone it is accepted. If a grading curve of a given sample lies above the specified grading, it is said to be



(a). Grading Limits for Zone I and II of Fine Aggregate



(b). Grading Limits for Zone III and IV of Fine Aggregate

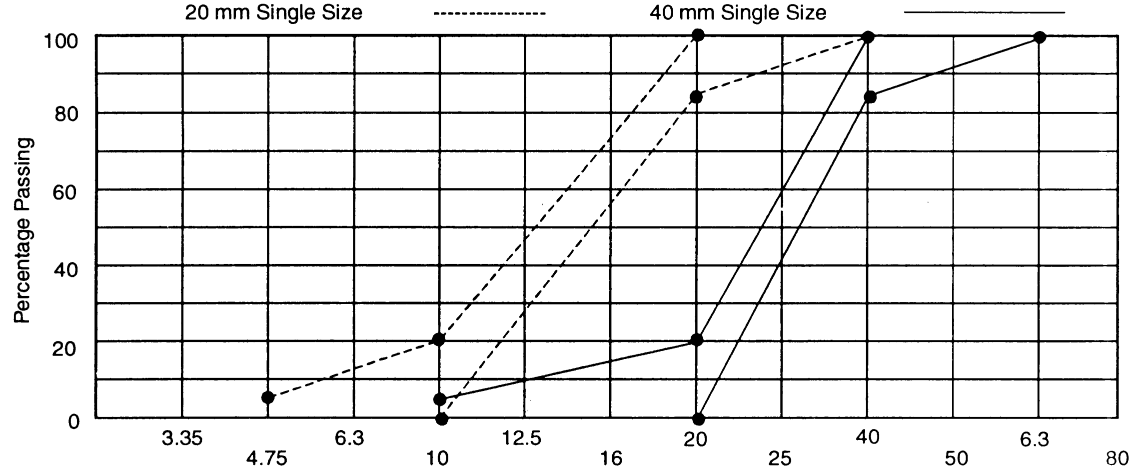
Fig. 3.10. Grading Curves of Fine Aggregate

**Table 3.12** Fine Aggregate Limits (Sand Zones)

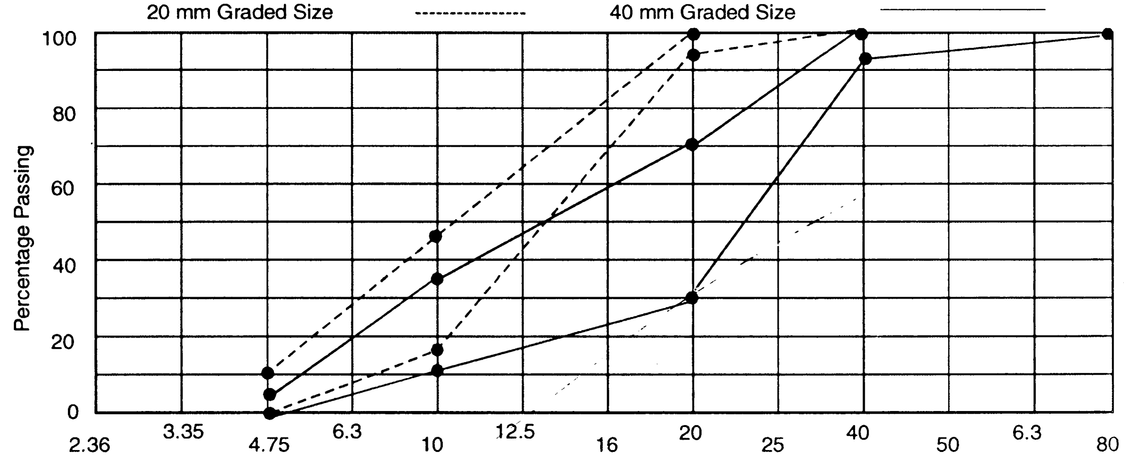
| | *I.S. Sieve Size* | | *Percentage Passing* | | *Remarks* |
|---|---|---|---|---|---|
| | *Grading Zone I* | *Grading Zone II* | *Grading Zone III* | *Grading Zone IV* | |
| 10mm | 100 | 100 | 100 | 100 | For crushed Stone sands, permissible-Limits on 150 micron-sieve is increased to **20 percent** without **affecting** 5 percent allowancepermitted in other **sieves** |
| 4.75mm | 90-100 | 90-100 | 90-100 | 95-100 | |
| 2.36mm | 60-95 | 75-100 | 85-100 | 95-100 | |
| 1.18mm | 30-70 | 55-90 | 75-100 | 90-100 | |
| 600 micron | 15-34 | 35-59 | 60-79 | 80-100 | |
| 300 micron | 5-20 | 8-30 | 12-40 | 15-50 | |
| 150 micron | 0-10 | 0-10 | 0-10 | 0-15 | |

* **Note:** Zone classification is mainly based on 600 micron sieve.

finer than the specified grading. If a **grading curve** of a given sample **lies below** the specified grading, it is said to be **coarser than the specified grading.** Horizontal **flat portion** in a grading curve **indicates missing of a particular size** and represents **gap grading.**



**(a).** Grading Limits for Coarse Aggregate 20 mm and 40 mm Single Size



**(b).** Grading Limits for Coarse Aggregate 20 mm and 40 mm Graded

**Fig. 3.11.** Grading of Coarse Aggregate

For preparing good concrete mixes there are standard grading Zones specified in IS: 383-1970 for single size coarse aggregate, graded coarse aggregate, all in aggregate, and fine aggregate. According to grading, sands (fine aggregate) are grouped in 4 Zones: **Zone I, Zone II, Zone III** and **Zone IV** (Refer Table 3.12). **Zone I is coarsest grading,** while **Zone IV is the finest** of all and as far as possible it should not be used for important structural concrete. Most commonly available Indian sands are of **Zone II** and **Zone III.** These 4 sand grading Zones are shown in **Fig. 3.10 (a)** & **(b).** Grading limits of coarse aggregate of single size and graded type is shown in **Fig. 3.11,** and limits are given in **Table 3.13.** Grading limits of all in aggregate is shown in **Fig. 3.12** and given in **Table 3.14** and such a grading is obtained by combining coarse aggregate and fine aggregate in suitable proportion. Specified grading can be obtained by combining different single size or graded aggregates in suitable proportions determined by analytical or graphical method.

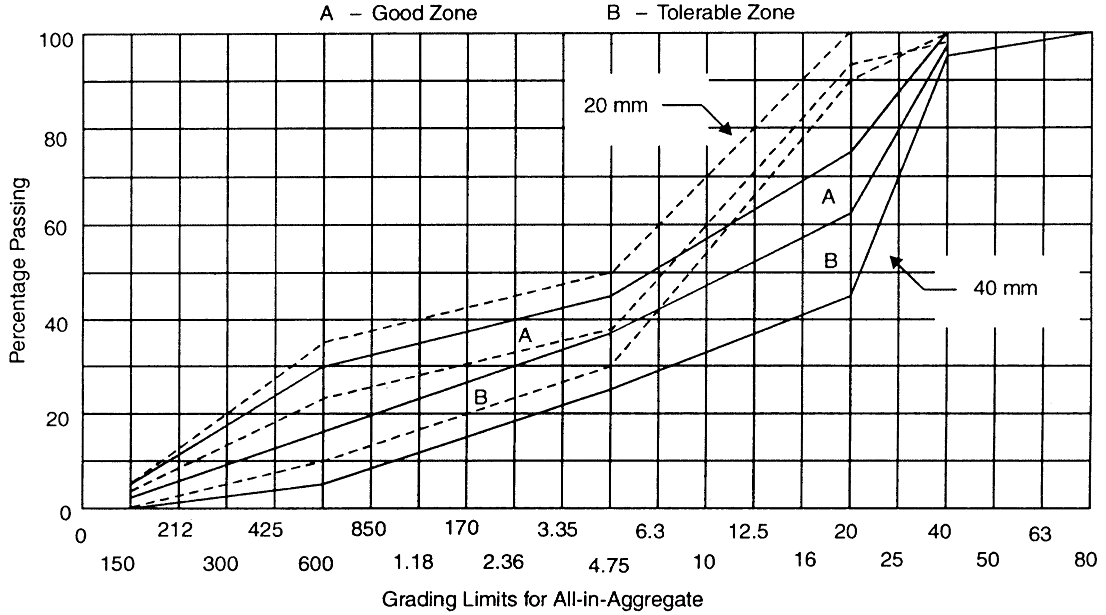


**Fig. 3.12.** Grading Curves of All in Aggregate

**Table 3.13** Grading Limits of Coarse Aggregate

| *IS Sieve* | *Percentage passing for single-sized aggregate of Nominal size* | | | | | | *Percentage passing for graded Aggregate of Nominal size* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *63mm* | *40mm* | *20mm* | *16mm* | *12.5mm* | *10mm* | *40mm* | *20mm* | *16mm* | *12.5mm* |
| *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* | *(7)* | *(8)* | *(9)* | *(10)* | *(11)* |
| 80mm | 100 | —— | —— | —— | —— | —— | 100 | —— | —— | —— |
| 63mm | 85 to 100 | 100 | —— | —— | —— | —— | —— | —— | —— | —— |
| 40mm | 0 to 30 | 85 to 100 | 100 | —— | —— | —— | 95 to 100 | 100 | —— | —— |
| 20mm | 0 to 5 | 0 to 20 | 85 to 100 | 100 | — | — | 30 to 70 | 95 to 100 | 100 | 100 |
| 16mm | — | — | — | 85 to 100 | 100 | — | — | — | 90 to 100 | — |
| 12.5mm | — | — | — | — | 85 to 100 | 100 | — | — | — | 90 to 100 |
| 10mm | 0 to 5 | 0 to 5 | 0 to 20 | 0 to 30 | 0 to 45 | 85 to 100 | 10 to 35 | 15 to 45 | 30 to 70 | 40 to 85 |
| 4.75mm | — | — | 0 to 5 | 0 to 5 | 0 to 10 | 0 to 20 | 0 to 5 | 0 to 10 | 0 to 10 | 0 to 10 |
| 2.36mm | — | — | — | — | — | 0 to 5 | — | — | — | — |

**Table 3.14** Grading limits of all-in-aggregate

| *IS Sieve Designation* | *Percentage passing for All-In-Aggregate of* | |
|---|---|---|
| | *40mm Nominal size* | *20mm Nominal size* |
| 80mm | 100 | — |
| 40mm | 95 to 100 | 100 |
| 20mm | 45 to 75 | 95 to 100 |
| 4.75mm | 25 to 45 | 30 to 50 |
| 600 micron | 8 to 30 | 10 to 35 |
| 150 micron | 0 to 6 | 0 to 6 |

### 3.3.16 Effect of Aggregate on Concrete

Aggregate is generally stronger than the cement paste in concrete. The strength of concrete is the **lowest** of **strength of paste, strength of aggregate,** and **bond between cement paste** and aggregate. **Strength of cement paste** is mainly governed by **water-cement ratio** while characteristics of aggregate governs the other two strengths. In **low strength concrete** failure may occur by **failure of cement paste** while in high strength concrete failure is likely to occur by **loss of bond between** cement paste and aggregate. Bond between cement paste and aggregate depends on the **surface area of aggregate** particles which is influenced by **size, shape** and **surface texture** of particles. Thus for high strength concrete small size, angular shape and rough texture aggregate shall be more suitable due to availability of higher surface area for adhesive strength. Finer grading also provides higher surface area for higher bond strength. Aggregates of 40mm size and rounded shape may be permitted for concrete of grades M10 and M20 while aggregates of **20mm size and angular shape** are preferred for concrete of **grades M25 and above.** Angular (crushed) rough textured aggregate of **10mm size** shall be found most suitable in case of very high strength concrete (**M40, M50** grade).

The influence of aggregate **size, shape, texture,** and **grading** may be opposite in nature on workability and strength and hence these characteristics should be chosen with proper analysis and tests.

Aggregate characteristics such as specific gravity, bulk density and moisture absorption should be determined for proper design and adjustments of mix proportions for a job site. Determination of **deleterious materials, soundness** and **alkali aggregate reactivity** help in **quality control for proper durability and strength** of concrete. Thus aggregate characteristics play an important role in concrete chain for the desired quality.

## 3.4 WATER

Although water is an important constituent of concrete, but it does not receive due attention in preparation and quality control of concrete. Strength and other properties of concrete are developed as a result of reaction of cement and water (hydration) and thus water plays a critical role. Quality of mixing and curing water sometimes leads to distress and disintegration of concrete reducing the useful life of the concrete structure. Water use for concrete mixture should not contain substances which can have harmful effect on strength (i.e. on hydration process of cement) or durability of the concrete in service. Certain substances if present, in sufficient quantities in water, may have an injurious effect upon concrete. Water used for mixing and curing shall be clean and **free from injurious** amounts of **oils, acids, alkalis, salts, sugar, organic matter, sewage,** and **other substances** which are deleterious to concrete or steel reinforcement.

Potable water is generally considered satisfactory for mixing and curing of concrete. In case of doubt, water should be tested for its suitability. The details of various tests (physical and chemical) for water used in concrete are given in IS: 3025-1964. Permissible limits of impurities in mixing water are specified in IS: 456-1978 and is given in Table 3.15.

**Table 3.15** Permissible limits for solids and concentrations of impurities (Ref. IS: 456-1978)

| *S.No.* | *Impurities (test IS: 3025-1964)* | *Permissible limits (max)* |
|---|---|---|
| 1. | Organic solids | 200 mg/litre |
| 2. | Inorganic solids | 3000 mg/litre |
| 3. | Sulphate solids (as $SO_4$) | 500 mg/litre |
| 4. | Chloride solids (as C1) | 2000 mg/litre for plain concrete work<br>1000mg/litre for RCC |
| 5. | Suspended matter | 2000 mg/litre |
| 6. | To neutralise 200ml water sample using phenolphthalein as an indicator | Should not require more than 2ml of 0.1 normal NaOH |
| 7. | To neutralise 200ml water sample using methyl orange as an indicator | Should not require more than 2ml of 0.1 normal HCl |
| 8. | PH value | Generally not less than 6 |

For evaluating the effect of using a water of questionable quality, make comparative tests for time of set and soundness, and strength with water of doubtful quality and distilled water. **Compressive strength test for performance of water in concrete** shall be carried out on the 150 mm concrete cubes prepared with water proposed to be used. Average 28 days compressive strength of 3 cubes of 150mm size shall not be less than 90 percent of the average strength of 3 similar cubes prepared with distilled water. Initial setting time of test block made with proposed water and cement shall not be less than 30 minutes and not differ by ± 30 minutes from the initial setting time of control test block prepared with the same cement and distilled water.

Based on the minimum strength ratio of 85 percent, the following waters were found to be suitable for concrete making:

- Marsh water;
- Sea water (salinity not above 3.5%), for plain concrete only;
- Water with a maximum concentration of 1% $SO_4$;
- Alkali water with a maximum of 0.15% $Na_2SO_4$, NaCl;
- Pumpage water from coal and gypsum mines; and
- Waste water from slaughter houses, breweries, gas plants, paint and soap factories.

The water found unsuitable for the purpose of preparing concrete are:

- Acid waters;

- Lime soak water from tannery waste;
- Carbonated mineral water discharged from galvanizing plants;
- Water containing over 2 percent of sodium chloride or 3.5 percent of sulphates, and
- Water containing sugar or similar compounds

The lowest content of dissolved solids in these unacceptable waters was found to be over 6000 PPM except for a highly carbonated mineral water which contained 2140 PPM of total solids. Normal potable (drinking) water (except that containing sugar) is suitable and does not contain more than 2000 PPM of dissolved solids and also the specification of potable water excludes all above polluted water. SP: 23-1982 specifies tolerable limits on the basis of test results and is given in Table 3.16.

**Table 3.16** Concentrations of some impurities in water considered as tolerable (Ref. SP: 23-1982)

| *Sr. No.* | *Impurity* | *Maximum Tolerable Concentration* |
|---|---|---|
| 1. | Sodium/Potassium Carbonates and Bicarbonates | 1000 PPM (total)(if this exceeds, tests of setting time and 28 days strength conducted) |
| 2. | Sodium Chloride | 20000 PPM |
| 3. | Sodium | 10000 PPM |
| 4. | Calcium and Magnesium Bicarbonates | 400 PPM of bicarbonate ion |
| 5. | Calcium Chloride | 2 % by mass of cement in plain concrete |
| 6. | Iron Salts | 40000 PPM |
| 7. | Sodium Iodate, Phosphate Arsenate and Borate | 500 PPM |
| 8. | Sodium Sulphide | Even 100 PPM warrants testing |
| 9. | Hydrochloric and Sulphuric and other Common Inorganic Acids | 10000 PPM |
| 10. | Sodium Hydroxide | 0.5 % by mass of cement if setting not affected |
| 11. | Silt and Suspended Particles | 2000 PPM |

Wherever suitable waters are not available locally, then water processing, modification of cement quality or transporting suitable water from long distances may be resorted or loss of strength and durability may be accepted.

Except for possible discoloration, the presence of silt, oil, or salts in curing water does not appear to have harmful effects. However, water containing higher concentrations of acid or organic substances should be considered with suspicion and subjected to investigation.

## 3.5 SUMMARY

Cement concrete comprises of cement, fine aggregate, coarse aggregate and water as its basic ingredients. Properties and proportions of each ingredient influence the quality of the concrete during fresh as well as hardened states.

**Cement** acts as **binding material** and is obtained by pulverising clinker formed by calcining raw materials comprising of Lime, Silica, Alumina and Ferric Oxides. Principal compounds formed are **$C_3S$, $C_2S$, $C_3A$** and **$C_4AF$** (where C = CaO, S = $SiO_2$, A = $Al_2O3$, and F = $Fe_2O_3$).

Proportions of these four principal compounds influence the characteristics and type of cement. Physical properties of cement viz. **fineness, setting and hardening, strength, soundness** and **heat of hydration** directly affect the concrete properties. Fineness and strength of cement helps in classifying the cement into different grades (**33, 43, 53**). For producing desired concrete quality various characteristics of cement must be considered. Finer cements hydrate rapidly to develop higher strength and also results in better workability of concrete. Strength of cement can be evaluated by making **1:3 cement: standard sand mortar** cubes. Soundness of cement can be checked with the help of Le-chatelier apparatus. Setting time can be evaluated using Vicat's apparatus.

Aggregate (FA and CA) forms bulk of concrete mass and also provides volumetric stability to concrete. **Aggregate** properties affect **workability, strength, durability** and other special characteristics of concrete. Aggregate characteristics comprise of **size, shape, texture, strength, absorption, bulking, density, sp.gravity, thermal properties, impurities, durability** and **gradation.** Smaller the particle size of aggregate greater will be surface area per unit volume resulting in lesser workability of concrete. Aggregate crushing value, impact value representing strength is obtained as percent of sample passing 2.36 mm sieve after 15 blows of standard hammer or a pressure of 400 kN. Fineness modulus is commulative percentages of particles retained on standard set of sieves. **Fineness modulus** represents **average sieve size of aggregate** starting from the finest sieve size. Proper grading of aggregate eliminates harshness, segregation and bleeding.

Sand grading zone also affects the properties and qualities of concrete. Sand Zone I is coarsest and leads to coarser grading for production of economical and good quality concrete. Bulking of sand should be measured and adjusted for good quality concrete production. **Surface saturated dry** aggregate **forms the basis of calculations** for design of mix proportions.

Aggregate is generally stronger than cement paste and hence for producing high strength concrete, use of smaller size, angular shape and rough textured aggregate is recommended. Aggregate grading within specified grading zones can be accepted for the design mix.

Potable water is generally acceptable for the production of good quality concrete. Water should not contain deleterious impurities beyond those specified in Indian standards. Acidic water is avoided as far as possible.

## PRACTICE QUESTIONS

3.1 List basic ingredients of cement concrete.

3.2 List characteristics of cement.

3.3 Describe: fineness, strength and hardening of cement.

3.4 Explain the effect of strength and heat of hydration of cement on quality of concrete.

3.5 Differentiate: strength and soundness and setting and hardening of cement.

3.6 Describe Indian standard specifications of ordinary portland cement.

3.7 List and define characteristics of aggregate.

3.8 Explain the effect of size of aggregate on the properties of fresh concrete.

3.9 Explain the effect of **shape of aggregate** on the properties of concrete.

3.10 Explain the effect of strength of aggregate on the strength of concrete.

3.11 Explain **bulking of sand** and its influence on concrete. Describe how to compensate bulking at site.
3.12 Explain the influence of alkali-aggregate reaction on the properties of concrete.
3.13 Explain the influence of **aggregate grading** on concrete properties.
3.14 Explain the influence of **sand grading zone** on concrete properties.
3.15 Define finess modulus of aggregate.
3.16 Explain the effect of quality of water on the quality of concrete.
3.17 Specify minimum standards of water required for concrete.
3.18 Explain the role of basic ingredients in achieving the desired quality of cement concrete construction.
3.19 Explain the role of site engineers for managing the quality of cement concrete construction.

CHAPTER 4

# *Influence of Special Admixtures on Quality of Concrete*

## LEARNING OBJECTIVES

The learner understands the influence of special admixtures on properties and quality of cement concrete and will be able to:

- Describe importance of admixtures in modifying properties of cement concrete;
- Define admixtures to concrete;
- State general influence of admixtures in fresh and hardened cement concrete;
- List type of admixtures used for cement concrete;
- Describe properties and influence of plasticizers on properties of concrete;
- Describe properties and influence of **Accelerators**, Retarders, and Air entraining agents on properties of cement concrete:
- Describe properties and influence of mineral admixtures on properties of concrete;
- Describe properties and influence of Water proofing compounds, Bonding admixtures, Curing compounds, Non shrinking grouting agents, and Pozzolanic admixtures on properties of cement concrete:
- Explain the criteria of selection of admixture for cement concrete or mortar.

## 4.1 INTRODUCTION

Cement concrete is the most widely used construction material in the world. Cement consumption in the world is around 20 billion tonnes annually (2 tonnes/capita/annum). The reasons for such widespread use of cement concrete are its easy adaptability, durability, strength, availability, easy construction and overall economy in construction. Cement concrete is the only material which can be used everywhere from buildings to big projects (viz power houses, irrigation, transportation, railways, bridges and shipyards).

Cement concrete comprises of basic materials: cement, aggregates, and water. Quality control in cement concrete construction is based on its properties both in plastic (or fresh) and hardened states. The most important property of cement concrete sought in fresh state is "**workability**" while "**strength**" and "**durability**" are important in hardened state. With the development of concrete technology, it is now possible to achieve desired properties and quality both in fresh and hardened states. Achievement of desired qualities in concrete can be made economically possible by mixing of certain additives in the cement concrete.

The strength development of concrete with age is dependent on the curing method consistent with the use of admixtures (Fig. 4.1).

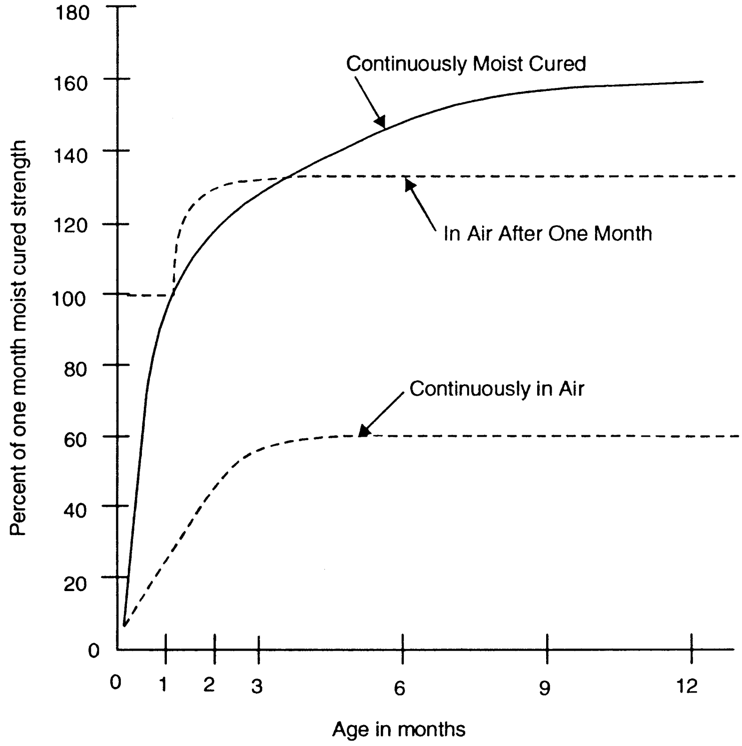


**Fig. 4.1.** Influence of moist curing with age on strength development of cement

An **admixture** is defined as the material added in small quantities to cement concrete, mortar or grout during mixing or before mixing to modify the properties both in fresh and hardened states. The proportion of admixtures does not generally exceed 5% by mass of the cement content in concrete, mortar or grout. Concrete admixtures are a new category of ingredients used in addition to the basic materials (cement, aggregates and water). These admixtures are added just before mixing of basic ingredients for uniform consistency.

The quality of concrete or mortar may be defined by the extent of **accomplishment of desired properties** for the specific purpose by the user at a **most optimum cost.** Several materials have been produced for addition to cement concrete or mortar to modify certain properties as required for a specific purpose and situation.

The admixtures may influence one or more than one property of cement concrete. Some of the admixtures may improve one property in positive direction while affect the other property in negative direction. The admixtures should, therefore, be used carefully only after ensuring the desired property through scientific **trial tests** and study of manufacturer's literature. Thus the proportion and the type of admixture is decided on the basis of modified property and optimum cost of concrete production.

Admixtures are normally supplied in liquid form for accurate dose measurement through automatic dispensing equipment by volume in relation to cement mass. Some admixtures are also supplied as powders.

Admixtures can be classified by the nature of their composition or the properties required to be modified.

## 4.2 ADVANTAGES OF ADMIXTURES

Use of admixtures in cement concrete, mortar or grout makes it possible to modify the properties of concrete both in fresh and hardened states. This facilitates in achievement of desired quality at site. There are many advantages of using admixtures in concrete, mortar or grout. Main advantages of using admixtures are:

- Reduction of cement possible by use of admixtures;
- Reduction in quantity of water possible due to use of plasticizers;
- Improvement of workability for better pumpability and compaction in general;
- Partial replacement of cement possible in case of mineral admixtures;
- Reduction in heat of hydration;
- Improvement in impermeability of concrete or mortar specially by using water proofing admixtures;
- Improvement of strength and durability due to use of various admixtures;
- Reduction in bleeding and segregation;
- Improvement or reduction in shrinkage cracking;
- Improvement in freeze-thaw resistance specially by use of air entraining admixtures;
- Improvement of resistance to aggressive environments;
- Modify setting and hardening characteristics as required in a particular situation by use of accelerators or retarders;
- Improvement in bond characteristics by use of bonding agents;
- Reduction in corrosion by using corrosion inhibitors;
- Improvement in surface resistance to abrasion and impact;
- Control and achievement of desired properties according to situations.

## 4.3 ADMIXTURE TYPES

Admixtures are grouped under two main categories as:

- Chemical admixtures; and
- Mineral admixtures.

Chemical admixtures are manufactured under variety of trade names to serve specific purpose of modifying properties of concrete in fresh as well as hardened sates.

### 4.3.1 Types of Chemical Admixtures

Chemical admixtures can be subdivided into the following types:

I. **Plasticizers** (also called **water reducers**)
  - Normal plasticizers (water reducers)
  - Super plasticizers (high range water reducers)

II. **Accelerators**
III. **Retarders**
IV. **Air Entrainers**
V. **Special Purpose Admixtures**

### 4.3.2 Types of Mineral Admixtures

Mineral admixtures are finely divided silicon particles added to cement concrete or mortar in large proportions. These finely divided mineral admixtures contain reactive silica for providing pozzolanic action and economical concrete. Mineral admixtures are further subdivided into: **Natural** Materials and **Bye** Product Materials.

| Natural Materials | Bye Product Materials |
|---|---|
| Volcanic gases | • Fly Ash |
| Volcanic tuffs | • Blast Furnace Slag |
| Calcined clays or shells | • Condensed Silica Fumes |
| Diatomaceous Earth | • Rice Husk Ash |

These materials can be regrouped on the basis of physical and chemical properties as:

- Cementitious
- Pozzolanic
- Pozzolanic and Cementitious
- Inert Material

## 4.4 PURPOSE OF ADMIXTURES

### 4.4.1 Chemical Admixtures

Chemical admixtures are used to modify following properties of fresh and hardened concrete:

***a) Fresh State***

- To increase workability;
- To accelerate or retard setting;

- To reduce settlement or create slight expansion;
- To modify the rate and capacity for bleeding;
- To reduce segregation;
- To improve pumpability; and
- To reduce slump loss.

***b) Hardened State***

- To reduce heat evolution during early hardening;
- To accelerate strength development at early ages;
- To increase ultimate strength;
- To increase durability;
- To decrease permeability;
- To control expansion due to alkali-aggregate reaction;
- To increase steel-concrete bond;
- To increase bond between existing and new concrete;
- To improve impact resistance and abrasion resistance;
- To inhibit corrosion of steel; and
- To produce coloured concrete or mortar;

### 4.4.2 Mineral Admixtures

Finely divided mineral admixtures are used for one or more of the following purposes:

- To correct the deficiency in the concrete to provide 'fines' missing in the fine aggregate so as to avoid problems of workability and finishing;
- To improve one or more qualities of the concrete, such as to increase sulphate resistance, to reduce expansion due to alkali-silica reaction, to reduce permeability, or to decrease heat generation; and
- To reduce cost of concrete-making materials, cost of concreting operations, or both.

Finely, divided mineral admixtures, particularly pozzolanas, can provide reduced cost of concrete-making materials because the optimum mix for given work usually will contain less cement, than a comparable mixture not containing finely divided pozzolanic admixtures. Apart from economy in cement concrete construction, the use of some of the bye products such as fly ash provides solution to its disposal problem. Large number of chemical and mineral admixtures are available and their characteristics and special features are discussed in next section.

## 4.5 CHEMICAL ADMIXTURES

### 4.5.1 Plasticizers (Water Reducers)

Normal plasticizers act directly on the individual particles of cement causing them to deflocculate and disperse more uniformly through the mixing water. This results in a significant increase in workability of the mix. Since water-cement ratio remains the same, the strength is not affected much. However, there is likelihood of minor improvement in strength on account of better compaction as a result of higher workability. The improved workability can be used to aid in placing due to self-leveling and easy flowing characteristics of concrete. The principal active components of plasticizers are surface-active agents comprising of long-chain molecules that are hydrophobic (nonwettable) and hydrophilic (wettable).

Such molecules tend to concentrate and form a film at the interface between cement and water and alter the physio-chemical forces acting at the interface. Further, absorption of these substances on cement particles gives rise to a negative charge thereby leading to repulsion between the particles to cause better dispersion. Due to the charge, a protective sheath of oriented water molecules is also developed which increases the mobility of fresh concrete. The water freed from the restraining influence of the flocculated system becomes available to lubricate the mix for increased workability. Thus the quantity of water can be reduced for achieving the same workability. A more uniform distribution of the dispersed cement throughout the mix also contributes to the higher strength.

These plasticizers can also be used to reduce water for maintaining the same workability and thus reducing water-cement ratio. This decrease in water-cement ratio results in increase of strength in accordance with the **Duff Abram's** principle. Thus higher strength can be achieved by keeping the cement content the same.

For keeping the workability and W/C ratio the same, water and cement content per cum can be reduced by use of plasticizer and thus economising the production cost. Cost of concrete production will reduce if the cost of the admixture added is less than the cost of cement saved.

The normal plasticizers are mainly based on lignosulphonates and/or polymeric carbohydrates. These water-reducing plasticizers are:

- Lignosulphonic Acids and their salts
- Hydroxylated carboxylic acids and their salts

These plasticizers are used in amounts of about 1% by mass of cement and are quite effective with all types of portland cements and also with high alumina cement. Water reducing admixtures may be classified as water reducing set retarding or simple water reducing. Water reducing admixtures are produced under different trade names and their optimum doses may be studied from the producer's literature.

### 4.5.2 Super Plasticizers (High Range Water Reducers)

These admixtures work on the same principle as normal plasticizers (water reducers) but their effect on workability or water reduction is much greater. This is partly because they can be used at much higher dosage without undesirable side effects.

Super plasticizers are mainly based on synthetic polymers such as sulphonated Naphthalene or Melamine Formaldehyde condensates. Super plasticizers can be used at higher doses and are generally expensive than normal plasticizers. Generally super plasticizers cost more than the cement saved and hence these are used to modify certain properties necessary for long-term effects. Use of super plasticizers from durability point of view is justified. The main uses of super plasticizers are:

- Very high workability to facilitate self leveling of concrete in floors;
- Very high workability to facilitate compaction through congested reinforcement;
- Low water-cement ratios for high strength concretes; and
- Low water-cement ratios to give impermeable durable concrete in adverse conditions.

Some of superplasticizers work very effectively when used alongwith mineral admixtures for cement replacement. Use of silica fume, flyash, calcined clays and blast furnace slag alongwith superplasticizer makes cement replacement quite effective and economical in achieving desired quality of concrete.

Many companies are producing liquid plasticizers under their trade names. Some of these plasticisers also known as workability agents and are: **CONPLAST, CICO, SUPAPLAST, EMCEPLAST, ZENTRAMENTSUPER,** etc. While using any plasticizer, its optimum doses and other instructions must be observed as per manufacturer's literature as well as practical test results.

### 4.5.3 Accelerators

Accelerators are those materials which enhance the rate of hydration to reduce the setting time and/or gain of early strength. These admixtures fall into three categories viz set accelerating, strength gain accelerating and both set and strength accelerating.

**Set accelerators** cause an early stiffening of the concrete mix with atleast one-hour acceleration over the standard normal mix. The most effective admixtures in this category are based on aluminates or silicates and give initial set in few minutes. Unfortunately these admixtures result in reduction of the later age strength. These admixtures are mainly useful in sprayed grout for mining and tunneling operations.

The other accelerators, which meet the 1-hour set acceleration, are chlorides. Chlorides promote corrosion of steel. Chloride based accelerators cannot be used in RCC and hence are banned. Chloride based accelerators are both set and strength accelerators. Set accelerators are mainly used in early finishing and repair of floor slabs and concrete highways. These accelerators are quite suited to repair and maintenance jobs and laying concrete in extreme cold weather conditions. Accelerators are used for plugging the leakages, quick rendering work, quick installing of railing posts and underwater concreting.

**Strength accelerators** give high strength at an early age upto 24 hours. This gain of an early strength may not continue at later ages. Generally inorganic salts such as chlorides, nitrites and thiocyanates form the basis of strength accelerators. Because of many side effects their use is superseded by High Range Water Reducing Agents. High range water reducing agents (superplasticizers) offer the advantage of more cost effectiveness and much higher strength gain at 1-day (200 %) along with better ultimate strength. The inorganic salts are however, more effective at very low temperatures (around 5°C) in producing very early strength (8 –10 hours).

Most common accelerator for cement concrete is calcium chloride ($CaCl_2$). Some other accelerators are sodium chloride, sodium hydroxide and sodium silicate. Some companies have started producing chloride free accelerators to offset bad effects of chlorides. There are varieties of accelerators produced under different trade names both in liquid and powder forms. Calcium chloride produces greater acceleration in hydration than sodium chloride. Maximum acceleration in hydration occurs during first few hours, whereas there is little or no effect on the 28 days strength. Research indicates that effect of calcium chloride is much more predominant in rapid hardening cement than OPC. Two percent addition of $CaCl_2$ by mass of cement is quite adequate to reduce the initial setting time of OPC by two thirds to about 1 hour and will reduce the final setting to about 2 hours. Three percent $CaCl_2$ may lead to flash set while one percent may even retard the setting.

The use of $CaCl_2$ has been found to increase the resistance of concrete to erosion and abrasion. The use of $CaCl_2$ may increase drying shrinkage and possibly creep. It may also lead to corrosion of steel and hence use of chlorides must be avoided in prestressed concrete. $CaCl_2$ should not be used in sulphate resisting concrete to avoid alkali-aggregate reaction. $CaCl_2$ should not be used in lightweight concrete placed over metal decks. $CaCl_2$ does not affect the Air Entrained concrete but it facilitates improvement in workability. Use of $Cacl_2$ enhances freeze-thaw resistance of concrete in very low temperatures.

Accelerators may also comprise of calcium lignin sulphonate, or organic catalyst such as orthohydroxyl Benzoic Acid, and Combinations of these materials depending on the environmental conditions. All instructions for use of accelerators must be followed carefully for optimum results in improving the desired properties without adverse effects on other properties.

### 4.5.4 Retarders (Retarding Admixtures)

Retarders are used to cause a delay in the time to retard setting and/or hardening of cement concrete. Some retarders may not confer with workability retention initially or at the time of placing. Calcium sulphate (Gypsum) is added to cement at the time of its manufacture to prevent too quick set. The addition of gypsum beyond certain proportions causes unsoundness in cement and hence requirements of retardation cannot be fully realized by gypsum especially in tropical climates. Delaying of setting may be necessary for placing concrete under high temperatures or special conditions. Retarders are necessary for grouting deep voids behind concrete arch tunnel linings, for transporting concrete over long distances, for pumping concrete for avoiding cold joints between successive lifts in mass concrete, and hot weather concreting. Retarders facilitate monolithic action and better bond in consecutive layers in continuous concreting operations.

The requirements of retarders are **workability retention, initial set, final set** and **hardening** of concrete. The concrete needs adequate workability at the point of placing for full compaction. This is achieved by using plasticizers to increase initial workability so that even after the loss of workability at the time of placing, the concrete can be compacted properly. Whenever there is likelihood of delay between two adjacent concrete pours, then the first pour still needs sufficient workability to allow fully monolithic construction. This level of workability refers to initial set requirements. Longer delays in the second pour will still bond to the first pour if the first pour has not passed its final set time due to use of retarder. Thus use of retarders result in workability retention, delay initial and final setting to **avoid cold joints.**

A special feature of most of the retarders is its ability to reduce water requirements of concrete mix and thus increase in ultimate strength in general. Retarders generally reduce the resistance of concrete to freezing and thawing but has no or insignificant effect on contraction or expansion. Water reducing effect of retarders have been studied in relation to strength and economy of concrete construction.

Some retarders also entrain air and result in increase of 3, 7 and 28 days strengths if air entertainment remains below 8 percent. Advantage of this fact could be taken to reduce the quantity of cement for the same strength or reduce W/C ratio to achieve higher strength. The water reducing aspect of retarders is very useful.

A wide variety of retarding agents are produced by different companies under their trade names. Each producer specifies optimum proportions of retarder for a specific purpose and placement conditions. Retarding admixtures are usually sugars, hydroxyl carboxylic acids, phosphates or unrefined lignosulphonates, ammonium chlorides, ferrous and ferric chlorides, calcium borates and oxychlorides, calcium tartarate, alkali bicarbonates, tannic, gallic, humic and sulphonic acids in sodium hydroxide solutions, starch, and salts of sulfuric acid. Sugar acts as a good retarder. It has been found that 0.05 to 0.10 % sugar by mass of cement has very little effect on the rate of hydration while addition of 0.20 percent sugar by mass almost stops hydration such that final set occurs after 72 hours. Skimmed milk powder has also retarding effect due to its sugar content. Use of 0.10 percent of sodium hexameta phosphate can retard initial setting to about 12 hours and final setting to about 13 hours.

The use of any retarder should be made after studying the quality requirements, placing conditions, temperatures, dosage, humidity, wind velocity, cement composition, initial workability requirements and other architectural considerations. Retarders should be selected only after proper testing and study of its specifications.

### 4.5.5 Air Entraining Agents

Air entraining agents are well selected and blended surfactants designed to entrain large volume of very small air bubbles into concrete or mortar. The main purposes of air entrainment is to: **Increase workability** with improved cohesiveness, enhance freeze-thaw resistance and to limit the loss of strength. The adverse effect of strength loss on account of entrained air can be compensated by use of water reducing plasticizers. Air entrained concrete becomes more cohesive, workable and easier to work. The tendency of segregation and bleeding in plastic concrete reduces considerably. Air entrainment becomes essential in adverse cold weather conditions when durability requirements are more critical compared to strength considerations. Air entrainment plays critical role in improving workability of harsh concrete with rough angular or crushed coarse aggregate and low W/C ratios. The increase in workability due to air entrainment makes it possible to reduce water and W/C ratio, thus compensating part of loss of strength due to air entrainment.

Air entraining agents can either be mixed with cement during its manufacture or added during mixing operation. **Air entrainment does not refer to large unintentional air voids present in concrete forming continuous channels.** The deliberate air entrainment consists of discontinuous channels and of much smaller size particles (less than **0.05mm** diameter). There are several billion of these minute air voids introduced by air entrainment in concrete. These bubbles provide cushioning effect against thermal fluctuations and minimize crazing and cracking in concrete.

When water in the capillary network in concrete freezes, it expands by upto 9% in volume and generates an internal crushing force to break up concrete. If the capillary network is intersected by entrained air voids then the expansion force/pressure can be relieved by flow of water particles into the air voids. 5 % air entrainment can result in good freeze-thaw resistance of concrete.

Air or gas cells can be introduced in any of 3 ways:

- Addition of Aluminium powder or zinc powder which reacts with cement to generate gas or hydrogen peroxide forming gas cells within the concrete;
- **Surface active** agents (called air entraining agents) which reduce surface tension;
- Cement dispersing agents, which are surface-active chemical compounds, which cause **electrostatic charge** to cement particles rendering them mutually repellent and thereby preventing coagulation. They do not reduce surface tension by wetting or foaming.

Aluminium powder is generally not used on construction job, as it requires strict controlled conditions for desired quality results. This can produce 60% or even more air voids (hydrogen bubbles).

Surface-active agents can further be subdivided into:

- Natural wood resins and their soaps, such as vinsol resin;
- Animal or vegetable fats and oils, such as beef tallow and olive oil;
- Wetting agents such as alkali salts of sulphonated or sulphated organic compounds. e.g. commercially produced synthetic detergent with trade name as Darex.

There are many air-entraining agents produced by different names such as Airalon, Teepol, Cheecol, Orvus, Petrosan, CicoAiren (IS9103), MC-Mischoel and AEA.

Vinsol resin is first neutralised with sodium hydroxide to convert it into soap to avoid chemical reaction with cement. These admixtures can entrain air upto 30 %. Only small quantities of these AEA are required (0.005 to 0.05 % by mass). The amount of air entrained depends on the type of cement, A/C ratio, FA/CA ratio, mixing time and type and temperature. **Five percent** air entrained can improve compacting factor by **0.07** or **slump by 45-50 mm.** Air entertainment can be done in no slump concrete. Air entrained concrete have much better workability and require much shorter period of compaction to avoid loss of air entrainment.

## 4.6 MINERAL ADMIXTURES

Based on their properties, the mineral admixtures can be grouped into: cementitious, inert or pozzolanic.

### 4.6.1 Cementitious

Cementitious materials have binding properties of their own. Cementitious materials include finely ground granulated blast furnace slag, natural cement, hydrated lime and combination of these materials. These admixtures provide additional binding properties when used alongwith main cementitious material.

### 4.6.2 Inert Mineral Powders

Finely divided mineral admixtures can be used with cement concrete or mortar for variety of purposes such as to correct the deficiency of aggregate grading for suitable workability, reduce permeability, decrease heat of hydration and decrease the cost by reducing cement. These mineral admixtures are ground atleast as fine as cement and usually finer than cement. Many of these mineral powders may comprise of chemically inert materials such as: limestone, quartz, bentonite, kaolin, chalk, hydrated lime, blast furnace slag, diatomaceous earth, volcanic ashes, calcined clays and fly ash. Some of these finely divided mineral admixtures may contain reactive silica, which may result in pozzolanic action.

The addition of these fine powders increase the workability by increasing the amount of paste in the concrete and hence cohesiveness. Excessive use of such finely divided powders may necessitate larger water requirement and consequently result in decrease in strength. The finely divided mineral powders are used in concrete mixes or mortars, which are deficient in fines to improve their workability to reduce the rate and amount of bleeding and possibly increase the strength indirectly. The substitution of lime for a certain portion of cement in mortars is frequently used method of increasing the workability. An excessive use of these finely ground powders may also increase the shrinkage of the concrete. Sometimes the addition of such minerals may not be economical especially in concrete due to the harmful influences on shrinkage and reduction of strength. These mineral admixtures become more useful if they fall in the pozzolanic category.

### 4.6.3 Pozzolanic Admixtures

A pozzolana is a finely divided siliceous material which whilst itself possessing no cementitious properties but will react in the presence of water with lime at normal temperatures to form compounds having cementitious properties. These pozzolanic materials are either natural or artificial. The action and properties of pozzolanas differ widely and their proportion and efficacy in any particular circumstances can be determined only by careful tests by considering appropriate practical situation.

The principal use of pozzolanas is to **replace a part of the cement** in making concrete or mortar to achieve improved workability, reduced bleeding and segregation, and economy in cost of construction. The improvement in the workability may not necessarily be reflected by an increase in slump or compacting factor. In fact addition of pozzolana may necessitate higher water requirements for the same slump but the concrete mix behaves more cohesive and needs lesser effort in its compaction. Other minor advantages of pozzolanas are greater **imperviousness**, better **resistance to freezing and thawing**, better **resistance to sulphate attack, reduction in alkali-aggregate reaction,** and **reduction in heat of hydration specially** in mass concrete.

Principal natural pozzolanas are: **calcined clays** and **shells,** calcined or uncalcined **diatomaceous earth, opline cherts, shales, volcanic ash,** and **pumicites.** The most active of the natural pozzolanas are diatomites, opline cherts, and some shales. Some of the natural pozzolanas need to be calcined and ground to fine powder for making them reactive. Generally the optimum amount of pozzolana as a replacement for cement may normally range between 10 to 30%.

Artificial pozzolanas are finely ground blast **furnance slag** and **fly ash** produced in thermal power plants. Fly ash or **pulverised fuel ash** (PFA) is the residue from combustion of pulverised coal and collected by mechanical or electrostatic separators from the flue gases of thermal power plants. Its properties and composition vary widely and depends on the type of fuel burnt and method of collection. Most of the pozzolanas are rich in silica and alumina and may also contain small quantities of alkalies. Specific surface area of flyash may vary from 3500 to 5000 sqcm per gm. The principal constituents are silicon dioxide ($SiO_2$), Aluminium Oxide ($Al_2O_3$), unburnt fuel as carbon, calcium oxide (CaO), and small quantities of Magnesium Oxide (MgO), and Sulphur trioxide ($SO_3$). The properties of pozzolanas mainly depend on the **fineness**, reactive silica and carbon contents.

The action of **pozzolanas** mainly depends on the **reaction of active silica** (amorphous form) with the free lime released during the hydration of cement. Recent studies indicate that Alumina and iron also take part in a complex reaction. It is, therefore, necessary to examine the optimum proportion and properties of cement concrete or mortar mixed with pozzolanas by laboratory testing prior to use in construction. The properties and suitability of a pozzolanic admixture can be determined by referring to code IS: 1727.

## 4.7 SPECIAL ADMIXTURES

There are many admixtures, which are used for producing a special purpose concrete or mortar. Some of these special purpose admixtures are:

- Gas Forming Agents/Foam Forming Agents;
- Expansion Producing Agents;
- Bonding Agents (polymer Admixtures);
- Grouting Agents;
- Pigments and Colouring Agents;
- Water Proofing and Permeability Reducers;
- Shotcrete Accelerators; and
- Curing Compounds;

### 4.7.1 Gas or Foam Forming Agents

Gas forming agents are used in production of cement grout and lightweight concrete. Gas forming agents are also known as foaming agents. These concrete are also called as gas concrete, cellular concrete, foamed concrete, aerated concrete or porous concrete. Gas or air bubbles are used as aggregate in gas concrete. Air bubbles are different from those formed in air-entraining agents. These agents are used to form foam during mixing in the mixing truck. The proportion of gas forming agent can control the density of concrete to as low as 500 kg/m$^3$. The gas or foam concrete slightly expands to fill the gaps in confined spaces in grouting ducts and machine bases.

There are variety of gas forming agents such as Aluminium Powder, Powdered Zinc, Hydrogen Peroxide, Soaps and resins, Air entraining materials, and calcium carbide ($CaC_2$). Hydrogen or oxygen gas is liberated by the chemical reaction between the admixtures and $Ca(OH)_2$ released from cement. Generally these admixtures are used in amounts less than 0.2 percent by mass of cement. For controlling the amount of expansion and density the optimum quantity of the admixture is determined by practical testing. When these admixtures are used in large quantities, these produce gas or cellular concrete. Appropriate use of gas forming agent can produce lightweight concrete with unit weights varying from 4 KN/m$^3$ to 20 KN/m$^3$. Special techniques are used for mixing, placing and compacting such concrete for retaining adequate air or gas uniformly in the mix. Gas forming agents are mixed first with cement. Sometimes certain quantity of preformed foam is added to freshly prepared concrete to achieve desired density.

Hydrogen peroxide breaks into water and oxygen when added to cement to produce lightweight concrete or mortar. Aluminium or zinc powder is used for production of cellular or gas concrete. Finely ground aluminium or zinc powder is mixed with the cement in the proportion of **0.10 to 0.20%** by mass of cement to form a fluid paste which is placed in respective moulds to about one-third full. Chemical reaction produces hydrogen bubbles, which fill the mould completely. Slightly excess material shall be struck off level with the top of the mould. Addition of pozzolana such as fly ash, calcined clay or blast furnace slag to this mixture reduces drying shrinkage, which helps in controlling cracking of these blocks/or moulded members. Various gas forming agents should be tested for their optimum proportion and desired effect on the quality of concrete.

### 4.7.2 Expansion Producing Agents

Gas forming agents cause expansion during plastic stage itself while expansion producing agents are required to produce some expansion in cement concrete during hardening process. This expansion occurs either by the expansion of the admixture itself or by its reaction with other constituents of cement concrete or mortar. The desired expansion may be obtained by using the following common admixtures:

- Granulated iron, expansive cement (Sulpho-Aluminous cements),
- Self-stressing cement, and Anhydrous Sulfo-Aluminates.

The expansion-producing agents are used for filling the cracks and confined spaces difficult to approach. These admixtures are specially suited for repair works.

### 4.7.3 Bonding Agents (Polymers)

The bonding agents are water emulsions or any of several organic materials that are resistant to saponification. Liquid resin latex can be added to cement or mortar grout for improving its bond strength. These admixtures are suitable for cement concrete, cement mortars, lime and gypsum mortars for increasing the bond strength between the old and new concrete. These admixtures increase the resistance of the toppings against wear and renders the mortars watertight. These materials have also been found useful in the manufacture of **cement paints.**

Commonly used bonding agents are made from natural rubber, synthetic rubber, or organic polymers. Sometimes these are available in two-pack system of epoxy resins for one time use for bonding slurry coat between old and new concrete or mortar toppings. Cement slurry with appropriate proportion of bonding agent is coated on the prepared old concrete surface prior to laying of fresh plastic concrete which may also contain bonding agent. These bonding agents are manufactured under many trade names such as: Monolithex, DP Bonding agent, Nafufil, Acrylic based bonding agent and Epoxy Resins.

### 4.7.4 Grouting Agents (Pumping Aids)

Grouting admixtures may exhibit the most desired property of flowability of concrete/mortar/cement slurry. These agents may be in the form of air entraining agents, workability agents, set retarders, accelerators, and waterproofers to produce the desired property of grouting material. The most important purpose of the grout is to fill the discontinuity due to holes, ducts, cracks and congested reinforcement areas. Grouting admixtures are also used for grouting machine foundation bolts and for stabilised beam supports. Grouting material with specific admixtures are used to seal oil wells, stabilize foundations, and repair of architectural features.

Grouting admixtures must ensure the following characteristics in the grouting material:

- Good flowability and pourability;
- Continuity throughout the grouted portion;
- High initial and ultimate strength;
- Excellent bonding with grouted surface;
- No shrinkage or change in volume;
- Compatibility of the grout with grouted member;
- Transfer and bearing of loads well in time; and
- Freedom from harmful chemicals (chlorides).

There are many grouting admixtures produced under different trade names such as: Emce Krete, Centricrete, CICO Pagel GP, CICO Polygrout, CICO Moushrink, Polymeric Grouting Compound, Epoxy Grout, etc.

For optimum effect of grouting admixture, the producer's instructions must be studied thoroughly and trial tests carried out before using. These admixtures are produced as fine powders, pastes, or liquids.

### 4.7.5 Pigments and Colouring Agents

Inorganic pigments are added to cement to produce colour in the finished concrete. All pigments must be permanent and in particular these should not be affected by the free lime in cement concrete. For better result and deep colouring effect, the pigments are ground with the cement in a ball mill. Sometimes pigments are mixed with fillers or extender such as chalk and barium sulphate, which are insoluble in water and have no harmful chemical effect. Materials, which enter into chemical reaction with cement, should be avoided. Concrete strength gets reduced when fillers or extenders are used in large quantities. For better results the pigments should be blended well with dry cement before adding mixing water. Table 4.1 gives list of pigments.

**Table 4.1** Colour and Pigment Compounds

| *Sr. No.* | *Colour* | *Pigment Compounds* |
|---|---|---|
| 1. | Brown | Burnt Amber (Ferrous Oxide and Hydroxides, Manganese Oxides) |
| 2. | Grey to Black | Carbon black, Magnetic Ferrous Oxide, Manganese black. |
| 3. | Red | Red Oxide of iron |
| 4. | Blue | Ultra Marine Blue Phathalocyanine, Barium Manganese |
| 5. | Yellow | Natural and chemically prepared orchres, Hydroxide of iron |
| 6. | Green | Chromium oxide and Chromium Hydroxide |
| 7. | White | Titanium dioxide |

### 4.7.6 Damp Proofing Agents (Permeability Reducers)

These are also known as water proofers and these block capillary pores or coat them with hydrophobic material to inhibit water transmission. Waterproof concrete are impervious and resist water absorption. By adding damp proofing agents to well designed concrete mix, the required qualities of impermeability alongwith some saving in cost can be achieved. The admixtures improve the resistance of concrete to absorption of water. These are very essential for concrete elements in contact with water or exposed to external weather conditions of rain, sun and heat.

Damp proofing agents are available in powder, paste or liquid form and consist of pore filling materials or water repellent materials. These materials are chemically active or inert. The pore filling materials are used to reduce capillary flow of moisture through concrete, which is in contact with water or moist earth. The main pore filling materials are: alkaline silicates (sodium silicate), Aluminium and zinc sulphates, and aluminium and calcium chlorides. Mineral admixtures such as flyash and other pozzolanas are also used to reduce permeability of concrete with low cement content and deficient in fines. Damp proofing materials are either chemically active or inactive. The main inactive pore filling materials are chalk, fuller's earth, and talc. These materials are usually ground to high fineness, which facilitate filling of fine pores.

Chemically active water repellent materials are soda and potash soaps to which sometimes lime, alkaline silicates or calcium chloride may be added. Chemically inactive water repellent materials are calcium soaps, resin, vegetable oils, fats, waxes, coaltar and bitumen residues. These materials fill or block pores in concrete.

Proprietary water proofers may consist of calcium, aluminium or other metallic soaps and water repellent materials. Some of the commercially produced water proofing admixtures also contains acrylic polymers.

### 4.7.7 Shotcrete Accelerators

These are special set accelerators mixed with concrete or mortar to cause rapid set and early strength gain. These are mainly used in mining and tunneling and repair tasks. The details of accelerators have already been discussed under 4.5.3

### 4.7.8 Curing Compounds

In real sense, the curing compounds cannot be considered as admixtures but these are aids for achieving desired quality under specific conditions of placement. Curing compounds are generally coated after placing the fresh concrete so as to form a **impervious membrane film** on the exposed surface. This prevents evaporation of water from the body of concrete, which is required for continuance of hydration process. These compounds are of many types as follows:

- Thinned coal tar with solvents;
- Rubber latex emulsions;
- Clear or translucent compounds (emulsified in water or volatile solvents);
- An emulsion of paraffin wax and boiled linseed oil in water and stabilised by stearic acid and triethanolamine; and
- Plastic compounds

The use of curing compounds becomes necessary for places where there is shortage of water or it is inaccessible or difficult to cure continuously and properly. Curing compounds should have no toxic solvents and should be capable of forming a **membrane film** on wet **concrete surface.**

The consistency of curing emulsions should be such that it can be sprayed easily at normal temperatures from atomising nozzles as a continuous coherent film. The film should have sufficient elasticity to form an unbroken film for atleast 7 days. It should not run when applied to a vertical surface at the specified rate. The membrane film may be pigmented. Black bituminous coatings may be white washed after 3-4 hours of application to avoid excessive rise of concrete temperature. The chemical effect of these curing compound coatings should be investigated by trial for harmful influence, if any. The curing compound coatings should be applied immediately after the free water has disappeared from the surface. The curing compounds should remain stable when stored for a period of atleast 3 months (Fig. 4.1).

Emulsions are generally cheaper than membrane compounds of solvent type due to additional cost of solvents. There are varieties of commercially produced curing compounds under different trade names such as: Emcoril liquid, Emcoril white, CICO free cure, etc.

## 4.8 SELECTION CRITERIA

Selection of specific admixture for specific purposes requires evaluation of primary and secondary properties from various sources. Primary properties of admixtures have been specified in previous paras. Primary properties refer to the specific purpose for which an admixture is used. For example plasticizers have primary role of **improving workability** (flowability or plasticity) while **retarders** have primary role of **reducing the rate of hydration.** After assessing the primary role to be played, the admixtures are tested for their secondary roles in respect of side effects on other properties, chemical reactivity, long term durability and cost.

Most of the admixtures have one or more secondary properties which are similar to other primary properties but of much lower effect. For example certain plasticizers selected for their primary role of increasing plasticity (workability) may also slightly affect the setting and air entrainment properties of the concrete. The secondary properties achieved by the admixture must be considered in light of the situation of placement and desired quality of concrete. The **selection of admixtures** is thus made for **primary characteristics** and positive **gain on secondary properties** required for a given situation.

All admixtures must be **tested by** preparing **trial mixes** with the same materials and conditions of placement, **prior to its use in concrete** construction. Optimum proportion of admixtures is also determined by trials to exhibit desired primary and secondary properties of the concrete.

For achieving desired quality of cement concrete, the use of admixtures plays vital role. The use and proportion of a particular admixture in a particular situation must be decided by conducting scientific trials and **study of manufacturer's literature.**

Admixtures can also play a vital role in improving durability of concrete elements placed in adverse conditions of weather, chemical and mechanical attacks. Most of the problems of durability of concrete is associated with corrosion of reinforcement and carbonation of concrete. These problems are related to the permeability of the concrete. Water reducing admixtures with or without cement replacements can be used to reduce W/C ratio. This reduction in W/C ratio leads to: reduced permeability, reduced rate of carbonation and chloride diffusion.

## 4.9 SUMMARY

Admixtures in small quantities can **modify the properties** of cement concrete to obtain the desired characteristics. Admixtures influence the quality of fresh as well as hardened concrete. Use of admixtures improves placing techniques and construction methods.

The use of admixtures bring about many advantages in terms of **cost, quality** and **construction techniques.** The use of admixture can facilitate achievement of desired qualities by adopting scientific mix design procedures.

Admixtures are generally grouped as **chemical and mineral.** The most common chemical admixtures are **plasticizers, accelerators, retarders, air entrainers** and other special purpose admixtures. Mineral admixtures are obtained from natural materials or bye-products in blast furnaces or super thermal power stations. Mineral admixtures are finely ground **flyash, blast**

**furnace slags, silica fumes, volcanic ashes, volcanic tuffs,** and **calcined clays.** Most of these mineral admixtures exhibit pozzolanic properties and facilitate cement replacement and improvement in **impermeability** and other properties.

Plasticizers, also known as water reducers, improve workability of concrete and lead to better compaction and economy in concrete construction. Plasticizers comprise of **lignosulphonic acids** and their salts or hydroxylated carboxylic acids and their salts.

**Accelerators** enhance the rate of hydration. Set accelerators comprise of aluminates or silicates while hardening accelerators comprise of chlorides or nitrites.

**Retarders** are required to delay the setting of cement and generally consist of gypsum ($CaSO_4$), or sugars. Hydro carboxylic acids, phosphates or unrefined lignosulphonates, ammonium chloride, ferrous and ferric chlorides, calcium borates, Oxychlorides, Calcium Tartarate, Alkali Bicarbonates, Tannic, Humic and Sulphonic Acids may be used in producing retarders. Retarders facilitate better **bond and monolithic** construction and long distance transportation.

**Air entraining agents** are used to entrain large volume of very small air bubbles for better workability and resistance to **freeze and thaw.** Aluminium powders or vinsol resins are required for air entrainment. Sometimes vegetable and animal fats can also be used for air entrainment. There are many commercially produced air-entraining agents.

**Mineral admixtures** are either inert or **pozzolanic** in nature. Pozzolanic action is caused due to **reactive silica** content. Very commonly used pozzolanic admixtures are **flyash, calcined** clay, volcanic ashes, and blast **furnace slags.** These are ground very fine and facilitate in making concrete **more cohesive, reducing shrinkage** and replacing part of cement.

There are many admixtures available for specific purposes. The selection is based on primary purposes and secondary effects of admixtures. The use of admixtures is adopted after ensuring its characteristics. The use of admixtures facilitates controlling of quality of concrete.

## PRACTICE QUESTIONS

4.1 Define admixtures.

4.2 State benefits of using admixtures in cement concrete.

4.3 State importance of admixtures in quality management of cement concrete construction.

4.4 List type of **admixtures** in each category.

4.5 State use of admixtures in fresh and hardened states of cement concrete.

4.6 Explain use of **plasticizers** in cement concrete.

4.7 Explain use of **accelerators** in cement concrete.

4.8 Explain use of **retarders** in cement concrete.

4.9 Explain the purpose and use of **air entraining agents** in cement concrete.

4.10 Describe type of **mineral** admixtures.

4.11 Explain the purpose and use of **fly ash** in cement concrete.

4.12 List special purpose admixtures.

4.13 Write short notes (not more than 100 words) on:
Gas forming agents, bonding agents, damp proofing agents and curing compounds.

4.14 State selection criteria for admixtures.